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Tortoise - a conceptual carrying system for sensitive equipment

Master of Science Thesis in the Master Degree Programme Industrial Design Engineering

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Gothenburg, Sweden 2013

Department of Product and Production Development
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ABSTRACT

The Master Thesis project “Tortoise - a conceptual carrying system for sensitive equipment”, by Rasmus Lindström and Alexander Littorin was conducted at the department of Product and Production Development at Chalmers University of Technology. The project was made in collaboration with the Malmö-based company Boblbee.

Boblbee produces carrying solutions for the active user, mainly through various backpacks for skiing, motorcycle riding and photography. However, there is a gap in their product portfolio, manifested by the lack of a comfortable and reliable carrying system for sensitive equipment. The aim of this project is to design, develop and present a product concept for an ergonomically comfortable and impact resistant carrying system for tachymeters that may be used all over the world. Tachymeters (or total stations) are sensitive optical instruments that are used by professionals to produce accurate measurements. They are large, expensive, heavy and easily damaged by impacts. Hence, in the development of a carrying concept for sensitive equipment, tachymeters constitute an ideal reference product. Furthermore, as tachymeters are currently transported in protective cases that are unsuitable for longer hikes there is a market for a novel carrying solution that combines the necessary protection with well-developed ergonomics.

The final concept is a backpack with a hard and a soft shell. Sensitive equipment can be safely transported in a padded compartment, designed to prevent ingress of fluids and particles. The softer elements serve to attenuate impacts as well as connecting the final concept to Boblbee’s brand identity. The bottom of the backpack is reinforced in order to allow for a stabile placement and heavy usage. The back panel and waist belt are designed to provide a comfortable carrying experience.

The research for the design comprised interviews and observations of survey engineers, a benchmark, ergonomic evaluations and a literature review on anatomy, load carriage and form design. Boblbee’s brand identity was analysed in order to ensure that the final concept would fit in the company’s product portfolio.

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Table of contents

RESEARCH

- Problem description
- Methods and process
- Information gathering
- Conclusions from information gathering

- List of requirements

1. Introduction and problem description

Boblbee is a Malmö-based company founded by industrial designer Jonas Blanking in 1997. Since the start, Boblbee has focused on developing novel and innovative solutions for transporting various products, from skis to mobile phones. The transport is most frequently realised by different backpacks, often with added features to enable a wide range of usage. There is a gap in Boblbee's product portfolio, manifested by the lack of a reliable carrying system for sensitive equipment. Sensitive equipment can be defined as products or scientific instruments that require utter most care and protection during transport as well as operation. Examples of sensitive equipment are tachymeters (sometimes referred to as tacheometers or total stations), cameras, video cameras and medical devices. These equipment are used by professionals in various conditions and locations all over the globe. Thus, there is a need and a demand for a well-functioning transport solution for the equipment. Existing carrying systems are highly similar and consist of a hard cuboid-shaped outer shell and a shock absorbing interior foam. These cases satisfy the relevant technical requirements regarding safe transportation and protection from environmental effects; however, they are neither perceived as comfortable nor suitable for longer walks. Consequently, there is a market for a carrying system for sensitive instruments that is designed with the user in centre.

Its sophisticated optics, heavy weight, awkward dimensions and high price render tachymeters an ideal reference product when developing a carrying concept for sensitive equipment. Currently, tachymeters are used to produce accurate measurements for almost all land development projects. Since the instruments are sometimes carried for longer periods, a carrying solution must - in addition to provide adequate protection - fulfil high ergonomic requirements. If the requirements placed on carrying systems for tachymeters are met, it can be assumed that the principle of the concept will be applicable to other sensitive equipment as well. Thereby, a comfortable, safe and reliable transport solution for sensitive equipment may be realised. Hence, the focus of this project will be to fulfil the demands related to the transport of tachymeters.

1.1 Purpose

The purpose of this project is to study how a carrying system for sensitive equipment may be designed and constructed to ensure a safe, reliable and comfortable transport from the storage room to the working site(s) and back again.

1.2 Aim and research questions

The aim of this master project is to design, develop and present a product concept for an ergonomically comfortable and impact resistant carrying system for tachymeters that may be used all over the world. The intended users are professionals in various industries. The presented concept, albeit optimised and designed for tachymeters, should be applicable to other sensitive equipment. Moreover, the presented concept should be a complement to Boblbee's existing line of products and target their lack of carrying systems for sensitive equipment. In the project, the following questions will be addressed:

- With regards to human physiology and the usage context, what is the optimal method of transporting a tachymeter from the storage room to the measuring site(s) and back?

- How should a carrying solution for sensitive equipment be designed in order to express safety and professionalism and fit Boblbee's product portfolio?

- How could a carrying system for tachymeters be designed to be differentiated from the existing products on the market?

- What materials appear promising to be used in a carrying solution for sensitive equipment?

1.3 Goals and deliverables

The project will result in a product concept with considerations taken to materials, production possibilities, ergonomics, user experience and sustainability. The concept for the carrying solution will be presented through a functional model, computer renderings, drawings and an academic report. The delivered concept should be viable for realisation within two years from initiation.

1.4 Delimitations

A functional model will be made, however, an actual prototype of the carrying solution is outside the scope of this project. Laboratory testing of different materials and their respective properties under various conditions will not be performed, instead material data sheets will be used. As tachymeters are treated as a reference product, the presented carrying system will focus on the demands placed on tachymeters. Consequently, additional fields of application (e.g. transport of photo equipment) will not be studied in detail.

2. Boblbee

This master thesis is made in collaboration with Boblbee. Below is a brief introduction to the company and its products.

2.1 Company

Boblbee is a Swedish company founded in 1997 as a design and research hub focusing on sports and recreational equipment. The first product to be launched was the characteristically S-shaped Megalopolis backpack, a novel and innovative backpack featuring a hard shell with three sides and a soft back harness, see far left in figure 2. The construction and materials allow for the backpack to be used as a back-protector during various activities (e.g. skiing, skateboarding and motorcycling). Following Megalopolis, Boblbee has developed a large number of different carrying systems.

The brand vision is “to be the lighthouse of smartly engineered solutions for individual mobility”. The vision is communicated through the logo which symbolises a “person in confident action”, see figure 1 (Boblbee 2013a). Boblbee’s brand values are evident in the design of their products as components and parts are aimed at solving problems related to active situations. In addition, the products are often equipped with details found in sports equipment (e.g. in climbing gear). Jonas Blanking, founder of and designer at Boblbee explains that the emphasis on an active lifestyle in Boblbee’s products have made them popular among the urban population as well as among professionals in various fields (e.g. photographers).

2.2 Product portfolio

Boblbee’s product portfolio consists of a wide range of bags and backpacks designed for mobility and functionality in tough conditions. The products are made to protect the content as well as the user; consequently, many carrying solutions are equipped with back-protection features. The back-protection is either incorporated in the main structure or as an added shell. Most bags and backpacks from Boblbee are designed to allow attachment of various add-ons (e.g. mesh structures for external storage capacity). Finally, the products are often constructed to facilitate disassembly, thus enabling replacement and repair of damaged parts or components. Some examples from Boblbee’s product portfolio are shown in figure 2.

2.3 New segment

Currently, Boblbee’s product line include carrying systems that cover the sports and as well as the urban backpack segments. To widen the company’s portfolio and target users with high demands, a carrying solution for extreme conditions is desired. To satisfy the users, the carrying system(s) must have a superior impact and water resistance compared to the existing products. The new segment is intended to be used for transporting expensive and sensitive products in various climates and conditions.

2.3.1 Project brief

At the start of the project, a brief specifying the technical requirements placed on a carrying system for three different models of tachymeters was provided. These requirements can be found in chapter 7.7.

BOBLBE-E®

Fig.1 Boblbee logo symbolising a person in confident action.

Fig.2 Examples from Boblbee’s product portfolio

3. Reference carrying solution

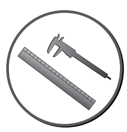
The reference carrying solution is a protective case from Leica. Sensitive equipment (e.g. tachymeters, GPS units and handheld remote control units) produced by Leica are delivered in these cases. Different tailoring of the internal foam (see figure 3) allows for a safe transport of various instruments. The end customers (e.g. surveying companies) frequently use the protective cases for storage and transport of their instruments. As can be seen from figure 3, two attachable shoulder straps enable the case to be carried on the back, and an integrated handle allows for one-hand carriage.

The case features two latches and opens in two halves. A rubber gasket is placed along the edge of the opening. The construction is resistant to dust and splashing water and can withstand high impacts (Leica n.d). The red protective outer shell is made from Acrylonitrile Butadiene Styrene (ABS) plastic and the interior foam is made from Polypropylene (PP).

Fig.3 Existing protective case for transport of tachymeters. Hard shell in ABS, interior foam in Polypropylene.

ABS (thermoplastic): 2350 g
PP (thermoplastic): 550 g

Total weight: 2900 g



Dimensions (width x depth x height):
470 x 350 x 265 mm

Volume: 43,5 l

4. Methods

In this project, large focus is placed on the ergonomics involved in load carrying. The physical ergonomics as well as the users' subjective perception of the task will be analysed. In addition to the study of relevant ergonomic aspects, form theory and design possibilities will be explored. For the second and third phase of the project, creativity stimulation methods will be used.

4.1 Information gathering

4.1.1 Literature study

Literature study is a widely used method for collecting domain-relevant information. Domain-relevant information can be found in various publications, from electronic journals to books (Bohgard et al. 2008). The most efficient method of gathering published literature is often through electronic searches. In order to achieve a balance between the number and relevance of the search findings, it is important to determine useful keywords and limit the scope of the search (Ulrich & Eppinger 2012).

4.1.2 Function Analysis

A function could be defined as what an element of a product actively or passively is performing (Warell 1999). Different parts of a product account for different functions. The aggregate function of a product is constructed from multiple subfunctions (Österlin 2003). By sorting and connecting the subfunctions a comprehensive overview of the whole product is created. The function analysis is a method of studying the roles of the various parts and components in a product. The subfunctions are described as concise as possible, preferably with a verb and a noun, e.g. "allow lifting" (Ibid.). Thus, a function analysis serves to reduce larger, complex problems and functions to a number of smaller ones (Johannesson, Persson & Pettersson 2004).

4.1.3 Rapid Entire Body Analysis

Rapid Entire Body Analysis (REBA) is a method for ergonomic evaluation of the effect on a person's musculoskeletal system when performing a static or dynamic task. When performing a REBA analysis, data regarding body postures, forces, movements, repetitions and coupling are collected. The most valuable postures to analyse may be the most frequent ones, the ones that are maintained the longest or the ones that previously have been revealed to prompt discomfort. Deviations from an anatomically neural position are noted and given scores from a table. Generally, a divergence from the neutral position corresponds to an increased risk of injury. In order to reduce the risk of injury, recommendations are associated with each REBA score (Hignett & McAtamney 2005).

4.1.4 Benchmarking

Benchmarking refers to the study and evaluation of existing products with functions similar to that of the product or concept to be developed. Through a benchmark, strengths and weaknesses in the existing competing products can be identified and analysed (Ulrich & Eppinger 2012).

4.1.5 Design Format Analysis

DFA is a method for assessing and analysing explicit design cues that create visual brand recognition. These cues may consist of shapes, colours, materials, textures, graphics and logos. The decision regarding what design cues to analyse can be made in several ways - from a strict pair-wise evaluation matrix, to a subjective judgement on what features that are the most prominent and brand specific (Warell 2006; Karjalainen 2007). For the analysis, a DFA matrix is constructed by placing the selected design cues on the x-axis and the products on the y-axis. The products are compared against the selected design cues and given scores based on the occurrence of or correspondence to the design cues. The result from the DFA can be used as building blocks in the form development process, thereby ensuring a coherent and brand specific product portfolio (Karjalainen 2007).

4.1.6 Field observations and interviews

Field observations are used to study and analyse the user and the usage situation in a, for the task, natural environment. The observer may thereby gain insights to the domain-relevant problems and difficulties. In order not to influence the users, it is essential that the observer is discrete yet notes everything of importance. A disadvantage of field observations is the inability to identify the cognitive aspects present in the interaction, e.g. why the user chose a specific approach to solving a problem or how satisfied the user is with the task. This inherent disadvantage may be compensated for by the addition of complementary interviews (Bohgard et al. 2008).

Interviewing is a method of collecting information related to the subjective experiences of users, their values and views (i.e. qualitative data). The method is flexible and questions can be arranged and altered when deemed beneficial. It is essential that the interviewer can establish a relationship of trust to obtain true and honest answers from the respondent (Ibid.).

4.1.7 List of requirements

A list of requirements is a document that formulates what a product or system must perform or fulfil. The requirements should be expressed as precise as possible in order to reduce the potential of subjective interpretation (Ulrich & Eppinger 2012). The list of requirements must not include any solutions (Ulrich & Eppinger 2012; Bohgard et al. 2008). The requirements in the list may, for instance, be related to the ergonomics, economy, quality or aesthetics of the intended product or system (Bohgard et al. 2008). Some requirements (e.g. regarding visual appearance and product expression) may be difficult to quantify (Ulrich & Eppinger 2012). The document is not static and should be continuously updated as new needs and requirements arise during the product development process (Bohgard et al. 2008).

4.2 Creativity stimulation and concept development

4.2.1 Persona

Persona is a method for defining the intended user of a product. Compared to the more elastic "user", the persona is definite. The persona does not reflect every possible user but rather the specific goals of a user in an ideal interaction with the product in question. Personas are based on research data and created as realistic and precise as possible - with name, age, picture and personal data. The persona is used to provide the product developers with a clear direction throughout the product development process. By satisfying the needs and requirements of the user in an ideal interaction, an ideal product for that user can be created (Cooper 1999).

4.2.2 Scenario

The scenario method is closely related to the persona. The scenario formulates the tasks the persona performs in order to achieve his or her goals. Thus, the scenario describes the interaction between the persona and the product. As concepts evolve in the product development process, so does the scenario. In addition to be used as a source of ideas, the scenario can function as a concept evaluation method. It is common to formulate different scenarios for different types of usage, e.g. everyday use, necessary use and edge case use (Cooper 1999).

4.2.3 Moodboard

A moodboard is essentially a collage with images and photos that could, for instance, represent a target group and communicate their values. A moodboard can be used as a source of inspiration during the product development process (Österlin 2003).

4.2.4 Brainstorming

Brainstorming is the most frequently used method to stimulate creative thinking (Thompson 2003). The rules for a brainstorm session are fairly specific: no criticism is allowed, participants are encouraged to change and combine ideas, a great quantity of ideas are desired, and the participants are urged not to be constrained - all ideas are welcomed, no matter how wild or weird (Thompson 2003; Österlin 2003). The ideas generated during the brainstorm session are written on a board or a large sheet of paper. Following the brainstorm, the ideas are evaluated and further developed (Österlin 2003).

4.2.5 SCAMPER

SCAMPER is a method to apply modifications to a concept or idea. SCAMPER is an acronym that stands for: substitute, combine, adapt, modify (make bigger or smaller), put to other uses, eliminate, and reverse. These words corresponds to a change in the existing concept. The proposed alteration to the concept is then analysed as a means to discover novel and innovative ideas (Green 2009).

4.2.6 Sketching and modelling

Simple sketches constitute a fast method of exploring and evaluating different form possibilities (Ulrich & Eppinger 2012). Sketching is a method of analysing, synthesising and integrating information related to the realisation of a product. Designers use sketching as a means of communicating ideas. The sketching process is generally iterative and through the process forms are manipulated until a promising design is reached (Do 2005). Models of concepts are often made from foam-core board (e.g. Kapa board) to visualise and evaluate concept(s) in three dimensions (Ulrich & Eppinger 2012).

4.2.7 CAD modelling

Computer Aided Design (CAD) modelling is a method of representing three-dimensional forms by constructing them from geometrically more simple forms (e.g. blocks and curves). CAD modelling can be used to produce realistic images of a concept, thereby allowing evaluations of aesthetics and functionality prior to production. Moreover, CAD modelling can be used to assess the mass, strength and volume of a concept (Ulrich & Eppinger 2012).

4.2.8 KJ-analysis

The KJ-method, sometimes referred to as 'affinity diagram', is a method for organising data. Data is written on individual index cards or sticky-notes. These notes (on which the data is expressed) are then randomly placed on a horizontal surface. Participants in the KJ-analysis then silently organise the ideas into groups based on their perceived interrelationship. The method is usually performed in two teams. When the teams are satisfied with the organisation, ideas that fit into multiple groups are duplicated and the groups are given headings. The organising method is relatively fast and, as it is conducted in silence, the risk of participants influencing each-other's judgements is minimised (Plain 2007).

4.2.9 Morphological matrix

Morphological matrices can be constructed in multiple ways but the underlying principle is nevertheless the same (Österlin 2003). A morphological matrix is a method of combining part functions and part solutions into a functional and consistent concept or system (Johannesson, Persson & Pettersson 2004). The part functions can be combined using a matrix to organise the different part solutions or by writing the part functions on sticky-notes and combining these. Through a morphological matrix, novel and innovative solutions to a problem can be found (Österlin 2003).

4.3 Evaluation

4.3.1 Pugh matrix

The Pugh matrix is a method for reducing the number of concepts through elimination of the least favourable ones. The basis for the Pugh matrix is a relative comparison between different concepts (Johannesson, Persson & Pettersson 2004; Ulrich & Eppinger 2012). In the Pugh matrix, the concepts to evaluate should be presented or expressed at the same level of detail. Identified user needs and requirements are written to the left in the matrix, these form the selection criteria (Ulrich & Eppinger 2012). The reference concept, against which the other concepts are compared, is usually a well-known existing product. The concepts are rated against the reference product as to how well they fulfil the selection criteria (better - equally - worse). The scores for each concept is calculated and the concepts are ranked according to their relative score. Following the ranking of the concepts, a decision regarding what concepts that are suitable for further development is made (Johannesson, Persson & Pettersson 2004; Ulrich & Eppinger 2012). If some criteria are deemed more important than other, weights can be added to the selection criteria (Johannesson, Persson & Pettersson 2004).

4.3.2 Product expression evaluation

A user's perception of a product is difficult to assess yet may provide useful insights regarding its design. A product's success or failure is, to a large extent, dependent on its visual impact. Users' perception of a product is related to its shape, form, materials, colour(s) and semantics (McDonagh, Bruseberg & Haslam 2002) . Evaluation of users' impression of a product can be made in numerous ways, the aim is nevertheless to provide designers with data concerning the users' (or customers') perception of a product and what it expresses.

4.3.3 Digital ergonomic evaluation

Digital ergonomic evaluation can be used to assess the physical ergonomics of a concept that exists as a three-dimensional digital representation. The software includes a mannequin that can be modified to reflect the anthropometric data of the intended users (or target group). Various software for digital ergonomic evaluation exist, e.g. Jack from Siemens and Human Builder in Catia V5 from Dassault Systems.

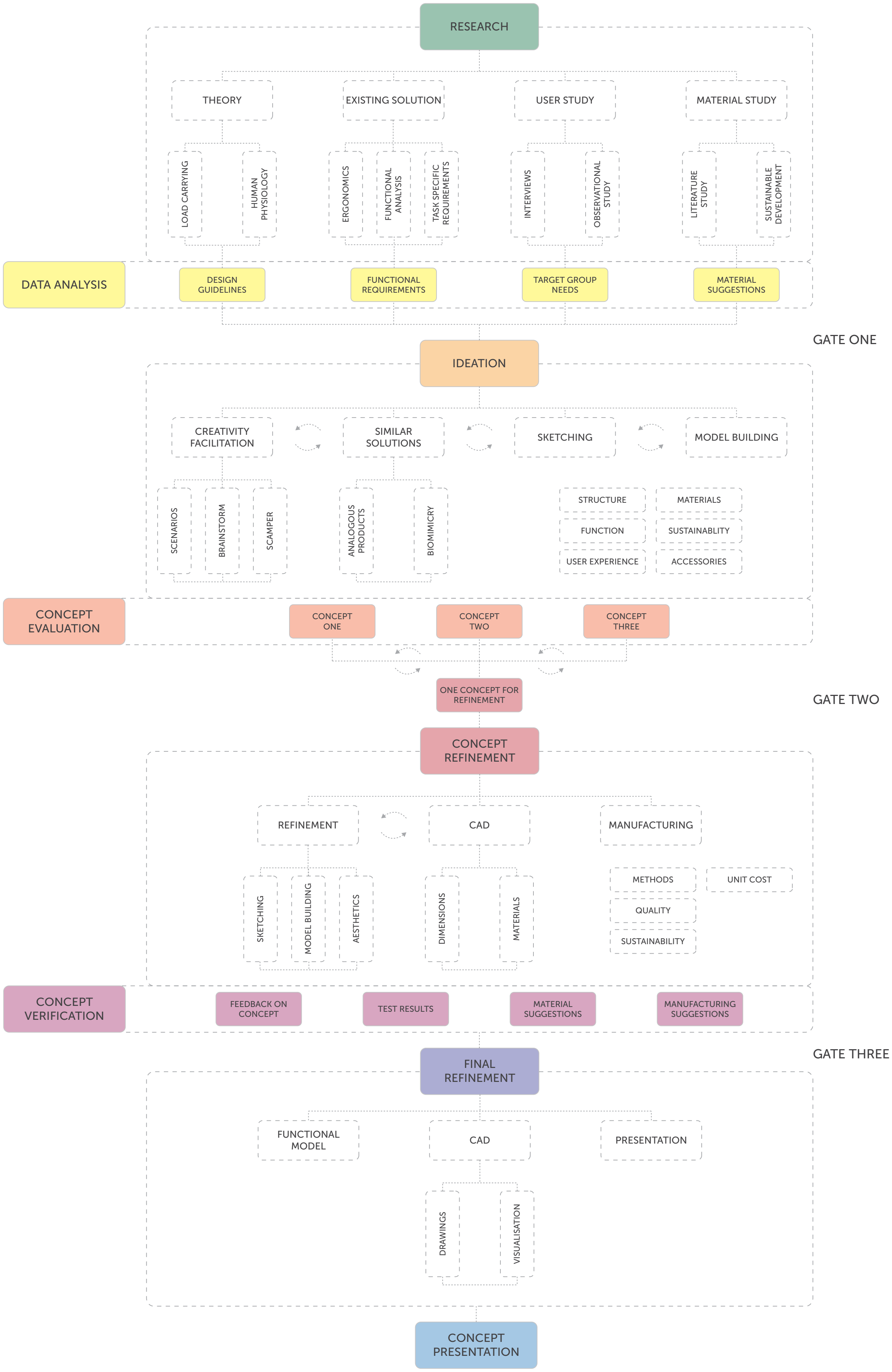


Fig.4 Overview of the concept development process.

5. Process

To provide an overview, the different phases and gates in the project are illustrated by a flowchart, see figure 4. The project was scheduled to be conducted in four stages. However, as the project advanced, a number of iterations had to be performed. The iterations were necessary as new requirements emerged during the concept refinement phase.

5.1 Information gathering

As a means of developing a domain-relevant knowledge base for the project, an initial information gathering process was conducted. The process consisted of a literature review, interviews, observations and a study of the existing carrying solutions.

5.1.1 Literature study

The literature review comprised a study of articles related to load carriage, human physiology and form design. The information collected from the article review was expanded and complemented by textbooks on anatomy, ergonomics and form. Relevant articles were found using databases accessible through the Chalmers Library in combination with search engines on the internet (e.g. Google Scholar). In addition to the initial literature review, a short study on natural resources and global infrastructure was made.

5.1.2 Material and manufacturing study

A study of materials and manufacturing methods was conducted in order to be able to present a realisable carrying concept that fulfilled the relevant requirements. Textbooks and the Cambridge Eco Selector (henceforth CES) material database were used to scan for and compare different materials and manufacturing methods. During the review, the sustainability potential of the materials and their joining methods were considered.

5.1.3 Photokina

At an early stage of the project, the Photokina Trade Fair in Cologne was visited to gather inspiration and information regarding the existing products and competitors on the market. Photokina is the largest European fair for optics, cameras and photo equipment. As the leading suppliers of protective cases for sensitive equipment (i.e. Peli, Nanuk, HPRC, B&W and Explorer) were represented at the fair, specific information regarding their respective products were obtained through questioning and testing. Throughout the visit, products and product details were documented using cameras and notebooks. The information collected during Photokina was used in combination with data from the producers' homepages to create a benchmarking.

5.1.4 Function analysis

A function analysis of the reference protective case was performed to generate a list of functions that were necessary for a new carrying system to fulfil. The list of functions was used - in combination with other data - to form a basic framework for the list of requirements.

5.1.5 REBA I

Using Rapid Entire Body Analysis (REBA), an ergonomic evaluation of the reference protective case was executed. Prior to the evaluation, the case was loaded until a combined weight of 12 kg was reached. The risk for musculoskeletal disorders while lifting, standing and walking was analysed for hand and back carriage, respectively. The test subject was a male of 185 cm with a weight of 70 kg. The REBA analysis was conducted indoors. The process was documented using video uptakes. The duration of the walking phase in the analysis

Fig.5 Photos from the interviews and observations.

was approximately five minutes. The results were used as a basis for a number questions during the interviews and for the list of requirements, see Appendix 1.

5.1.6 Benchmarking

A benchmarking was conducted in order to collect and analyse information regarding the competitors' product portfolios. The benchmarking was based on information presented on the homepages of the different suppliers as well as on observations from the Photokina fair. The competing products were analysed and evaluated with respect to their functions, how they were achieved and their performance, see Appendix 2. For the evaluation of the various products, the function analysis and the project brief were used as a framework.

5.1.7 Design Format Analysis

Eight products representing Boblbee's product portfolio were studied using design format analysis (DFA), see Appendix 3. To give a just representation of the width of the company's line of products, the eight products were selected from different segments within Boblbee's product portfolio. Photos of the products from the side, front and back were placed and arranged on two A3 sheets. The eight products were compared against 17 identified design cues. If the product had no resemblance or correspondance to the specific design cue it was given a score of zero for that cue (represented by no circle in Appendix 3), if the product had low resemblance to the cue it was given a score of one (unfilled circle), and if the product displayed a strong resemblance it was given two points (filled circle). The aggregate score for the eight individual products and the 17 design cues was calculated and the products and design cues were ranked accordingly. The result was used as guidance in the concept development process. In the DFA, the products were analysed without considering historical aspects (i.e. when different products were launched).

5.1.8 Interviews and Observations

Three surveying enterprises (Lantmäteriet, Byggmätarna and Skanska) were visited for interviews and observations. Moreover, an interview and a field observation with two civil engineer graduates was performed. The interviews were conducted in a semi-structured manner based on a series of questions related to different topics, see Appendix 1. All interviews and observations were recorded on paper and later transcribed into a single text. Additionally, the processes were documented using photos, see figure 5. The interviews and observations resulted in insights and requirements regarding ergonomics and user experience. Furthermore, the data from the interviews and observations were used to create a persona and a scenario. The specific processes for the different interviews are presented in chronological order below.

5.1.8.1 Lantmäteriet

An interview with Per Rubendahl, Operations Manager at Lantmäteriet in Gothenburg was conducted to study various aspects of the usage of sensitive equipment. Lantmäteriet is the authority responsible for the management of the Swedish cadastral system and the subdivision of land. In addition, Lantmäteriet provides and publishes geographical and land information (Lantmäteriet n.d.).

The setting for the interview was Lantmäteriets storage room for surveying instruments and tools. The location provided an opportunity for observations as Rubendahl demonstrated the equipment and described how he and his colleagues work and prepare the themselves for different assignments.

5.1.8.2 Civil Engineer Graduates

A field observation of the measuring procedure with Linus Åberg and Joakim Hultenius, both BSc. graduates from the civil engineering programme at Chalmers was performed in order to study the user and the usage of the measuring instruments. The equipment used during the demonstration was provided by the Geo-engineering division at Chalmers. Two different tachymeters were used, one basic and one more advanced.

The setting for the observation was an area near Chalmers and started in the storage room. Åberg and Hultenius were asked to behave as the observation was a real work situation. Moreover, they were encouraged to talk freely and describe their routine and their attitudes (both positive and negative) towards the different tasks throughout the demonstration.

5.1.8.3 Byggmätarna

An interview with Mats Bergström and Bo R Nyström, managers and partners at Byggmätarna was conducted to study the use of sensitive equipment in a small measurement consultancy firm. Byggmätarna are contracted for short term measurement projects by larger construction companies that rely on their expertise.

The interview and observation at Byggmätarna was set partly in their office and partly in their storage room for sensitive equipment. The observation focused on the handling of the instruments before and after usage. Following the interview, Bergström and Nyström described and discussed the surveying business and their everyday work experience.

5.1.8.4 Skanska

An observation and an interview with Niklas Gottschalk, survey engineer at Skanska was executed in order to study the work process of a survey engineer in a large multinational corporation. Gottschalk has twenty years of experience from the industry.

Prior to the observation, a short interview was conducted. Following the interview, Gottschalk was observed during his work routine at a road construction site. Throughout the measuring process, questions were posed to clarify the procedure. The observation was concluded with a short discussion regarding differences between work sequences and necessary instruments for different sites and tasks.

5.2 Conclusions from information gathering

The data compiled from the information gathering process was analysed based on the relevance, consistency and frequency of the various statements. If a problem, theory, wish etc. was reported from multiple sources it was judged to be of high importance. The analysis was used to formulate a list of requirements, see Chapter 7.6. In addition, the analysis revealed valuable functions and features to be emphasised in the concept development phase. The list of requirements constituted the first gate in the project, after which the concept development stage followed.

5.3 Concept Development

The concept development phase was initiated following the information gathering process. The concept development process was performed in a series of different stages, starting with contextualisation then preceding to ideation and concept development.

5.3.1 Contextualisation

Prior to the ideation process, a contextual framework was constructed. Based on the information regarding different user groups, usage situations, sensitive equipment and the Boblbee brand a persona, a scenario and a moodboard was created.

5.3.1.1 Persona

The foundation for the persona was the actual users observed and interviewed during the information gathering, combined with the Boblbee target group. The collected data was then rearranged, interpreted and finally composed into a precise description of the persona. The construction of the persona followed the outlines described in chapter 4.2.1.

5.3.1.2 Scenario

A scenario was formulated to visualise the usage situation and context for the carrying system for sensitive equipment. As for the construction of the persona, the interviews and observations was used as a foundation for the development of the scenario. The scenario was created according to the method described in chapter 4.2.2.

5.3.1.3 Moodboard

A moodboard was created to establish a shared vision as to what visual appearance to aim for in the design process. Images that expressed the Boblbee brand values as well as separate aspects connected to the usage and user of the intended carrying system were collected and arranged on an A3 sheet. The collage was placed on the wall at the work station to serve as guidance during the ideation and concept development process. The moodboard was regarded as flexible and hence updated as new information emerged.

5.3.2 Ideation

The structure of the ideation process consisted of multiple methods to be executed in parallel. The results from the information gathering were used as a starting point and framework for sketching and brainstorming. Focusing on repeated iterations, ideas that were formulated during the (verbal) brainstorming were sketched and ideas that were sketched were translated into words describing their function and appearance. To ensure that the ideation process was not inhibited by the limitations of sketching on paper, a number of sketch-models were created from paper, Kapa-board, clay and wire. Throughout the ideation process, pictures were taken to document the process and the concepts. The photos of the sketches and models were, together with cut-out sketches, organised into categories using KJ-analysis. The concepts generated during the ideation process ranged from rather vague ideas to more explicit solutions. Some ideas were judged interesting and further developed whereas others were disregarded based on the lack of innovativeness, functionality or aesthetics. The

Fig.6 Mock-ups made from Kapa-board.

promising concepts were developed further and modified using the SCAMPER creativity stimulation method. The result from the ideation phase was a large number of ideas and sketches with varying levels of preciseness and feasibility.

To reach an understanding of the ergonomics and user needs, full-scale box-models of the instruments required to fit in the carrying system were constructed from Kapa-board. Velcro straps were attached to the boxes, thus enabling reorganisation into different configurations, see figure 6. The box-models were used during the whole concept development phase to illustrate and communicate the actual sizes of the instruments and equipment. Thereby, limitations on the form possibilities were made explicit.

Fig.7 Organisation of sketches and ideas.

5.4 Conceptualisation

The ideas generated during the ideation process were organised using KJ-analysis. The KJ-analysis resulted in a categorisation of the ideas based on their function, see figure 7. Through the use of a morphological matrix in combination with the KJ-analysis category ‘main solutions’, a number of concept solutions were created. The various concepts were created from combinations of different concepts and part solutions. As a means of reaching a novel and functional final concept, the focus during the conceptualisation was on obtaining easily differentiated concept solutions with high degrees of innovativeness.

5.5 Concept Evaluation

Following the conceptualisation, the concepts were analysed and evaluated through the use of a Pugh matrix, see Appendix 4. In the Pugh matrix, the concepts were rated in relation to how well they fulfilled the identified requirements. For the evaluation, the reference protective case was used as reference. The first Pugh evaluation indicated that a number of concepts had potential for further development, i.e. the concepts constituted a better carrying solution for sensitive equipment than the reference protective case. Following the first Pugh evaluation it was decided that some requirements should be regarded as more important than others. Consequently, a second Pugh matrix with weighted requirements was constructed. As in the first evaluation, the existing protective case served as reference. The second evaluation resulted in the selection of three concepts for further development. The weighted scores served as the basis for the concept selection. The scores were, however, not the only factor used for determining the potential of the concept solutions. In addition to the scores, the concept differentiation and level of innovation were considered in the concept selection. Following the concept selection, features judged to be interesting and promising in the other concepts were saved for the later stages in the design process.

5.6 Concept Selection

The selection of three concepts led to the second gate in which the concepts were presented to Boblbee, the examiner and the tutor. Through a discussion with the stakeholders it was decided to choose two concepts for further development. These concepts were the folding concept and the hard case soft back (HCSB) concept. As both concepts featured interesting part solutions it was decided that an investigation of the possibility to combine the two concepts would be beneficial to the final result.

5.7 Concept Refinement

The decision to study the possibility of combining two of the concepts resulted in a second ideation process and the creation of new sketches and models. The folding concept was explored using paper and Kapa-board. The development of the HCSB concept was largely focused on the configuration and organisation of its components. Attempts of adding elements of folding to the HCSB concept were made. Throughout the second ideation phase, the placement of the concept(s) on the ground and the access to the sensitive equipment were emphasised. As new ideas emerged they were categorised and clustered using KJ-analysis. By discussing the potential in the different ideas they were finally reduced to one main concept and a number of part solutions for the protective interior as well as solutions providing additional functionality.

5.7.1 CAD Modelling I

The refinement process was to great extent realised using CAD software. The initial phase of the refinement process concerned the layout of the concept. Consequently, important surfaces and volumes were arranged in order to create a configuration that allowed for the desired visual

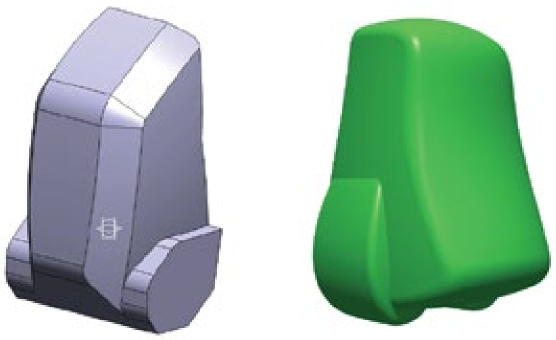


Fig.8 Development of forms using CAD.

appearance and functionality. Employing the theories from the form review (see chapter 6.1), a more precise form was created. Working in iterations, the CAD models became increasingly exact.

Most of the CAD modelling was made in Catia V5 Imagine & Shape. The programme was used to quickly modify and test a large number of concepts until the sought-after expression and functionality was achieved. The modelled concepts were tested for functionality (with respect to the physical ergonomics) using digital mannequins in Jack and Catia V5. In addition, a virtual model of a tachymeter (model Leica TS/TM30) was created in order to test and verify the dimensions of the CAD models.

Fig.9 Construction of the functional model.

5.7.2 Functional Model

Based on the dimensions on the sensitive equipment and measurements from the CAD files (which, in turn, were based on the dimensions of the sensitive equipment and anthropometric measurements), a full-scale functional model was created. The model was constructed from parts from existing Boblbee backpacks, laths and Kapa-board. The model enabled evaluation of the physical ergonomics and the functionality.

5.8 Concept Evaluation II

The second concept evaluation constituted the third and final gate. To ensure that the refined concept was approved by the initiators of the project, the evaluation was conducted in collaboration with Boblbee. The evaluation was made over telephone with renderings and describing images as basis for the decisions. During the evaluation it was decided to continue developing the hard case soft back (HCSB) concept, aimed at creating a fusion between soft and hard.

5.8.1 REBA II

The functional model was used to perform an ergonomic evaluation of the refined concept. As for the first REBA analysis, the functional model was packed until a combined weight of 12 kg was reached. The test subject and the location were the same as in the first REBA analysis. The lifting and carrying process was documented using video uptakes. The footage was analysed according to the method prescribed in chapter 4.1.4. The result was used in the development of the final concept.

5.8.2 User response

In order to assess the functionality and product expression an evaluation session with Per Rubendahl at Lantmäteriet was conducted. For the evaluation, Rubendahl was presented with renderings of the refined concept and the functional model. Rubendahl was encouraged to talk aloud as he familiarised himself with the concept. Moreover, Rubendahl was asked to provide positive as well as negative feedback on the concept. The response from Rubendahl was used in the development of the final concept.

5.8.3 Evaluation of expression I

The first expression evaluation process consisted of two steps. First of all, ten respondents (Industrial Design Engineering students aged 20-30) were presented with pictures of the reference protective case (see figure 3) and asked to rate its expression based on four pairs of characteristica, namely passive-active, casual-professional, unsafe-safe and uncomfortable-comfortable, see Appendix 5. Secondly, ten different subjects (Industrial Design Engineering students aged 20-30) were presented with pictures of the refined concept solution and asked to evaluate its expression based on the same criteria. Thus, the first evaluation process was conducted as a between subjects test. The respondents were asked to mark their perception of the expression on an unmarked 100 mm scale. The distance (from left to right) was measured and compiled in a spread sheet, and mean and median values were calculated. The result from the evaluation was used to illustrate how the concept and the reference protective case were perceived. The results were used for the development of the final concept.

5.9 Final Concept

Following the evaluations of the refined concept, minor details were modified on the CAD-model. Renderings were produced in order to communicate the concept expression, intended usage and functionality.

5.9.1 CAD Modelling II

The final concept was modelled in Catia V5 and Alias Automotive. Details were added to enhance the concept expression and more adequately display the functionality of the carrying system. Parts decided to be manufactured using injection moulding were given draft angles. The CAD model of the final concept was visualised through computer renderings.

5.9.2 Evaluation of expression II

In the second and final evaluation of the concept expression, twenty respondents (Industrial Design Engineering students aged 20-30) were asked to compare the expression of the reference protective case and the final concept solution. Thus, the evaluation of the expression was conducted as a within subjects test. As in the first evaluation of the expression, the respondents marked their perception of the expressions on an unmarked 100 mm scale. The result was used to illustrate the difference in perceived expression between the reference protective case and the final concept.

6. Results from information gathering

To answer the research questions relating to the design of a new carrying concept that is comfortable, reliable and innovative, an information gathering process was conducted. The form theory is associated with the expression of the concept and how it may be designed to fit Boblbee's product portfolio. The chapters regarding the products currently on the market and the function analysis serve to provide a basis for answering the research question related to product differentiation. The chapters that concern human anatomy, load carrying, global usage, REBA analysis and user interviews are connected to the research question regarding the optimal method of transportation. Finally, the study of materials is related to the research question about promising materials.

6.1 Form theory

To a large extent, product design is the realisation of a combination of form and functionality. These two factors influence the usefulness as well as the perception and understandability of a product. The interaction between the user and the product is commonly referred to as 'user experience'. In order for a design to be successful it must constitute a beneficial synthesis of form and functionality, in addition, it must evoke an emotional response. The structure and relative importance of the different components have been assessed from various perspectives. Hekkert (2006), focusing on the users' aesthetic perception of forms, suggests a set of design principles to reach what he refers to as 'pleasure in design'. Monö (1997) emphasises the connection between form and functionality and denotes the 'usefulness of a product'. Consequently, Monö advocates the usage of semantics and gestalt laws in product design.

The complexity of human behaviour depends on a combination of emotional reactions and conceptions. If these governing mechanisms are understood, it is possible to create a design that bridges the gap between the designer and the user (Monö 1997). As product development is contingent on commercial factors, a product must be regarded and understood in a brand context. A product designed to reflect a company's values, not just through a logo, will promote product understanding through association to brand values and heritage (Warell & Nåbo; Karjalainen 2007).

6.1.1 Aesthetics

The word 'aesthetics' is Greek and may be translated as: to recognise, perceive and feel (Monö 1997). Hekkert (2006) describes the aesthetic experience as a perceptual process resulting in two outcomes: aesthetic judgment and aesthetic emotion. Thus, the mechanisms of aesthetics affect the feelings for as well as the reasoning about the experience. Monö (1997) separates the traditional definition of aesthetics from aesthetics in industrial design. For the aesthetics in industrial design, Monö refers to an artefact's meta-product. A useful product conveys a meta-product. The meta-product may be explained as the expression of personal values, status and identity that a product communicates. Hence, aesthetics in industrial design could be defined as "the study of the effect of product (physical) gestalt (configuration) on sensations" (Monö 1997).

6.1.2 Semantics

There are numerous approaches to define good design. Monö (1997) states that useful products constitute the overall desired goal in design. A useful product is realised through a combination of semantics and aesthetics. Therefrom, a useful product may be defined as a product that expresses and explains its intended usage and usage context through its design. According to Monö (1997), "[...] things which are designed to be useful must be understood to be usable". The semantic features are essential for creating a meaning in design as they communicate intentions. The basic component in a semantic function is the 'sign', i.e. the simplest, most basic, form of an object that can be interpreted for what it intends to describe (Ibid.). Thus, a product can be said to represent good design if the product is useful and the product is useful if it communicates semantic features (⩾ the sign) that enable an understanding of the product, by the user.

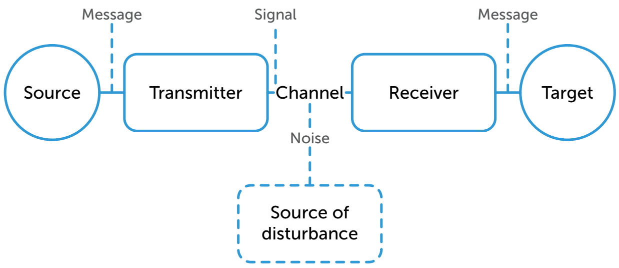


Fig.10 Transmission of information, after Monö 1997.

Product design may therefore be regarded as a form of communication where the product is given functionality and, through its embodiment, informational cues. The product form a medium of communication that transmits this information to the user/receiver (see figure 10). A common language between the designer and the user is a prerequisite for successful communication, i.e. the design must be clear enough to penetrate the contextual noise of the usage context. An ill-defined or ambiguous product design will result in misinterpretations and failing functionality - a product that is not useful. According to Monö (1997), these factors must be considered when engaging in product design.

6.1.3 Building blocks of form

A structural understanding of forms is required in order to assess the semantics and aesthetics of a product. This understanding may be achieved by reducing a form into basic visual elements. The most simple and fundamental elements are points, lines, planes and volumes. Together, these elements constitute the building blocks of form through which forms can be described as well as developed. The elements construct parts which may be combined into more complex figurations. The order of each part can be defined as dominant, subdominant or subordinate based on its prominence. The arrangement of the parts results either in symmetry or non-symmetry, and in balance or non-balance in the aggregate form (Akner-Koler 1994).

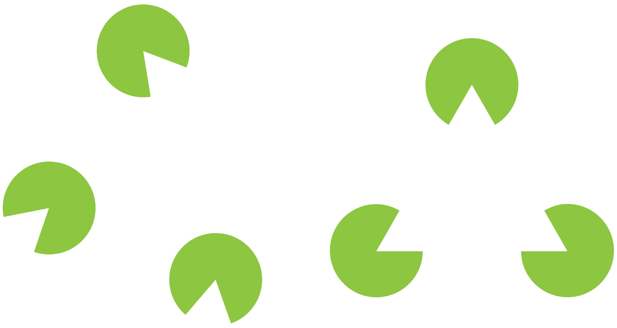


Fig.11 When organised in a specific way, three objects can create a form which is more than the sum of its components.

6.1.4 Gestalt

Gestalt can be described as: "an arrangement of parts which appears and functions as a whole that is more than the sum of its parts", see figure 11. Gestalt is the composition related to the form and the arrangement of form(s), colours and parts (Monö 1997). As a means to develop a product with good gestalt there is a set of arrangement rules, referred to as "Gestalt Laws" (see figure 12).

The gestalt laws are founded upon human cognition and perception and were developed by Max Wertheimer, founder of the Gestalt Psychology School. Despite that its functionality have never been fully explained and the lack of providing a satisfactory distinction between gestalt and design, the gestalt laws have gained acceptance among a great number of scholars (Becker-Carus 2004). According to Monö (1997), the eight gestalt laws are a suitable framework for developing understandable and functional products. Yet, it is important to note that an artefact is not automatically perceived as beautiful if the designer solely adheres to the prescribed gestalt laws. There must be an element of complexity and variety in order to evoke an emotional response from the users (Berlyne 1974, cited in Bloch 1995). Since the pleasure derived from a design is proportional to its complexity -displaying an inverted U-shaped relationship- there is an optimal level of complexity for an artefact (Messinger 1998). Consequently, a successful and useful product is the realisation of the most favourable balance of gestalt laws, usability and complexity.

6.1.5 Product experience

One of the main goals of product design is to induce a desired consumer response. To achieve this goal, the product has to be functional and able communicate with the user. For this to occur, the form of the product must fulfil six different design goals related to:

- functionality and aesthetics
- ergonomics
- production and costs
- regulations and legislations
- the designer(s)
- marketing.

These goals are combined into the final form of a product. The user's (or consumer's) psychological reaction - on an affective as well as cognitive level - to the form results in a behavioural response to the product, i.e. approach or avoidance. This response is partly moderated by the context of the interaction (Bloch 1995).

One method of approaching the behavioural response is to develop an understanding of how the user experiences form. Crilly et al. (2009) and Warell (2008) have formulated frameworks as to how to model product experience. Although somewhat different, both scholars attempt to deconstruct the experience by introducing sub-categories. The former focuses on the intentions of the designer regarding user response. He defines eight intentions, all considered to be cognitive. These are: attention, recognition, attraction, comprehension, attribution, identification, emotion and action (Crilly et al. 2009). Warell (2008) develops a similar framework called 'Perceptual Product Experience' in which he expands the user's response to include sensorial and affective experiences. Three core modes describe the different types of experience, i.e. sensorial, cognitive or affective (see figure 13). The core modes have two dimensions with sub-modes referred to as presentation and representation (Warell 2008).

Understanding the user's experience of a product enables the designer(s) to more effectively create

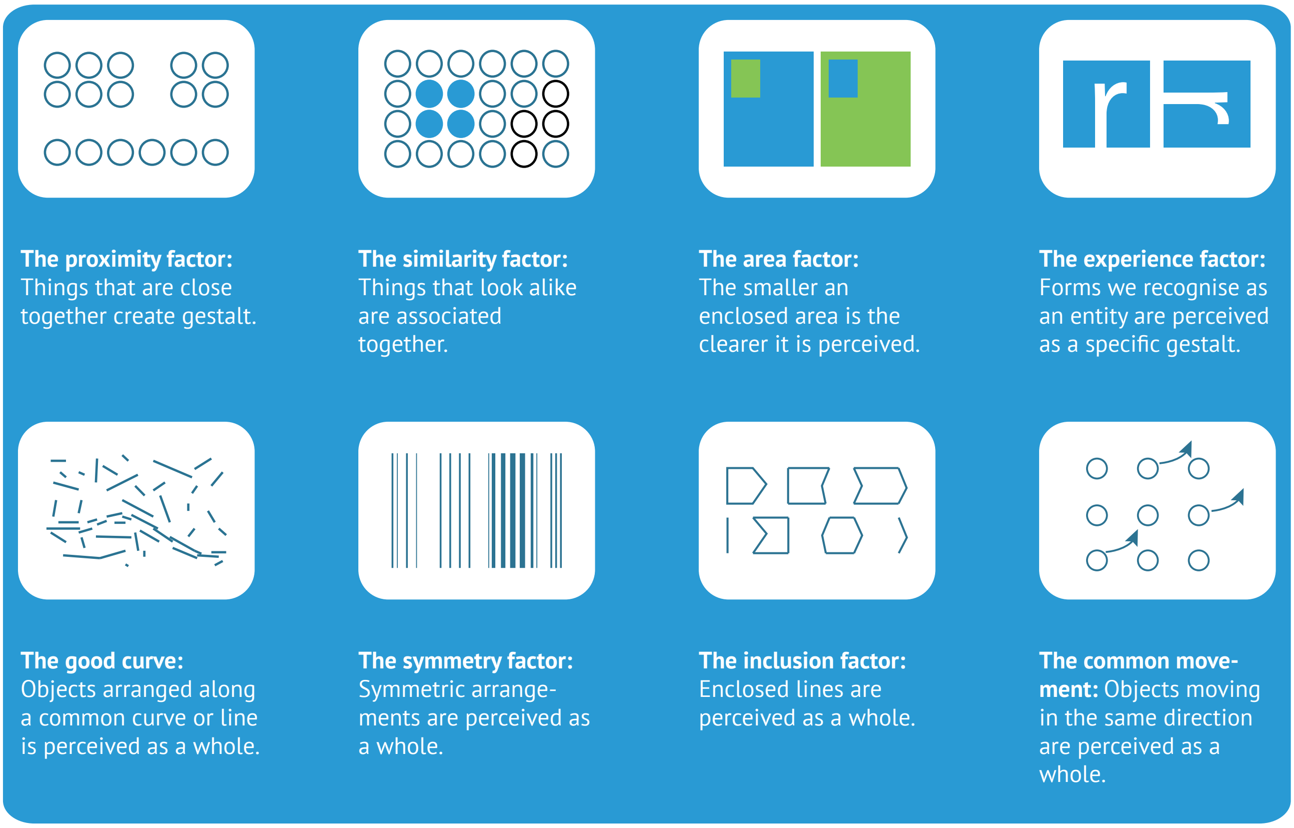


Fig.12 The eight different gestalt laws, after Monö 1997.

products that instill pleasurable experiences, that are easily differentiated on a market, and are easily understood (Ibid.).

Other scholars offer various theories regarding the specific elements of the product experience. Monö (1997), as mentioned, emphasises the semantic aspects and usefulness of a product, Desmet (2002) focuses on assessing emotional response, Hekkert (2006) on aesthetic factors, and Karjalainen (2007), Warell (2006) and Warell & Nåbo (2001) on brand recognition and product identity.

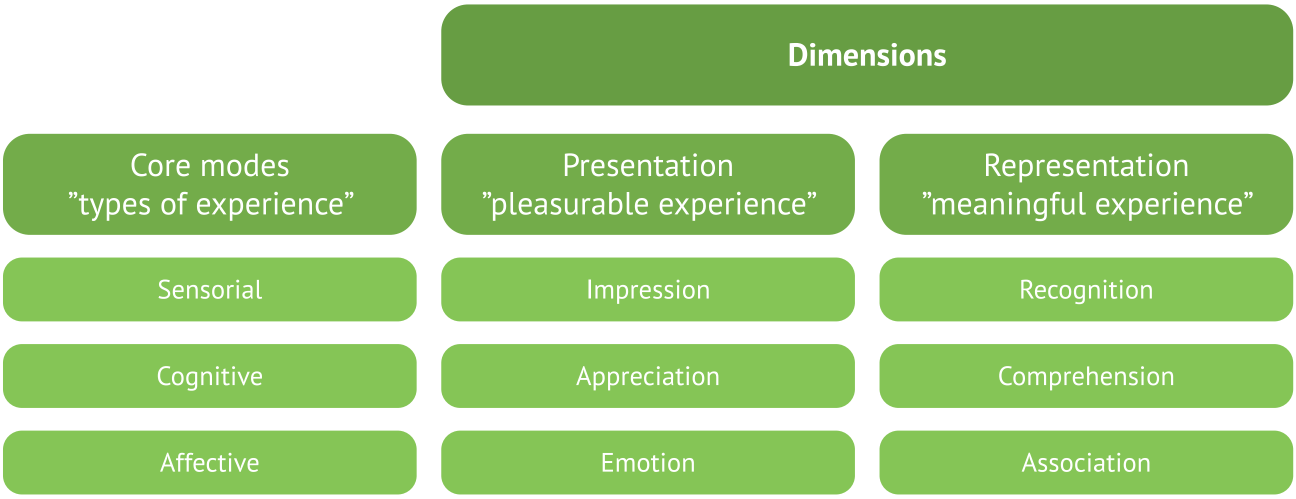


Fig.13 Core modes, dimensions and submodes of the perceptual product experience, after Warell 2008.

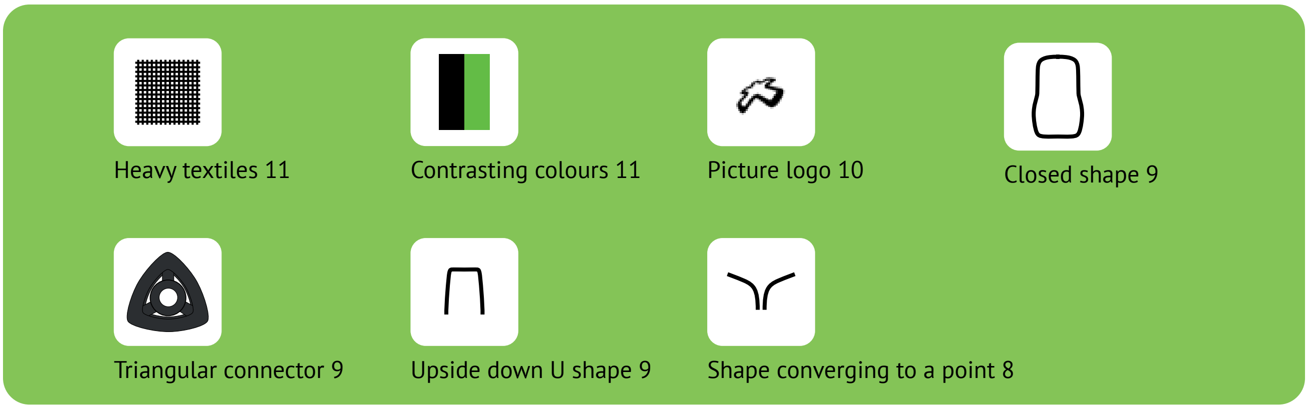


Fig.14 Most frequently occurring design cues identified from the design format analysis.

6.1.6 Brand identity

Brand recognition concerns the relation of product design to brand specific values (Karjalainen 2007). Knowledge and understanding of brand values is essential in order to be able to transfer or translate these into or onto products. Brand values are transferred to products through carriers of brand information, commonly referred to as 'design cues'. Design format focuses on transferring a brand's core values and identity onto the design of a product. This can either be achieved on an implicit level (e.g. creating a perception of Scandinavian through the use of light colours) or on an explicit level through the use of brand characteristic features, i.e. design cues. Design Format Analysis (DFA) is a method of identifying and analysis such design cues (Warell & Nåbo 2001; Karjalainen 2007).

Design Format Modelling is a framework for the development of brand recognition through design. From the use of form elements and/or 'fifth elements' (e.g. a special radiator grille on a car), a company can create user (or customer) recognition (Warell & Nåbo 2001). Design format may be regarded as a template but not a manual for product design (Ibid.). The design format can also be used to create a brand specific design reserve in which information related to the product aesthetics can be stored, thus ensuring a consistent and coherent product expression over time.

Through methods such as DFA, the design format concept is relatively easy to apply during the design process. In using the methods and theories, the designer(s) is able to connect different aspects of the design and communicate their intentions to the design team as well as to the users (Warell & Nåbo 2001).

6.2 DFA for Boblbee

The design format analysis resulted in an identification of the most frequently occurring design cues in Boblbee's product portfolio (based on the eight products analysed, see Appendix 3). Two of the design cues are specific to Boblbee, namely the picture logo and the characteristic triangular connector developed by the company. The most common features in the eight products analysed were heavy textiles and contrasting colours, see figure 14.

Furthermore, the DFA revealed three products to be prominent carriers of the design cues, see figure 15. These products, the Procam 500XT, the Megalopolis Aero and the Megalopolis Fast Back, are all found in the premium segment of Boblbee's product portfolio.

Fig.15 Highest scoring products from design format analysis.

6.3 Human anatomy and physiology

6.3.1 Skeleton and skeletal muscles

The postures and the movements of a human body are realised by a combination of the skeleton and its associated skeletal muscles. The spine, or vertebral column, provides the body with axial support, muscle attachments and weight transfer from the trunk to the lower limbs. In addition, the vertebral column protects the sensitive spinal cord, i.e. the nerves coming to and from the brain and to and from the muscles. As can be seen from figure 16, the vertebral column is S-shaped. This S-shape gives the spine flexibility and enables movement of the trunk. The upper, cervical vertebrae allow the greatest range of movement. The thoracic region allows for rotation of the trunk and the lumbar region allows for flexion and extension of the trunk. Since the vertebrae have to support more weight the further down the spine they are located, the vertebrae grows larger and sturdier towards the pelvic girdle. Movements and energy absorption of the vertebral column are made possible by the elastic intervertebral disks located between the vertebrae, see figure 16. Like the vertebrae, the disks are larger and thicker in the lumbar than in the cervical region. The vertebral column is supported and held in place through many different ligaments and muscles (Marieb & Hoehn 2007).

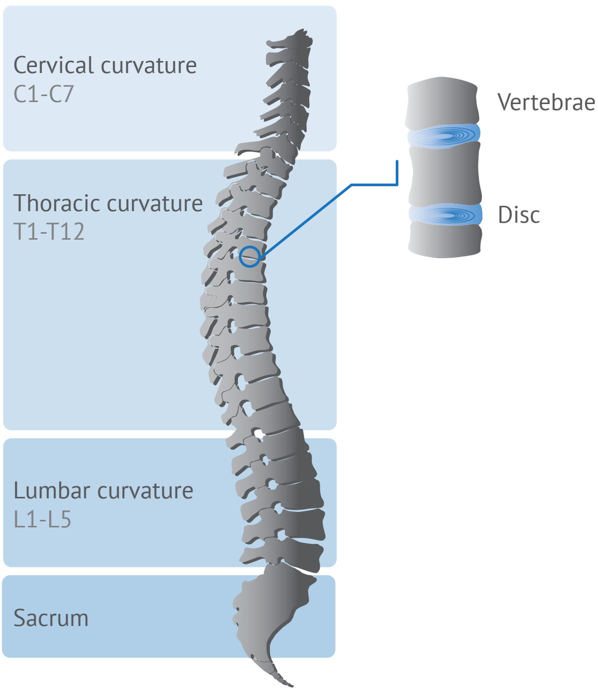


Fig.16 Illustration of the S-shaped vertebral column.

The hip or pelvic girdle, see figure 17, is attached and secured against the vertebral column with some of the strongest ligaments in the body. Like the vertebral column, the pelvic girdle transmits the weight of the upper body to the lower limbs. Consequently, the lower limbs carry the weight of the entire erect body and are subject to high forces. Therefore, femur (or the thigh bone) is the largest and strongest bone in the body (Ibid.).

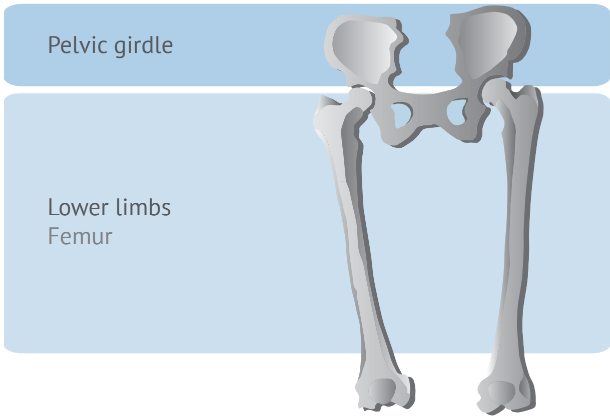


Fig.17 Illustration of pelvic girdle and the thigh bone.

The skeletal muscles are attached to the skeleton. The over 600 muscles are voluntary, i.e. they are subject to conscious control. Contrary to muscles that are not subject to conscious control (e.g. the heart) skeletal muscles easily tire and require rest. The skeletal muscles fulfil four vital functions: producing movement, maintaining posture, stabilising the joints and generating heat. Every movement of the body is the result of muscle contractions, and as the muscles contract heat is generated (as the efficiency of a human muscle is approximately 40%, the surplus energy is transformed into heat). This heat is necessary in order to maintain the body temperature.

Skeletal muscles work in pairs consisting of one muscle doing one action and one muscle reversing the action. The movers and its corresponding antagonist are located on opposite sides of the joint over which they operate. Almost all skeletal muscles work at a mechanical disadvantage, resulting in a loss of force. The muscles working at a mechanical disadvantage tend to be thick and powerful; moreover, they are often located close to the joints which enable rapid movements (Ibid.).

Some important muscles enabling movement of the upper body and limbs are erector spinae, trapezius, serratus anterior, pectoralis major, latissimus dorsi, rectus abdominis and the internal and external obliques, see figure 18. When designing a product to be worn on the upper body, it is important not to inhibit the movements of these muscles.

6.3.2 Anthropometrics

In a population, individuals vary in size, strength and shape. Therefore, knowledge of the relevant measurements are important in designing for a defined population or target group. Anthropometrics is a science concerned with human

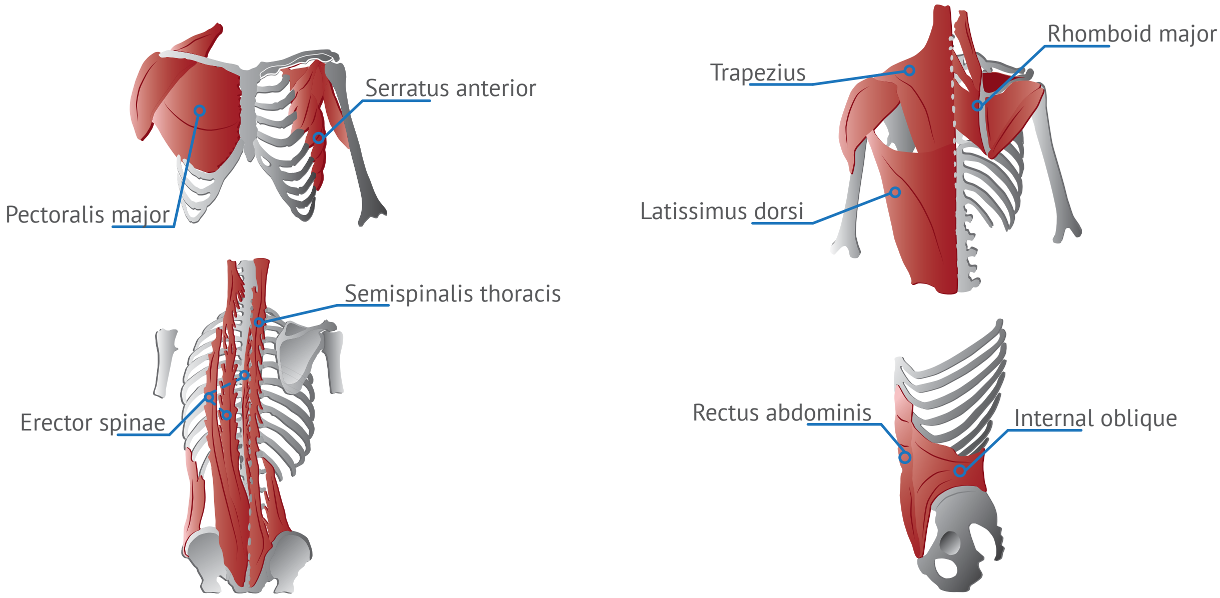


Fig.18 Illustration of the important skeletal muscles in the upper body.

measurements, more specifically body size, shape, strength, mobility, flexibility and working capacity. A primary concept is the notion of frequency distribution and its relation to gaussian distribution (commonly referred to as 'normal distribution'), see figure 19. Some measurements (e.g. stature) have been revealed to follow a gaussian distribution whereas others (e.g. strength) do not display this characteristic.

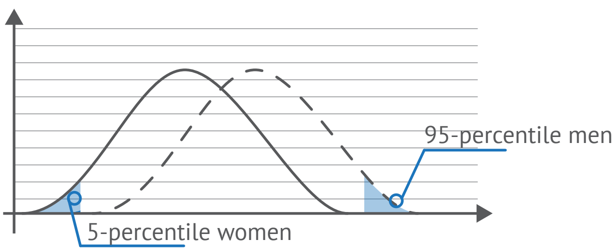


Fig.19 Illustration of a gaussian distribution.

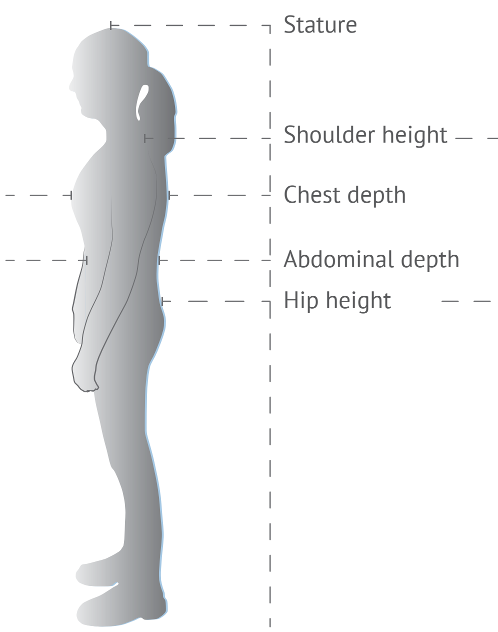
Anthropometrics is essential in design as the product(s) must fit its intended target group; usually the 5-95 percentile rule is applied to ensure that the product(s) fit the majority of users. The 5-95 percentile rule implies that a product is designed to fit all users in the range from the 5th percentile of women to the 95th percentile of men, i.e. the design will not be optimal for the lower 5% of the women nor for the upper 5% of the males. However, as stated, the most important factor to consider is the identification and analysis of the target user group which may or may not reflect the measurements of the general public (Pheasant & Haslegrave 2006). Some relevant measurements for adult Swedish men and women can be found in figure 20, note that the circumference measurements are for a US-population (Pheasant & Haslegrave 2006; Robinette et al. 2002). It should also be stressed that the anthropometric data displayed originates from measurements obtained in 1968-69. Currently, according to Blanking, Boblbee's products are designed to fit men and women with statures between 155-195 cm.

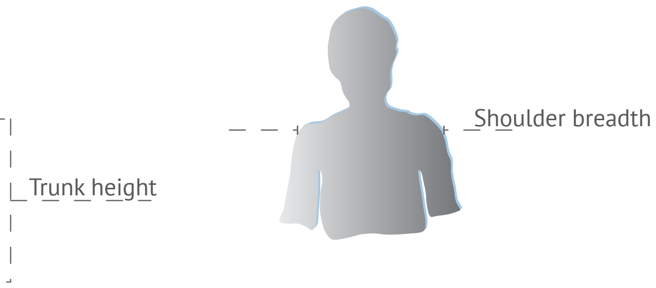
6.3.3 Sweating and sweat distribution

When the muscles work hard or the climate is hot, the body temperature is increasing. In these situations, the body temperature is reduced by a combination of two operations: blood vessel dilation and sweating. Increasing the diameter of the veins and arteries entail a greater surface area and a larger contact area between the warm blood and the cooler surrounding air. As warm blood flow through the vessels the heat is transferred to the air through radiation, conduction and convection.

Heat induced sweating generally begins at the forehead and then spreads over the roughly 3 million sweat glands over the body (Marieb & Hoehn 2007). The sweat glands are not uniformly distributed over the body; the gland density is the highest at the forehead, hands and feet, fairly high at the arms and the trunk and lower at the thigh and legs (Machado-Moreira et al. 2008). Sweating is involuntary and its principal function is to lower the body temperature and prevent overheating. Compared to blood vessel dilation, sweating yields a higher heat loss from the body (Marieb & Hoehn 2007; Smith & Havenith 2011).

Sweat is filtrated from the blood and consists of 99% water, vitamin C, salts and metabolic waste products (Marieb & Hoehn 2007). The amount of sweat secretion is highly individual yet sweating generally increases with exercise (Havenith et al. 2008; Smith & Havenith 2011). Furthermore, the sweat distribution regions are similar between





[mm]	5 percentile women	95 percentile men	
Stature	1540	1850	
Trunk height	510	580	
Chest depth	185	255	95 percentile women: 300
Abdominal depth	180	290	95 percentile women: 310
Shoulder breadth	325	435	
Circumference (US)	634	1114	

Fig.20 Illustration and explaination to anthropometrical data for Swedish men and women. Data from Pheasant & Haslegrave 2006 and Robinette et al. 2002.

individuals and between men and women (Ibid.). Sweating from the trunk accounts for roughly half of the entire body perspiration (Machado-Moreira et al. 2008). The sweat distribution on the trunk is not uniform and sweating is highest on the dorsal side of the torso, along the spine, see figure 21 (Machado-Moreira et al. 2008; Smith & Havenith 2011; Havenith et al. 2008). Women sweat less than men and the number of sweat glands in a region do not reflect the amount of sweat secretion in that region (Havenith et al. 2008; Smith & Havenith 2011). The influence of pressure on sweating is not perfectly exhausted, yet it has been concluded that a local pressure under a load of 5kg does not increase the sweating in that region (Ferres 1960).

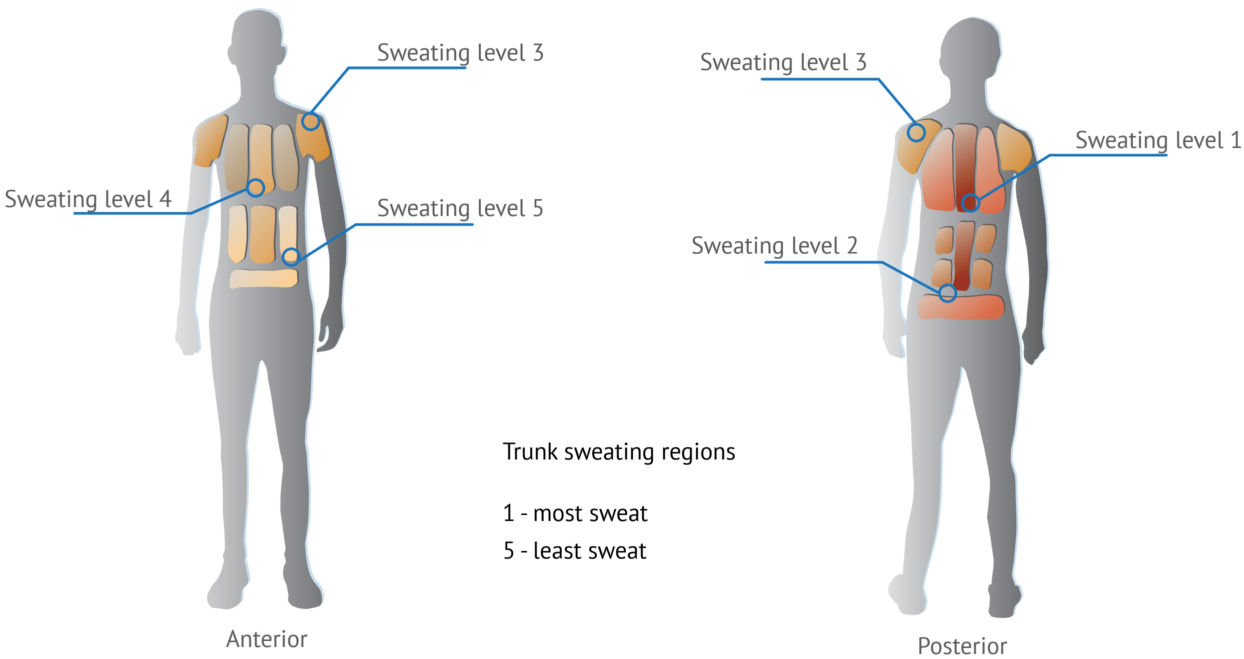


Fig.21 Sweat distribution on the anterior and posterior torso.

6.4 Load carriage

There are many separate factors that influence the performance of load carriage, among these are the weight, size and shape of the load, the duration for which the load is to be carried, the climate and terrain in which the load is to be transported, and the clothing, physical characteristics and condition of the person performing the exertion (Legg 1985). It is important that the the load, however carried, is not restricting the body movements of the carrier (Holewijn & Lotens 1992). The most efficient method of transporting a load is, in terms of muscle activity and comfort, on the torso (Cook & Neumann 1987). The closer the load is located to the body centre of gravity, the lower the moment about the vertebral column will be (Pheasant & Haslegrave 2006). There are essentially two methods of carrying a load on the torso: the conventional backpack and the double-pack, see figure 22.

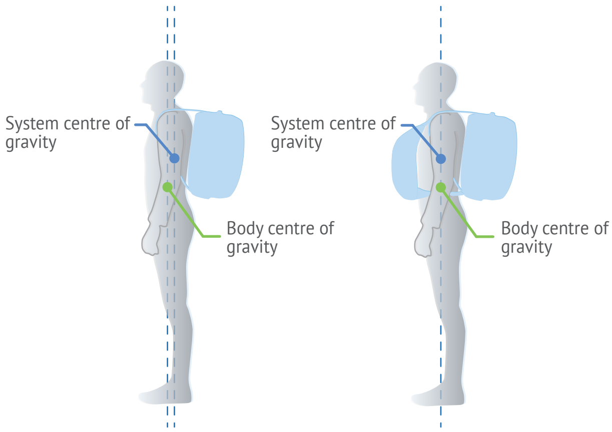


Fig.22 Shift in centre of gravity from wearing a conventional back-pack or a double-pack.

The two methods of carriage has their respective advantages and disadvantages; for instance, the double-pack enables a more upright posture for the carrier, however it is less versatile and more time-consuming to put on and to remove (Knapik, Harman & Reynolds 1996; Knapik et al. 1997). In effect, there are two designs for backpacks and double-packs, either the pack has an external or it has an internal frame. The purpose of the frame is to provide stability and to transfer weight from the shoulders to the hip region (Bloom & Woodhull-McNeal 1987). It must be noted that, independent of the method of carriage, energy consumption, muscle fatigue and discomfort increase as the weight of the load increases (Winsmann & Goldman 1976; Johnson, Knapik & Merullo 1995). Furthermore, the risk of injury increases as the weight of the load increases (Pheasant & Haslegrave 2006). In order to lighten the load one may reduce the number of items carried, produce the items from lightweight materials or move the load closer to the carrier's centre of gravity (Johnson, Knapik & Merullo 1995; Knapik, Harman & Reynolds 1996). The most comfortable and energy efficient carriage is achieved when the load is placed symmetrical (with respect to the vertical body axis) and as close as possible to the body centre of gravity (Bridger 2009; Knapik, Harman & Reynolds 1996; Cook & Neumann 1987; Legg 1985). There is a discrepancy regarding the optimal placement of the load centre of mass; some claim that the best method of carrying (in terms of perceived exertion, heart rate and oxygen consumption) is high on the back (T1-T6, see figure 16) (Stuempfle, Drury & Wilson 2004) while others suggest a mid back placement (Bobet & Norman 1987). Winsmann and Goldman (1976) did not discover any significant relationship between the placement of the load and the carrier's energy consumption, the main factor influencing energy consumption was instead the weight of the load. As a higher load placement results in an upward shift of the system centre of gravity it has been suggested that a high load placement is better suited for an even terrain whereas a more evenly distributed load may be beneficial whilst carrying in a more demanding and uneven terrain (Knapik, Harman & Reynolds 1996). It is important to note that not all studies analysed the carrier's perceived exertion but rather focused on energy consumption and heart rate related to different methods of carrying. When studied, participants expressed that packs that transferred weight from the shoulders to the waist region were the most comfortable (Holewijn & Lotens 1992). The most frequently used method of shifting weight from the shoulder region to the hips is through a frame and a waist belt.

A flexible frame and a well-padded waist belt reduce the load on the shoulders and lead to less perceived strain by the carriers (Holewijn 1990; Knapik, Harman & Reynolds 1996). In addition to the perceived discomfort, pressure on the shoulders may cause irritation and inflammations. Compared to the shoulder region, the hips are less sensitive to pressure and offer a larger contact area which, per definition, reduce the amount of pressure (Holewijn 1990). As a workload that is acceptable for larger muscle groups may severely overload smaller ones, it is necessary to be attentive to discomfort and fatigue in smaller muscle groups and to actively shift load from smaller muscle groups to larger ones (Bobet & Norman 1987). A large, well-padded waist belt, a frame and vertical rods may serve to transfer some of the load from the shoulders to the hips (Holewijn & Lotens 1992; Knapik et al. 1997; Reid & Whiteside 2000). The shift in the load will reduce the compressive forces acting on the torso above L3-L4 (Reid & Whiteside 2000). An internal frame will position the load lower and closer to the carrier's centre of gravity compared to an external frame. As a result, backpacks with internal frames are better suited for transporting loads in uneven terrains whereas backpacks with external

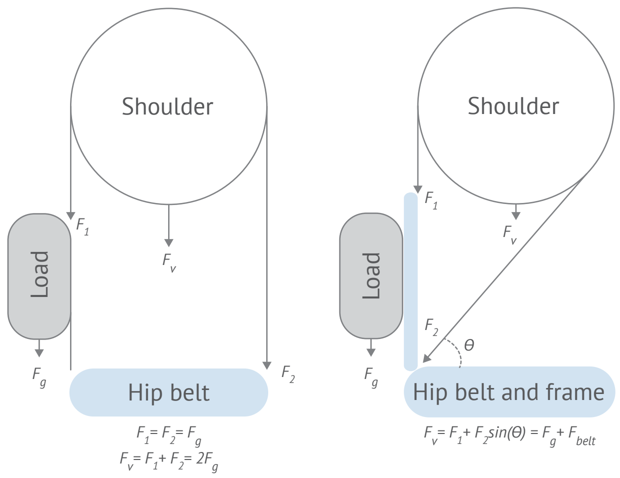


Fig.23 Illustration of how the forces are affected by the attachment placement for the shoulder straps (after Holewijn 1990).

frames are preferable for heavier loads and more even terrains (Bloom & Woodhull-McNeal 1987; Stevenson et al. 2004). It is essential that the load and pack is properly secured and attached to the carrier since displacement of the load is related to discomfort and injury incidence (Knapik, Harman & Reynolds 1996; Stevenson et al. 2004). The shoulder straps, present in conventional backpacks as well as double-packs, should be well-padded and run over the shoulders, under the arms and to the back, not to the hip belt. A design in which the shoulder straps run to the waist belt is unfavourable as it results in greater pressures being exerted on the shoulders, see figure 23 (Holewijn 1990). The optimal attachment angle for the lower fastening of the shoulder strap has, through an empirical study, been found to lie between 24 and 30 degrees measured from the vertical body axis, see figure 24 (Reid et al. 2000). Furthermore, as there can be high peak pressures at seams and edges, appropriate placement and padding of the shoulder straps are important (Stevenson et al. 2004).

Since placement of the load close to the body centre of gravity has, in some studies, been found to require less energy from the carrier, a double-pack design should theoretically be beneficial to the carrier (Knapik, Harman & Reynolds 1996). When using double-packs, carriers have reported less low-back discomfort, however, they also reported a higher neck and hip discomfort as well as heat illness (Knapik et al. 1993). One reason for the perceived heat illness may be that the front-pack serves as a heat barrier and thus induces a heat build-up on the torso (Johnson, Knapik & Merullo 1995). A suggested solution to the heat accumulation is increased ventilation by adding an external frame to the front-pack (Knapik et al. 1993).

6.5 Products on the market

There are multiple similarities between the existing carrying solutions for sensitive equipment offered by the leading companies in the industry (i.e. Peli, Nanuk, B&W, HPRC and Explorer). The most common product is a rigid case constructed from either a polypropylene or a reinforced ABS plastic outer shell and an internal protective impact foam, see figures 26 and 27. Since the function and the design of the cases from the leading manufacturers are highly similar, they tend to partly compete using advanced plastic compounds (e.g. TTX01™(HPRC), NK-7™-resin (Nanuk)). In addition to the stackable cases, some companies provide backpacks whereas others advance harness solutions for back transport of their boxes, see figure 25.

All major companies produce their respective protective cases in different sizes and with different interiors. The cases are equipped with a handle and are consequently designed to be carried in hand or, alternatively, be driven as close to the place of interest as possible. To protect the sensitive equipment from ingress of water and dust, the cases are manufactured with close tolerances and are sealed with strong latches and rubber gaskets (HPRC n.d, Nanuk 2010, Peli 2013, B&W n.d, Explorer 2013). Generally, the cases carry numerous certifications (e.g. IP67, STANAG 4280) and the companies offer lifetime warranty on their products.

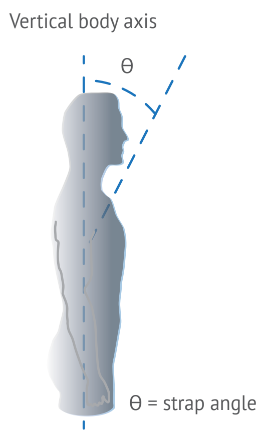


Fig.24 The vertical body axis and strap angle illustrated.

Fig.25 Two solutions for back carriage: HPRC 3500 and harness Explorer Back Pack System (BPS).

Fig.26 Three protective cases from three different manufacturers: Nanuk 925, Peli-Case iM2450 and Explorer 4820B.

The users of the heavy-duty protective cases are engineers, scientists, emergency workers, photographers, adventurers and military personnel. These professionals work in various climates and conditions all over the world, from Antarctica to the Sahara.

6.6 Function analysis

The reference protective case was analysed with respect to the function of its different parts and components, see figure 27. As the instruments stored and transported in the protective cases are sensitive to shocks, the cases are made in a cuboid shape with two (opposing) large flat surfaces. These surfaces allow for a stabile placement of the case on a horizontal surface. In addition, the flat surfaces provide a possibility of stacking the cases. Since ingress of fluids and dust is potentially detrimental to the functionality of the equipment, the cases have two latches to prevent unwanted opening. Moreover, as the latches allow for a firm closure of the cases, a rubber gasket serves to enhance the fit between the lid and the bottom. Consequently, the main function of gasket is to prevent fluids and dust from entering the case in the joint between the lid and the bottom. The construction with one rigid outer shell and one softer interior foam is analogous to that of bicycle helmets. In order to attenuate an impact and protect the instruments from the shock, the shells serve to reduce the acceleration (thus lessening the impulse). The tailored design of the interior foam allows for protection and an overview of the equipment. Thereby, the risk of forgetting necessary tools should be minimised.

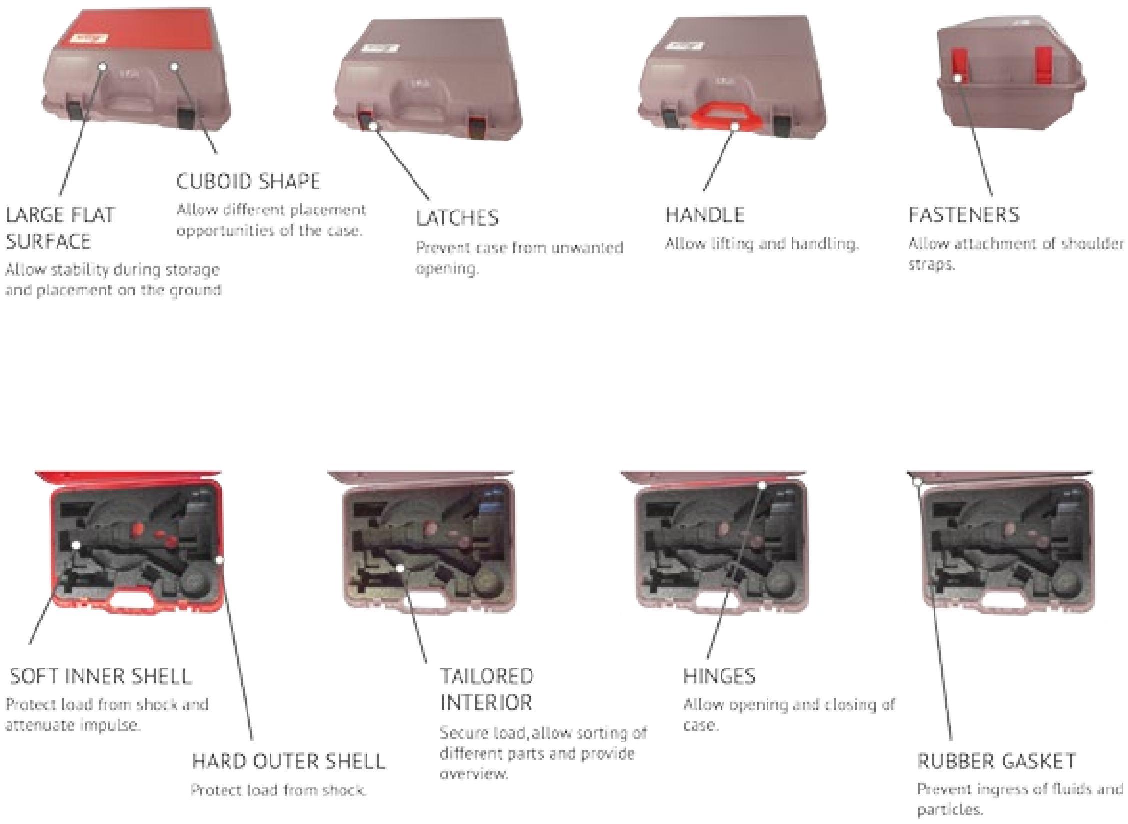


Fig.27 Function analysis of reference protective case.

6.7 Global usage

Tachymeters are used in order to produce accurate measurements for general construction, environmental research, mining and exploration. These sites may be located all over the globe, thus requiring functionality in various climates. In addition to the frequent usage in the more developed countries, some regions of future potential are described below. The data reveals areas with underdeveloped road, railroad and electricity infrastructure as well as countries with large amounts of natural resources. As can be seen from figure 28, some of the regions are also among the world's poorest.

6.7.1 Natural resources and renewable energy sources

Natural resources are for instance fuels, forestry and mining products. These resources are either renewable (e.g. forests or fisheries) or non-renewable (e.g. oil and natural gas). The importance of natural resources increase and their share of the world trade grows. The natural resources are not evenly distributed across our planet yet required by all in order to provide for our basic needs - from food to energy (World Trade Organization 2010).

Deepwater oil and gas production have increased steadily during the last decade. A great portion of the output is located off Brazil, West Africa and the Gulf of Mexico. The off-shore production is predicted to continue growing, and more than two thirds of the significant oil and gas findings since 2006 have been in deepwater (World Economic Forum 2012a). As tachymeters are used in this environment, it creates requirements regarding the resistance to (salt) water and humidity.

Renewable energy sources, primarily hydropower, accounted for approximately one fifth of the global electricity generated in 2010. The European Union has set a goal of obtaining 20% of the energy from renewables before 2020 (Ibid.). To reach the target figures, the European Union produces and invests heavily in wind power. China is also investing in renewable energy and in 2010 the country was the leading installer of wind turbines and solar thermal generators. Furthermore, China produces the greatest amount of hydropower in the world (Ibid.). The locations of the solar power stations or wind turbines (e.g. in a desert or at sea) result in requirements concerning the comfort of the carrying concept and its resistance to harsh environments.

Mining products are, in terms of world market share, significantly smaller than fuels. Nevertheless, mining products dominate the export of some countries in Africa and South America (World Trade Organization 2010). Since the climate in Africa and South America can be both extremely dry and arid with reoccurring dust storms or very humid with heavy rainfalls, it prompts requirements regarding resistance to ingress of water and particles.

Some countries rich in natural resources are the Russian Federation, Saudi Arabia, Canada, China, Brazil, Australia, United Arab Emirates, South Africa and Chile (United Nations 2010), see figure 28.

6.7.2 Electricity

A reliable supply of electricity with few interruptions guarantee that the society and economy can function unimpeded (World Economic Forum 2012b). Few interruptions in the electricity supply imply that tasks requiring electrical energy can be completed faster and more efficient; moreover, it is one of the prerequisites for long distance communication. As the modern society depends on the supply of more and more energy, this energy must be transported from its source to its user. Furthermore, as alternative (i.e. renewable) energy sources grow in importance, new power lines are required.

In addition to the demand for an expansion of the electricity infrastructure in developed regions, some countries currently lacking in electricity supply are Lebanon, Nigeria, Chad, Venezuela, Zimbabwe, Ghana, Paraguay and India (Ibid.), see figure 28.

6.7.3 Road and railroad infrastructure

A well developed infrastructure is a prerequisite for a modern functioning society. Infrastructure such as roads and railroads connect different regions within or between countries. This connection is in many cases necessary to ensure economic growth and reduction of inequalities (Ibid.). Roads and railroads enable efficient transportation of goods and people from one place to another (e.g. from home to work or from a factory to a market). The need for using tachymeters for the expansion of the electricity, the road and railroad infrastructure results in requirements related to the comfort of of the carrying concept as producing measurements for these areas may entail long hikes.

Some countries lacking in road and railroad infrastructure are Lebanon, Ukraine, Paraguay, Brazil, Albania, Uruguay, The Russian Federation, The United Arab Emirates, Libya and Romania (Ibid.), see figure 28.

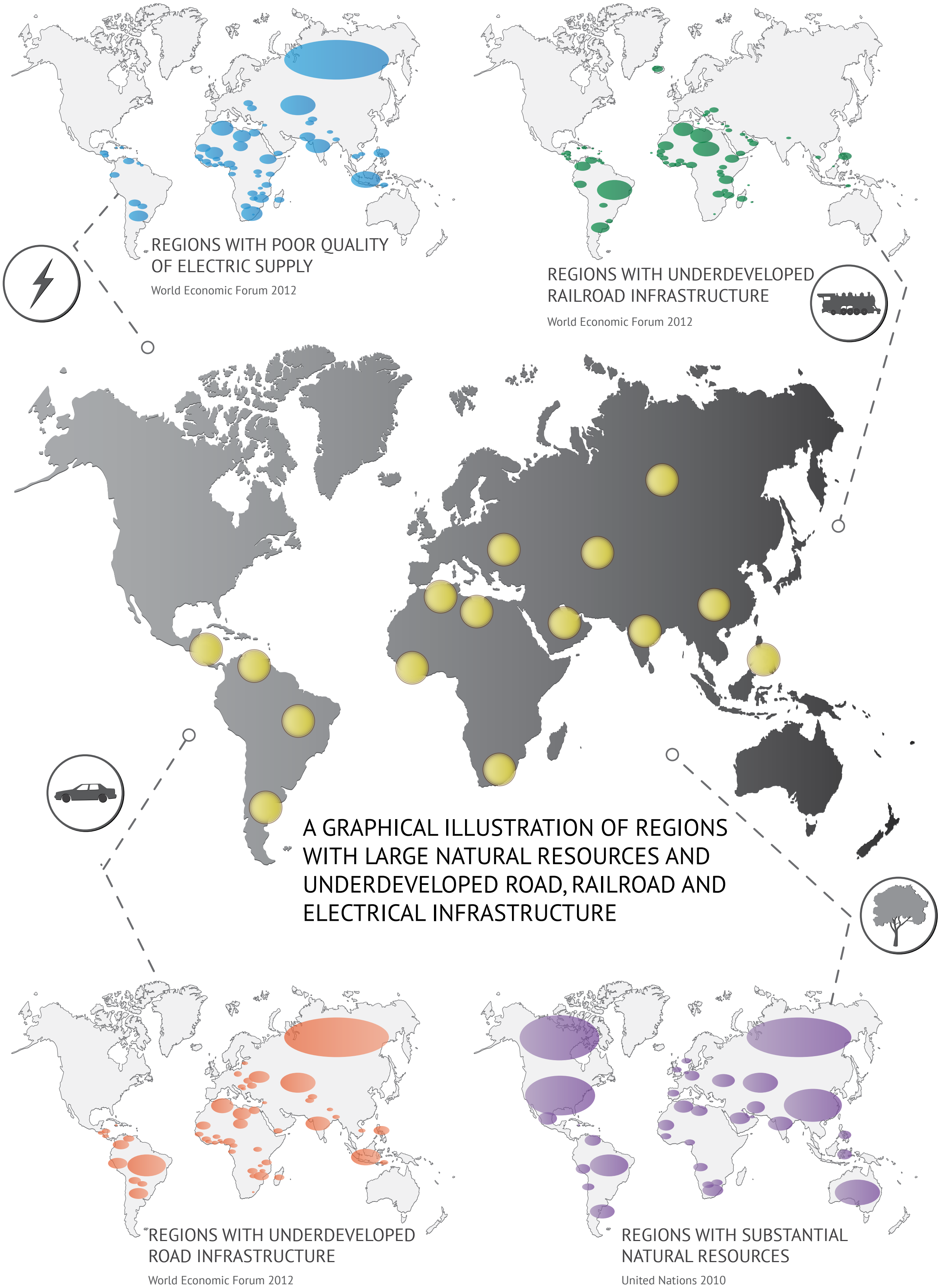


Fig.28 Illustration of regions across the world which constitute possible future sites of usage for tachymeters, the current regions in which tachymeters are used are not displayed (e.g. construction of roads and houses in Sweden).

6.8 Interviews and observations

The main results from the interviews and observations conducted with Per Rubendahl at Lantmäteriet, Linus Åberg and Joakim Hultenius BSc-graduates in civil engineering from Chalmers, Mats Bergström and Bo R Nyström at Byggmätarna and Niklas Gottschalk at Skanska are presented below.

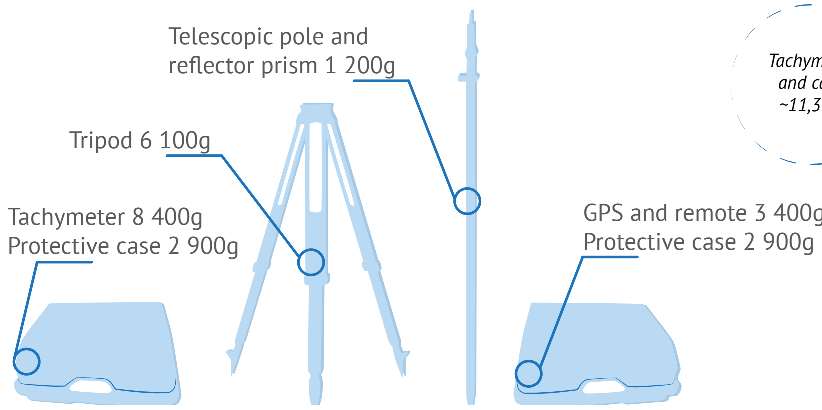
6.8.1 Instruments

According to Mats Bergström at Byggmätarna, there are essentially two producers of sophisticated instruments for providing accurate measurements - Swiss company Leica Geosystems and American company Trimble. Lantmäteriet and Skanska use equipment from Leica Geosystems and Byggmätarna works with instruments from Trimble. Lantmäteriet acquires instruments from a procurement, Skanska rents the apparatus necessary for each assignment through an in-house specialised department, and Byggmätarna purchases their equipment on the market. The instruments used at Chalmers are bought for educational purposes and are, Åberg states, significantly older and less advanced compared to the ones used in the industry. The measurement apparatus are waterproof, thus allowing usage in various conditions.

6.8.2 Storage and Transportation

A measuring job usually begins in the storage room. The necessary equipment is collected, each item having its dedicated place in the room. Tachymeters, handheld remote control and data storage units, and GPS-discs are generally stored in the plastic cases in which they were delivered (see chapter 3). The batteries are stored in chargers. All professionals interviewed concur that it takes approximately five minutes to prepare and collect the tools and instruments needed in order to complete a task. As observed at Skanska and confirmed during the interviews, it is rather easy to forget some items, particularly the batteries and the remote control. For a typical task of geographic data collection, the equipment consist of a tachymeter, a GPS-device, a handheld remote control and data storage unit, a tripod for mounting the tachymeter and a telescopic pole for the optical reflector prism (and GPS unit), see figure 29. Gottschalk, Nyström and Rubendahl explain that they bring all available apparatus and tools to the transport vehicle and, once at the working site, leave the instruments that are not required for the specific assignment in the van. Aside from the measuring apparatus, additional tools (e.g. drills, steel pipes and spray cans) vary with different jobs. Gottschalk notes that if special instruments or tools are necessary for the completion of a task two people are assigned for that job. Each of the persons interviewed agree that they prefer to use the GPS for measuring as it is lighter and allows for more efficient operation. However, the comparatively poor accuracy of the GPS-system renders it unusable in some situations. At Skanska, Gottschalk mentions that, due to lack of space, the GPS and the tachymeter are not transported in the same carrying solution. Moreover, as the GPS is less sensitive to impacts, it is sometimes transported mounted on the telescopic pole.

In the transport vehicle, the sensitive equipment are stored in their respective protective cases. Rubendahl states that he places the cases in the back compartment of his van and, as the cases are not secured, he can sometimes hear the them shifting and moving. At Byggmätarna, Bergstöm explains, the case containing the tachymeter is placed in the passenger seat and secured by the safety-belt. Due to the advanced optics in the tachymeter, Bergström continues, it must be stored and transported in an upright position. At Skanska, the tachymeter is stored in an external frame backpack, see figure 30. The top compartment of the backpack is used for storing spare batteries and the remote control unit, see figure 33. During transport, Gottschalk positions the instrument in the backseat of the pick-up truck and fastens it using the safety belt. According to Bergström, the instruments are subject to frequent bumps as one



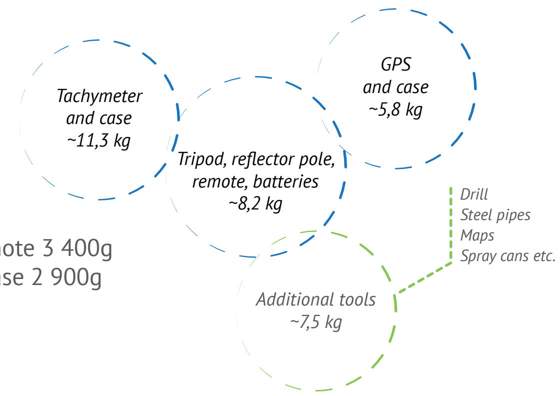


Fig.29 Typical equipment for a measuring task.

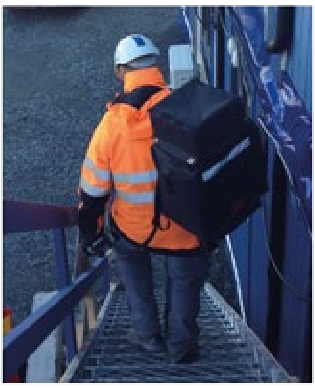
is driving in uneven terrain, hence the sensitive equipment must be properly secured to reduce the risk of damaging the optics. The distance to the working site can sometimes be long and require several hours of driving.

Fig.30 A soft backpack with an external frame. Used for transport and storage of tachymeters at Skanska and Lantmäteriet.

Approaching the site, all express that they try to drive as close as possible in order to minimise the transportation by foot. Consequently, the distance that the apparatus and the tools needs to be carried is usually less than 100 meters. Hultenius explains that most companies have four wheel-drive vehicles which allow for off-road transportation.

Following a measuring session, the apparatus are either returned to the storage room or driven to the next working site. Arriving at the storage room, there is a similar routine confirmed by all professionals interviewed. Since the jobs can occur in every possible climate, accumulation of dirt and moisture in the protective cases are not uncommon although the cases (or backpacks) are closed directly upon mounting the tachymeter onto the tripod. Bergström states that the cases are more or less hermetically sealed and that temperature changes (e.g. from a cold environment to a warmer room) will result in vaporisation of the water. As a consequence, the vapour will diffuse into the instruments, damaging the optics. Therefore, the cases are opened to allow for natural evaporation. Following the opening of the cases, the batteries are removed and placed in chargers. Skanska and Lantmäteriet use small batteries that are replaced during longer measuring sessions whereas at Chalmers and Byggmätarna a larger and heavier (6,4 kg) motorcycle battery powers the apparatus, see figure 32.

During the interview with Niklas Gottschalk at Skanska, the backpack containing the tachymeter was placed outdoors to adapt it to the surrounding temperature, thereby enhancing the accuracy of the measurements.



Leaving
Outside office

Transport
Backseat of car

Preparation
Work site

Transport
Work site

Mounting
Work site

Measuring
Work site

Transport
Work site

Leaving
Work site

Fig.31 An overview of the measuring process at Skanska.

6.8.3 Task description and users

According to Gottschalk and Åberg, there have been major technological developments in the industry during the past twenty years - more specifically the advent of the Global Positioning System (GPS), the wireless communication systems, and the tachymeter. The transition to wireless communication systems has resulted in one person being able to execute a measuring job that previously required two persons. At Byggmätarna, Nyström explains, assignments are usually completed alone as they are a relatively small company and it would be too expensive to have two persons per task. This, in turn, leads to more equipment per person to transport and carry to the working site. In contrast, at Lantmäteriet and Skanska measurement jobs are generally conducted in teams of two. Communication within the team is essential for producing efficient and adequate measurements; the workers communicate using radios or hand gestures. During the observation at Skanska, the employees communicated through hand gestures and eye contact. Civil engineers Åberg and Hultenius state that nowadays measurements are usually made by contract workers (e.g. Byggmätarna) rather than by employees at the construction companies.

Safety clothing is mandatory on the construction sites and the employer provides the employees with the necessary clothing. Nyström mentions that during warmer days one usually wear a t-shirt or a thin jacket and a reflective vest; during colder days one dresses in layers to maintain as much heat as possible. Gloves are almost always used. At Skanska, all employees and visitors are required to wear reflective safety clothing, a helmet, protective glasses and gloves. Sweating may occur but none of the interviewed regard this as a problem as they wear work clothes and shower after the job.

It is essential to plan the execution of the measuring in order not to hinder construction workers and other personnel in their processes. As Hultenius and Bergström explain, the working environment is regulated by legislations and company specific regimes (e.g. safety zones and concrete barriers), creating demands for careful planning and choice of location(s) for measuring. Throughout the task one must be cautious not to move the tachymeter from its initial position as this would ruin the measurements (since the point of reference is altered). During a working day, one moves the apparatus frequently to produce measurements at various locations. When observed, the set-up time was less than five minutes.

Fig.32 Large motorcycle batteries (6,4kg) used by Byggmätarna and a small battery pack (~0,2kg) used by Skanska.

Fig.33 Lid on backpack used for storage of spare batteries and remote unit. Padding on the inside of the main compartment.

All professionals interviewed confessed that they sometimes carry too much as they try to minimise the number of turns to the transport vehicle. As can be seen from figure 31, during the observation at Skanska Gottschalk carries the backpack over his right shoulder, using one shoulder strap. At Byggmätarna, Bergström demonstrates how he usually carries the tripod over his shoulder with one of its legs facing forward, see figure 5. The other shoulder is used for carrying the tachymeter in its protective case using one of its shoulder straps. Lantmäteriet stores two different carrying systems - the protective cases in which the instruments were delivered and a backpack identical to the one used by Gottschalk at Skanska, see figure 30.

It was observed at Skanska and Chalmers that during the measurement process one hand is occupied holding the remote control unit as the tachymeter is checked for measurement values. These values are then confirmed on the remote unit. This process is repeated until all relevant measurements are registered. The handheld storage unit is operated using fingers or a pen, see figure 31. After a measurement session is completed, the dismounting and packing of the apparatus takes approximately two minutes.

Although most of the measurement projects do not require long walks, Rubendahl, Bergström and Gottschalk express that the job can sometimes be physically demanding with strenuous hikes of several kilometers when the terrain does not allow for transport by car. According to Gottschalk, this situation usually arises when producing measurements for railways or power lines. The employees at Byggmätarna, Nyström explains, are relatively fit individuals, fond of open-air walks.

During breaks, the protective cases are often used as stools. Bergström states that the cases are made in bright, vivid colours to be easily distinguished from its surroundings, thereby reducing the risk of it being driven over by crossing construction vehicles.

6.8.4 Identified advantages and disadvantages

According to the interviewed, most complaints regarding pain and discomfort have concerned the back and shoulder regions. The probable cause, Rubendahl explains, is a combination of the weight of the load and the fine deliberate movements required to position the telescopic pole. Moreover, as Nyström at Byggmätarna mentions, the protective cases are, despite the padded shoulder straps, unsuitable for longer hikes and employees have reported that the cases "cut into their backs". The protective cases at Byggmätarna were delivered with waist-belts, however, none of the employees use these belts. The reason for the waist-belts not being used is, Nyström continues, that they were not suitable for the protective cases. For conventional backpacks, Nyström and Bergström appreciate hip-belts and praise its ability to shift weight from the shoulders to the waist. Gottschalk, who has experience from carrying the protective case from Leica, see figure 3, notes that is was very uncomfortable for long walks and that the backpack he currently uses is far better. Neither Hultenius nor Åberg has suffered any muscular or skeletal disorders from carrying the measuring equipment. Nonetheless, both state that the equipment, particularly the tripod, are irritating and difficult to carry due to the awkward dimensions.

The overall quality of the protective cases are appreciated, yet Byggmätarna and Lantmäteriet report of broken latches, see figure 34. The most frequent appraisal relates to the overview provided by the tailored interior of the cases, see figure 27. Bergström enjoys that the apparatus can fit into the case regardless of which direction the tachymeter is facing (as long as it is in an upright position) but deems the polyurethane padding to be too rigid for adequate protection.

All of the professionals agree that damages to the sensitive equipment are rare (approximately one accident every four years) since they are handled with great care. Rubendahl at Lantmäteriet and Bergström at Byggmätarna state that the most common sources of damage are tripods tipping over and instruments slipping from the hands of the users.

6.8.5 Wishes for the future

There is a consensus that backpacks are a preferable carriage solution as it allows the workers to have their hands free or, perhaps more realistically, use them for carrying additional tools and equipment. Rubendahl as well as Nyström and Bergström express a desire for a stabile carrying solution that places all apparatus (i.e. tachymeter, GPS, remote control and storage unit, and batteries) on the back, as long as the combined load would not be too high. Nyström, Bergström and Gottschalk wish for a versatile carrying solution that is easy to put on and to remove.

Fig.34 Broken latch on a protective case from Leica.

In addition, having experienced problems with condensation within the sensitive optical instruments, Gottschalk would like a carrying solution that allows for ventilation.

6.8.6 Work sequence overview

To provide an overview of the work sequence, the process of producing measurements was divided into subtasks based on data from the interviews and observations. As can be seen from figure 35, the process consists of several steps yet all fairly straightforward. The identified sources of problem are the collection of the required tools and equipment, the weight of the combined load, the risk of dropping the sensitive instruments when lifting them from or to their protective cases, and the instability of the tripod. The last problem is related to the design of the tripod (hence it is outside the scope of this project). During the collection of the necessary equipment there is an evident risk of forgetting important tools. The weight and dimensions of the load may be a problem as it could overload the muscles and place harmful stresses on the bones and joints of the body. Drop damages to the sensitive instruments from losing the grip could be a result from poor design of the equipment or difficulties in fitting the equipment into the protective cases, or a combination of both.

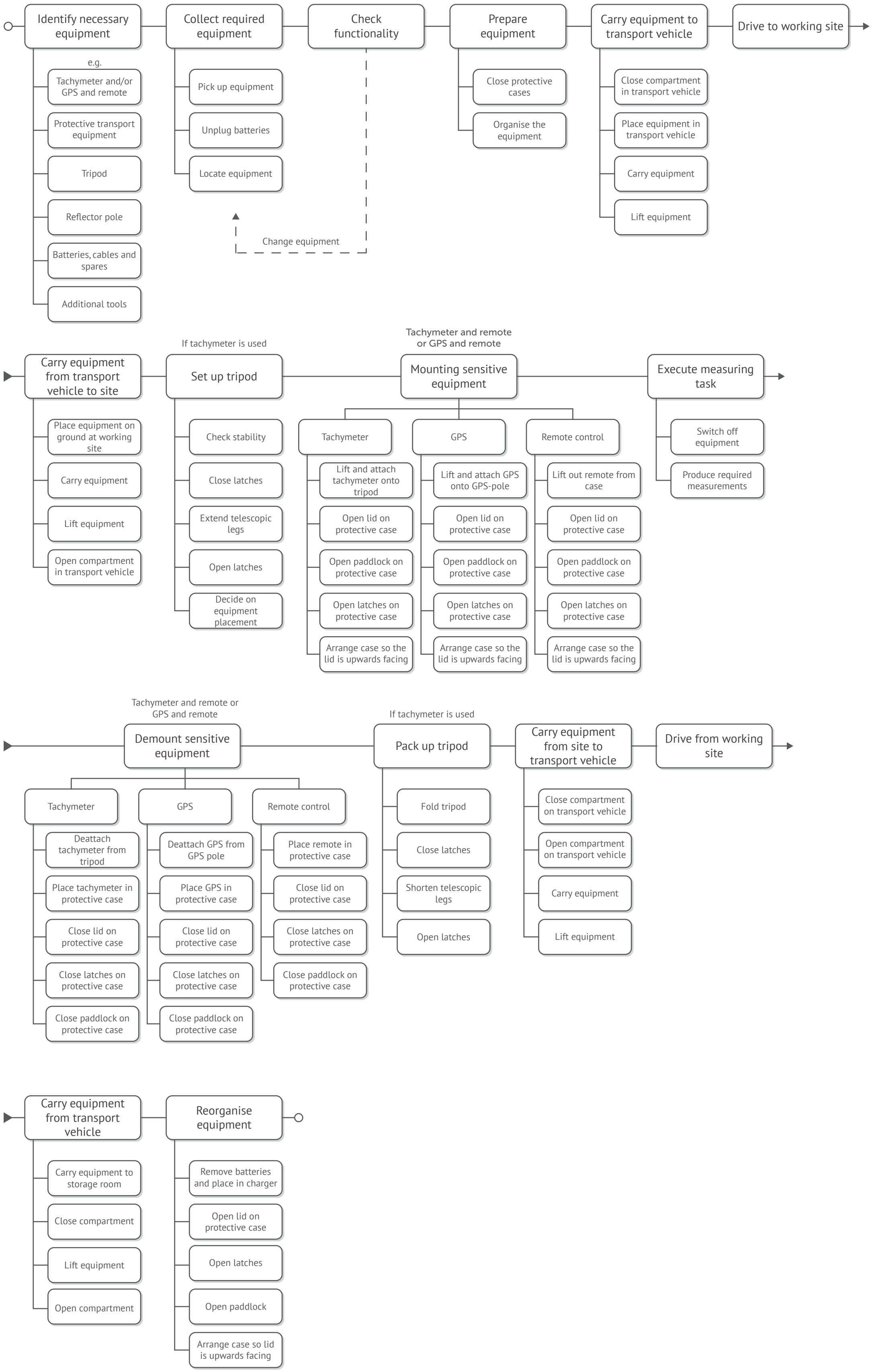


Fig.35 Work sequence overview.

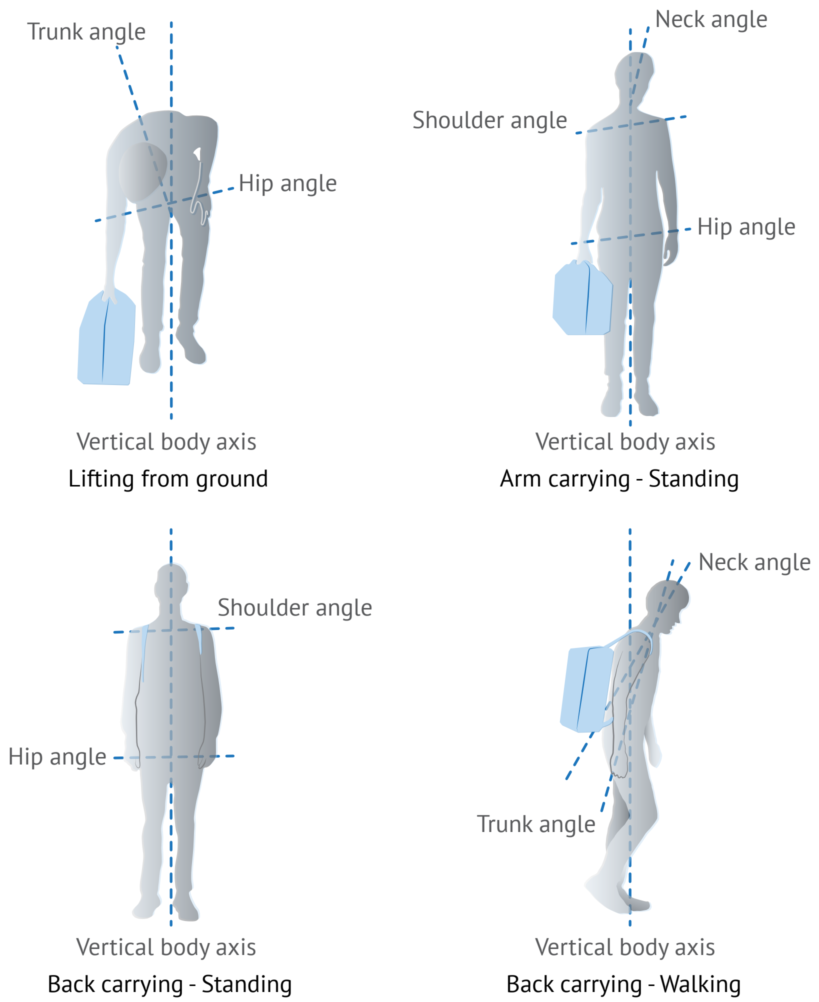


Fig.36 REBA analysis of the reference protective case.

6.9 REBA analysis

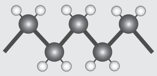
Illustrations of the carriage postures analysed can be found in figure 36. Lifting the protective case from ground level generated the highest REBA score (8 of a maximum of 15), a score that indicates a high risk of injuries and that action to change is necessary soon. The high risk during lifting is attributed to the twist and flexion of the trunk and the poor coupling provided by the integrated handle. The hand carriage resulted in a score of 7, which corresponds to a medium risk for injuries (see Hignett & McAtamney 2005). Carrying the protective case on the back resulted in a score of 5, also indicating a medium risk. The hand carrying prompted a high perceived tension in the back muscles compared to back carrying using the provided shoulder straps. As can be seen from figure 36, hand carrying resulted in greater deviations from the neutral posture in the hip and shoulder regions. Finally, in must be noted that the high weight of the load increases the risk of musculoskeletal injuries, regardless of the carrying method.

6.10 The world of plastics

Plastics are made from a combination of polymer chains and an additive (e.g. colour pigments, lubricants and UV-protection). In general, longer chains imply larger attractive forces between the polymer chains and a comparatively higher strength. Polymers are to 90% produced from fossil fuels such as oil and natural gas. The proportion of additives vary but is usually circa 2%. There are three large classes of plastics: thermoplastics, thermosets and elastomers (i.e. rubbers). Thermoplastics constitute the most widely used category with approximately 80% of the world production. Thermoplastics are formed by intermolecular forces acting between the polymer chains whereas thermosets are formed by strong chemical bonds. As a result, thermoplastics are softer than thermosets and can be melted repetitively (Klason & Kubát 2002).

Plastics are either semi-crystalline or amorphous. Crystallinity implies an ordered structure between the polymer chains. Plastics can never be fully crystalline, nonetheless materials that display a high range of order are often referred to as crystalline or semi-crystalline. Amorphous plastics are lacking in order. Crystalline and amorphous

MATERIAL PROPERTIES TO CONSIDER



MAINTAIN SHAPE AND FORM
- Young's modulus (E-modulus or tensile modulus)

CARRY LOAD
- Young's modulus
- Shear modulus

MAINTAIN FORM OVER TIME
- Creep

IMPACT RESISTANCE
- Toughness
- Glass-transition temperature

ENERGY ABSORPTION
- Ability to dampen vibration and stress

WITHSTAND HEAT
- Coefficient of thermal expansion
- Maximal service temperature of material

APPEARANCE AND USAGE
- UV-resistance
- Chemical resistance
- Surface quality
- Colouring possibilities

AVAILABLE METHODS OF MANUFACTURE AND JOINING

Fig.37 Important properties to consider when deciding on material(s) for a product (after Klason & Kubát 2002).

plastics have different fields of application due to their respective advantages and disadvantages. Crystalline plastics have high fatigue strengths, high resistance to chemical solvents and good flow characteristics in molten state. The stiffness of crystalline plastics is temperature dependent and reduced at higher temperatures, and its tendency to creep is increased at temperatures above the material's glass transition temperature. Furthermore, these plastics may shrink significantly during manufacture. Amorphous plastics have a high form stability and the influence of temperature on the stiffness of the material is almost negligible. Some disadvantages of amorphous plastics are their relatively low resistance to chemical solvents and the risk of crack formations when subjected to high and elongated stresses (Ibid.). Consequently, for usage in a carrying concept for a heavy load that is to transported in various climates, a crystalline plastic should be modified to increase its stiffness and resistance to creep at higher temperatures and an amorphous plastic should be tailored to better withstand stresses.

When manufacturing products from plastics one must consider that estimating and calculating the properties of the final result is more difficult than for metals (Ibid.). Moreover, the level of mold shrinkage can be hard to predict, resulting in a need for testing and prototyping. Software simulations can be used to predict the flow of the molten material in the forms (Kalpakjian & Schmid 2010). Some important aspects to review when selecting materials for a product are listed in figure 37 (after Klason & Kubát 2002). Note that no mention of recycling possibilities or sustainability are made in the list.

6.10.1 Common plastics and their properties

As for every material, different plastics have different advantages and disadvantages and are used for different applications. Some important characteristics of various common plastics are listed in Appendix 6. Many properties of the plastics can be altered using various fillers, for instance, the addition of fiber reinforcement will enhance the stiffness and toughness of the material. However, there are trade-offs that must be balanced when using additivies such as fiber reinforcements; the increased stiffness of the plastic will decrease its dampening properties and increase the warpage during manufacture. Another example is protection against UV radiation that is often realised through the addition of carbon black (i.e. soot) to the plastic. The increased UV resistance is achieved at the expense of the colouring possibilities of the material (Klason & Kubát 2002). When considering additives to alter the characteristics of a plastic, one must review the effect on the recycling possibilities of the polymer. Appropriate labelling (e.g. according to ISO) of the plastics may facilitate the recycling process as the plastics are easily identified. It must, however, be stressed that far from all plastics are recyclable other than for energy by incineration (Ibid.).

When adding requirements (see chapter 7.7) regarding price (<55 SEK/kg), service temperature (-40 to +70 degrees C), resistance to fresh and salt water as well as resistance to UV-radiation to the CES material database and plotting the results against the density, Young's modulus, shear modulus, fracture toughness and impact strength, eight materials emerged as possible candidates for the carrying solution, see figures 38-40 and Appendix 7 (data from CES Selector 2012 and Klason & Kubát 2002). In addition to the requirements regarding resistance to water and UV-radiation, the properties against which the materials were graphed were selected based on the important characteristics for a material that can maintain its shape, withstand the effects of load carrying and resist impacts (see figure 37). Currently, the companies providing protective cases use different plastic compounds for achieving the desired properties (see chapter 6.5). The contents of the compounds are not revealed. For their hard shell backpacks, Boblbee uses a high-impact ABS compound with a lacquer and a clear coat for an improved surface finish (Boblbee 2013b). Boblbee's softer backpacks are produced from a high density EVA-polyurethane foam (Boblbee 2013c).

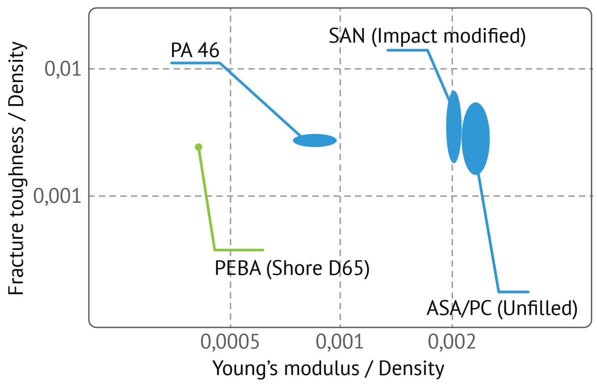


Fig.38 Fracture toughness / density ((Pa√m)/(kg/m³)) in relation to Young's modulus / density (GPa/(kg/m³)). Illustration after data from CES material database.

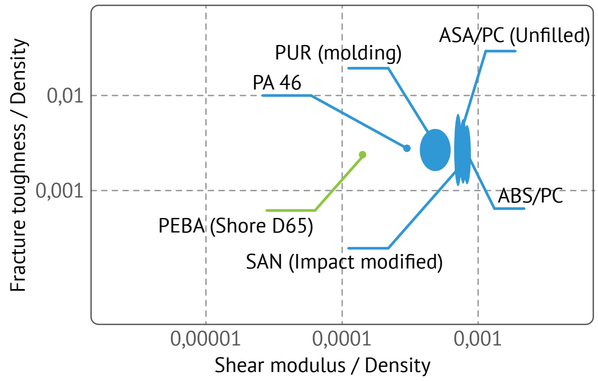


Fig.39 Fracture toughness / density ((Pa√m)/(kg/m³)) in relation to Shear modulus / density (GPa/(kg/m³)). Illustration after data from CES material database.

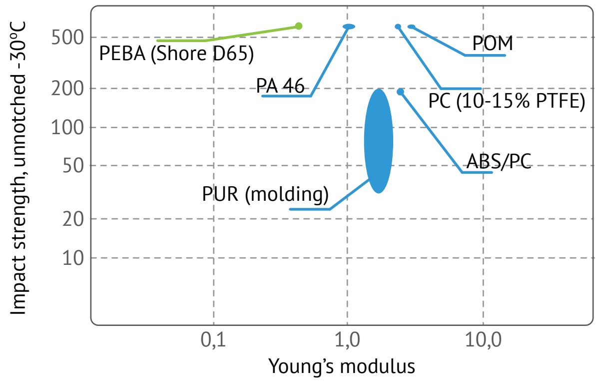


Fig.40 Impact strength (KJ/m²) in relation to Young's modulus (GPa). Illustration after data from CES material database.

6.10.2 Design and manufacturing

Products from thermosetting plastics are usually produced by compression molding and products from thermoplastics are generally manufactured using extrusion or injection moulding. Fiber reinforced plastics are formed using compression moulding (Kalpakjian & Schmid 2010). Injection moulding can be used to create complex shapes but the cost of the necessary tooling renders it unsuitable for small batch sizes (Klason & Kubát 2002; Kalpakjian & Schmid 2010). As thermosetting plastics require cross-linking (or curing) in a heated die, the cycle times and mould temperatures are dissimilar for themosetting plastics and thermoplastics. The cycle time for injection moulding of thermoplastics is between 5 and 60 seconds and it can be much longer for themosets. Generally, thick wall profiles increase the cycle time (Kalpakjian & Schmid 2010). Although thermoplastics can be melted and chilled indefinitely, repeated heating and cooling will result in a detrimental thermal aging of the plastic (Ibid.).

The warpage tendency, i.e. uneven shrinkage in different directions is smallest in thermosetting plastics and in amorphous thermoplastics (Klason & Kubát 2002). As little shrinkage and warpage as possible is beneficial when manufacturing a product that require close tolerances and a tight fit between the different components.

When designing a product to be manufactured from plastics, one should avoid large wall thicknesses as a means of providing structural stability, instead, one ought to place ribs or grooves in the form. The ribs or grooves should be roughly half as thick as the walls for an optimal result. One must also consider that holes and cavities in the profile will reduce the tensile strength of the product (Ibid.). Uneven cooling (when the surface cools down faster than the interior) in the mould will lead to residual stresses in the material (Klason & Kubát 2002; Kalpakjian & Schmid 2010). Since all plastics shrink as its temperature is decreasing, the profiles should have a draft angle of 1-3%. Otherwise, it would not be possible to remove the part from the die (Klason & Kubát 2002). Moulding defects may be problematic to resolve and require a combination of temperature and pressure adjustments as well as modifications on the design of the die (Kalpakjian & Schmid 2010). For parts to be produced using injection moulding, the gates from which the molten plastic will enter the die should preferably be located in the thickest section of the profile and placed symmetrically to facilitate an even flow of material (Klason & Kubát 2002). The viscosity of molten plastics are in general very high, requiring high pressures in order to attain an adequate flow in the mould (Ibid.).

6.10.3 Joining of plastics

As thermosetting plastics can only be in a liquid state once whereas thermoplastics can be remelted over and over, the joining methods for the two classes of plastics are slightly different. More specifically, thermoplastics can be joined using thermal joining, most commonly through ultrasonic welding. Thermal joining is particularly useful when the plastics cannot be joined by adhesives. Although it cannot be used for all plastics, adhesive joining is frequently used. The strength of the bond is temperature dependent. Neither adhesive nor thermal joining can be undone. Thermosetting plastics can be joined by co-curing, i.e. when two components are placed together and cross-linked simultaneously. Thermoplastics as well as thermosetting plastics can also be joined mechanically by screws or snap fasteners. The strength of the former may decrease over time and the latter is not effective for high loads. Snap fasteners can be made as an integrated part of a product thereby reducing its number of components (Klason & Kubát 2002; Kalpakjian & Schmid 2010).

By using appropriate methods of joining, the sustainability potential of a product increases. EU directive 2008/98/EC provides a hierarchical description as to how waste management should be prioritised to promote sustainability in the member states. The priority list, referred to as the "re-ladder", see figure 41, emphasise reuse, repair and recycling. By selecting suitable materials and joining methods, the reuse, repair and recycling is facilitated, resulting in a more sustainable product with a longer functional lifespan.

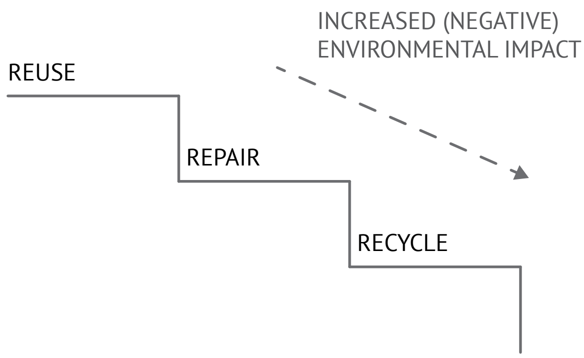


Fig.41 The 're-ladder' for creating sustainable product solutions.

7. Conclusions from information gathering

The results from the information gathering were analysed as a means of extracting the most important aspects for the development of a versatile carrying concept for sensitive equipment. The analysed results form a basis for the list of requirements, see figure 43. Furthermore, the results from the interviews and observations form a basis for the persona and scenario, see chapters 7.8 and 7.9, respectively.

7.1 The form and design of the carrying solution

From a marketing as well as a usability perspective, the form of the product must be consistent with its intended function(s). As Monö (1997) states, the users must be able to understand the product in order for it to be useful. When combined with the theories of Akner-Koler (1994), it becomes apparent that the building blocks of the form must be combined and arranged in a way that the user not only understands but also appreciates. The gestalt laws (see figure 12) should be used as guidelines for developing a comprehensive and visually pleasing carrying system. The carrying concept should also display a level of complexity and variety in order to evoke an interest from the users/ customers.

In addition, the design must be consistent with Boblbee's brand image and the carrying solution should be a transmitter of the same design cues as the other products in the company's portfolio. Boblbee's products are designed in line with their formulated vision to "be the lighthouse of smartly engineered solutions for individual mobility". The products are created for an active lifestyle, with respect to comfort and practical aspects. The brand image can be expressed through a set of core values. Active, protective, ergonomic, personalised, innovative and versatile are amongst the most frequently used words on Boblbee's homepage - words that well correspond to Boblbee's target group: active, sporty, outdoors people (Boblbee 2013d). As the carrying system for sensitive equipment is targeted at professionals active in a working situation, the concept should express safety, professionalism, activeness and comfort. These words form a basis for the moodboard, see Appendix 8.

Relating to the research question regarding how a carrying concept should be designed to fit Boblbee's product portfolio, the design format analysis of eight products revealed that, in addition to the Boblbee specific logo and triangular connector, heavy textiles, contrasting colours, a closed shape, an inverted U-shape and a shape converging to a point are frequently occurring elements in Boblbee's products. Consequently, to create a concept that is perceived as a Boblbee product, these elements should be used.

7.2 Anatomy, physiology and load carriage

In order to facilitate carriage and reduce the level of discomfort and injury incidence, the load should be carried on the back and placed as symmetrical and close as possible to the body. Furthermore, the carrying solution must not inhibit the natural movements of the skeletal muscles. As both the degree of sweating and the frequency of injuries increase with the weight of the system, the carrying solution should be as light as reasonably feasible. The carrying solution should not change the system centre of gravity too much as it would result in a decreased stability and an increased discomfort. A double-pack solution would be preferable with regards to the system centre of gravity, yet it is warmer and more difficult to put on and take off compared to a traditional backpack.

The heat build-up from the combination of load carrying and physical exertion will lead to sweating. Since sweating along the spine is common, the carrying concept should have a well-ventilated back panel. The suggested carrying solution should transfer weight from the pressure sensitive shoulders to the hip region through a padded waist belt. As a frame provides stability and enables weight transfer, the concept should include a frame. An even load distribution and an internal frame is preferred for hikes in uneven terrains and thus most relevant for this usage situation and context. Analogous to the literature study, the REBA analysis revealed that, from a musculoskeltal perspective, it is preferred to carry the load on the back compared to the in hand. Moreover, the combined load is heavy and should be reduced as much as possible to minimise the risk of injuries.

The anthropometric data presented are for swedish males and females as these measurements will enable testing and verification in Sweden. The circumference measurements are based on data from the United States as these measurements we not available for a Swedish population. The data should be used to provide estimates for the overall dimensions of the carrying solution and the length of the shoulder straps and the waist belt. As can be seen from figure 20, there is only 70 mm difference in trunk height between the 5th-percentile women and the 95th-percentile men. However, as the data is from the late 1960's it should be combined with the experience and expertise from Boblbee. As mentioned, Boblbee's product are currently designed to fit users from 155 to 195 cm.

Relating to the research question regarding the optimal method of transporting a load it appears from the research that the most efficient and comfortable means of transport is realised when the load is placed symmetrically and high on the back. Thus, a back carrying concept is preferable.

7.3 Existing products, functions and fields of usage

The products on the market are highly similar and carry more or less the same classification standards. As a result, the companies compete using brand images and plastic compounds tailored specifically to be used in the companies' protective cases. Since the current products share the same design features, a carrying solution that is differentiated from the existing cases may serve to fill a gap in the market. Regarding the research question related to the concept differentiation through design, a new concept must, in order to be competitive, instill the same level of trust in the functionality of the product and add elements that are missing or can be improved in the existing protective cases. One particular field open for improvements is the back carrying.

The carrying concept should have the same basic functions as the existing protective case(s), i.e. it must be stabile, protect the sensitive equipment from impacts and prevent harmful ingress of water and dirt. Since tachymeters - the reference product - are used in all seasons and all over the globe these functions must be maintained in harsh conditions and extreme temperatures. Tachymeters are used whenever accuracy is essential - from the construction of railways to the installation of solar panels. Some of these projects are located in terrains that do not allow for any other transport than by foot, resulting in long hikes carrying heavy loads. Thus, the presented carrying concept should offer a comfortable means of carriage.

7.4 User and usage

It was observed that the storage rooms are well-organised to allow for an efficient compilation of equipment. Nonetheless, objects are sometimes forgotten resulting in frustration and loss of time and income. Therefore, the presented carrying system should provide a good overview of the equipment to reduce the risk of leaving tools behind. As the sensitive equipment are placed and secured inside the car, the concept should allow for a stabile transport in that setting. The interviewed professionals all state that they try to drive as close as possible to the measuring site and then carry as much as possible in a single trip from the transport vehicle. The weight of the load in combination with its dimensions have reportedly resulted in complaints of pains in the back and shoulder regions. Hence, the carrying concept should be made as light and comfortable as possible. Sweating is frequent but not regarded as an issue as the professionals use safety clothing provided by their employers. Yet, it must be noted that sweating induced from the carrying concept should be reduced as much as feasible to minimise the loss of fluids and the sweat-related discomfort.

Although the instruments are waterproof, they are sensitive to ingress of vapour and are stored in open cases to allow for ventilation. Consequently, the concept should -to the greatest level feasible- prevent fluids and dirt from entering and provide a ventilation possibility. According to the subjects interviewed, damages to the sensitive instruments rarely occur when they are in their respective cases. The presented solution must protect the equipment at least equally well.
Regarding the research question concerning the usage context and the optimal method of transportation, the interviews and observations reveal that the carrying concept should be reasonably light, allow for a stabile placement on the ground as well as in the transport vehicle, protect the instrument(s) from impacts and provide a good overview of the equipment.

Finally, when working in teams of two, the employees communicate using gestures or radios. A natural and easily accessible place to fasten the radio should therfore be included in the carrying concept. Additionally, in line with the wishes from the professionals, the carrying solution should be easy to put on and take off. The interviewees also wish for a versatile carrying system that is able to store and transport different instruments and tools.

7.5 Material possibilities

The material study revealed that the most interesting plastics for the suggested concept would be a semi-crystalline or amorphous thermoplastic. Thermoplastics are preferred as they can be remelted and are more common. The crystalline plastics have a high fatigue strength but their stiffness decrease at higher temperatures. The amorphous plastics have a high form stability and less warpage tendency yet they are more sensitive to cracks when exposed to elongated stresses. The most commonly used plastic by Boblbee is ABS, an amorphous thermoplastic. For the premium camera backpacks (e.g. Procam 500XT, see figure 14), a high density EVA-foam is used. The EVA foam is, according to Jonas Blanking at Boblbee, relatively waterproof as long as it is in one piece, i.e. all seams must be taped.

Concerning the research question related to promising materials, the suggested plastics from the CES database (see Appendix 7) are an unfilled acrylonitrile styrene acrylate blended with polycarbonate (ASA/PC), impact modified styrene-acrylonitrile resin (SAN), polyamide 46 (PA-46) and polyether block amide shore D65 (PEBA). ASA/PC and SAN are amorphous thermoplastics, PA-46 is a semi-crystalline thermoplastic and PEBA is a thermoplastic elastomer. ASA/PC displays a good balance of the properties necessary to maintain its shape, resist impact and carry a load. Moreover, it is already used for various outdoor products such as garden furniture (CES 2012). Nevertheless, it must be noted that selection of materials is complex and that the results from CES should therefore be regarded as a guideline.

As a means of achieving the desired stiffness in the presented concept, ribs and grooves should be added to the form. Since the carrying concept suggestably will be produced from a thermoplastic, different parts can be joined using either ultrasonic welding or screws and snap fasteners; the latter two having the environmental advantage that they may be removed if used for joining two separate materials. For structural components that carry heavier loads, screw joining is preferable. Relating to the 're-ladder', the carrying concept should be constructed in a way that enables easy repair and replacement of components.

7.6 List of requirements

Figure 43(1-2) shows the most important requirements and their respective source.

7.7 Project brief

At the start of the project, a project brief was received from Boblbee. The focus of the brief is on the development of a carrying solution for three specific tachymeter models and not on sensitive equipment in general. Therefore, the technical requirements from the brief, see figure 42, should be fulfilled but the estimate of the number of units produced yearly is probably too small. The IP-classifications regarding fluids and particles, IPx4 and IP5x, correspond to water and dust not entering in levels that are detrimental to the functionality of the product or can be considered a safety risk. For testing and validating the IPx4 classification against ingress of fluids, water is sprayed (10l/min) for a minimum of five minutes and splashed against enclosures. For the IP5x classification against dust and particles, the object is placed in a pressurised chamber with a fine powder for 2-8 hours (SP n.d.). As no prototype will be constructed (see delimitations in chapter 1.4), the concept cannot be tested against the IP-classification standards. The same delimitation also renders an 8-hours carrying test impossible.

REQUIREMENTS FROM PROJECT BRIEF

The carrying solution should (provide/ allow):

- Comfortable carrying experience for up to 8 hours.
- Operational temperature between -20 and +50ºC.
- Storage temperature range from -40 to +70ºC.
- Be UV-resistant for a minimum of 3 years.
- Fulfil IP classification regarding water ingress, IPx4.
- Fulfil IP classification regarding dust ingress, IP5x.
- Sustain drop from 0,75 m onto all surfaces.
- Resistance to water, oil and common cleaning agents.
- Not contain any hazardous materials.
- Be produced in 550 - 700 units per year.

Fig. 42 Most important requirements from project brief.

USAGE

LITERATURE STUDY

- Minimise offset between system centre of gravity and body centre of gravity.
- Minimise weight.
- Vertical placement of load level with thoracic vertebrae T1-T6.
- Allow for a symmetrical load placement.
- Ability to transfer weight to large muscles in hip region.
- Minimise pressure on skin.
- Minimise heat accumulation during carriage.
- Provide a comfortable carrying experience for 5-percentile women to 95-percentile men.
- Minimise sweating.
- Provide good usability:
  - Time to access load same as or better than existing solution.
  - Users must understand when the system is opened or closed.
- Maintain functionality in various climates all over the globe.

INTERVIEWS AND OBSERVATIONS

- Allow one person to carry: reflector pole, tripod, remote unit, tachymeter and/or GPS.
- Minimise risk of forgetting equipment and/or tools.
- Allow steady placement in transport vehicle.
- Allow comfortable carriage while wearing thin and/or thick clothing.
- Provide comfortable temporary seating opportunity.
- Allow attachment of additional equipment and/or tools.
- Provide quick individual adjustment.
- Allow for load placement on back
- Allow easy access to equipment.
- Allow for a quick put-on and take-off process.
- Protect sensitive equipement.
- Maintain functionality during and after atmospheric pressure changes.
- Allow for an easy cleaning process.

ERGONOMIC ANALYSIS

- Minimise lifts from ground level.
- Carry load on the back.

SUSTAINABILITY

- Allow for easy disassembly and replacement of components.

Fig.43 (1) List of requirements.

TECHNICAL REQUIREMENTS

INTERVIEWS AND OBSERVATIONS

- Protect equipment from harmful moisture levels.
- Maintain tachymeter in upright position.

SUSTAINABILITY

- Manufacture with materials that can be up-cycled.

FORM AND MARKET DEMANDS

LITERATURE STUDY

- Be easily distinguishable from alternative products on the market.

INTERVIEWS AND OBSERVATIONS

- Provide an expression of safety, professionalism, comfort and an active lifestyle.

FORM ANALYSIS

- Fit Boblbee's brand identity.
- Transmit Boblbee's design cues.

Fig.43 (2) List of requirements.

7.8 Hans Johansson

Hans Johansson, or Hasse to his friends, is 52 years old and lives with his wife and two daughters in a terrace house in a suburb to Gothenburg. He starts every day with a walk with the family dog after which he drives to his job in a Volvo V70 that he and his wife bought used three years ago. Hasse works as a survey engineer at Precisionsmätning AB, a consultancy firm with 25 employees. As Precisionsmätning are contracted for jobs at various locations in Sweden and all over Europe, Hans is a frequent traveller.

At university, Hans studied a bachelor in civil engineering. By nature, he is close to a perfectionist, almost pedantic in his manners. However, Hasse would describe himself as reliable and efficient. At work, he prepares quickly for a task and tends to get frustrated if the tools and instruments are not at their designated locations. For the past years, Hans has suffered from a soar back. His back problems especially make themselves known during measurement tasks for infrastructure projects that require long hikes with heavy loads. As treatment Hasse uses a combination of liniments, massage and gel-based steroides.

In his spare time Hans loves long walks and hiking in the Scandinavian fells. Evenings and weekends are usually spent at home with his family. Hans loves to travel and is highly interested in different cultures. For this reason, he spends many evenings watching documentaries on BBC 4. Recently, Hasse and some of his old friends have started experimenting with

Fig.44 The persona Hans 'Hasse' Johansson.

home brewing. To Hans, the brewing is more of a hobby than a prospective business venture. As both of his daughters play handball and Hans drives them to their games he has started to take interest in the sport and carefully studies the national and international leagues. Hans is rather uninterested in fashion trends and wear more or less the same type of clothes every day - jeans and a tucked-in shirt. Neither is Hasse particularly interested in politics and he votes for the Socialdemocratic party by habit.

Hasse's goal is to be able to buy a holiday home for him and his family in the Scandinavian fells. And, although he does not admit it, move there permanently.

7.9 A walk in the woods

In early September, Precisionsmätarna are contracted for producing measurements for the construction of a power line in northern Sweden. Hans is assigned the project which entails that he will be away from home for three weeks during which he will be living in a temporary construction trailer.

Since the measurements will be executed in September it is fairly warm during the midday but the temperature drops quickly in the late afternoon. There are frequent showers of rain, resulting in a humid climate. The terrain is demanding and is made even more difficult by the damp ground.

The working day for Hans starts with a breakfast after which he quickly assembles the necessary equipment and load them into the company's pick-up truck. Dressed in functional softshell clothes, Hasse enters the car and leaves for the measuring site at seven thirty. Half an hour later he arrives at the point closest to the measuring site. The closest point, however, still means that Hans has to walk many kilometers.

Little after eight, Hasse has put on his backpack storing the tachymeter, spare batteries, the remote control unit and a map of the terrain. He uses the reflector pole as a walking stick and hangs the tripod over his left shoulder.

After thirty minutes of hiking, the physical exertion and the warmth of the sun is starting to affect Hans and he starts to perspire. Shortly thereafter, he comes to a roughly one meter high fence that he needs to climb over before he is able to continue his hike towards the measuring site.

When arrived at the measuring site after two and a half hours, a short rainfall occurs. The ground turns to mud and becomes slippery. Under these conditions, Hasse starts the measuring process.

IDEATION

- Concept development
- Concept selection
- Concept refinement

- Further refinement

8. Concept Development

8.1 Conceptualisation

The ideation process (see chapter 5.3.2) resulted in 11 concepts, see figure 45. As the developed concepts were based on the conclusions from the information gathering (see chapter 7), most of the concepts were various backpacks. The main features of the concepts are described below.

8.1.1 Folding

The concept can be described as a solution that creates a volume by folding a flat material. The underlying idea was that different folding techniques would potentially provide the concept with two advantages. Firstly, it would create an interesting and innovative form design. Secondly, the folds would render expensive injection moulding and dies obsolete. The folding concept was rather vaguely defined and intended to describe a method for solving various functionality issues. The folding concept would require additional examination if selected for further development.

8.1.2 Shoulder bag

The shoulder bag concept was developed since the interviewed professionals expressed a wish for a versatile carrying solution that allowed the tachymeter to be carried over one shoulder for shorter distances. The concept would be easy to put on and take off. In addition to the shoulder strap, a comparatively shorter strap around the waist would serve to stabilise the load during longer transports.

8.1.3 Hard case, soft back (HCSB)

The hard case, soft back was developed as a concept that would provide uttermost protection for the sensitive equipment in combination with an ergonomically suitable back panel. The protection would be realised through an impact resistant hard case. Implementing the results from the literature review regarding load carriage over long distances, the concept was designed as a backpack with a padded waist belt. The concept was intended to place the load fairly high on the back, i.e. on the upper thoracic curvature.

8.1.4 Similar to today

As Boblbee offers a wide range of different carrying systems for various activities, a concept similar to their existing backpacks was developed. The concept was intended to feature the most optimal elements and solutions from the existing product portfolio, thereby ensuring that the concept would be perceived as a premium Boblbee product. The concept would essentially be a three-sided hard shell with attachment possibilities for additional tools.

8.1.5 Hard case side

The hard case side-concept was created as a means of studying and evaluating the effect of placing openings on the sides of the carrying system. The case would be placed laying on the ground and the instrument would be accessed through the side of the carrying system. The orientation of the openings was inspired by similar solutions in existing camera bags, where the backpack is swung to the front of the body in order to access the equipment (by removing one shoulder strap and maintain the waist belt closed).

8.1.6 Soft - hard – soft

The soft-hard-soft backpack was developed as a concept that was differentiated from the existing protective cases on the market. As opposed to the hard plastic compounds and surfaces, the soft-hard-soft concept was intended to feature a soft outside, a harder middle section and a soft back-plate. The soft outer fabric would attenuate the impact in case of a drop, thus reducing the required padding inside the concept. The equipment would be accessed through a zipper-opening integrated in the soft back panel.

8.1.7 Ex. Frame mesh

The external frame mesh was a concept based on a robust external frame with an attached mesh of powerful straps. The mesh would be used to secure a protective case similar to the ones offered by the leading companies in the industry (see chapter 6.5). Moreover, the frame and mesh concept could be used to transport various other tools and equipment. The concept was intended to constitute a cheap, robust and versatile carrying system.

8.1.8 Frame hold case

The frame hold case concept was similar to the external frame mesh but inspired from baby carriers and, as such, more ergonomically developed and optimised for transport of protective cases alone. A protective case is placed and secured in the carrying concept. The frame hold case concept was, albeit probably more costly than the external frame mesh, intended as the main budget solution.

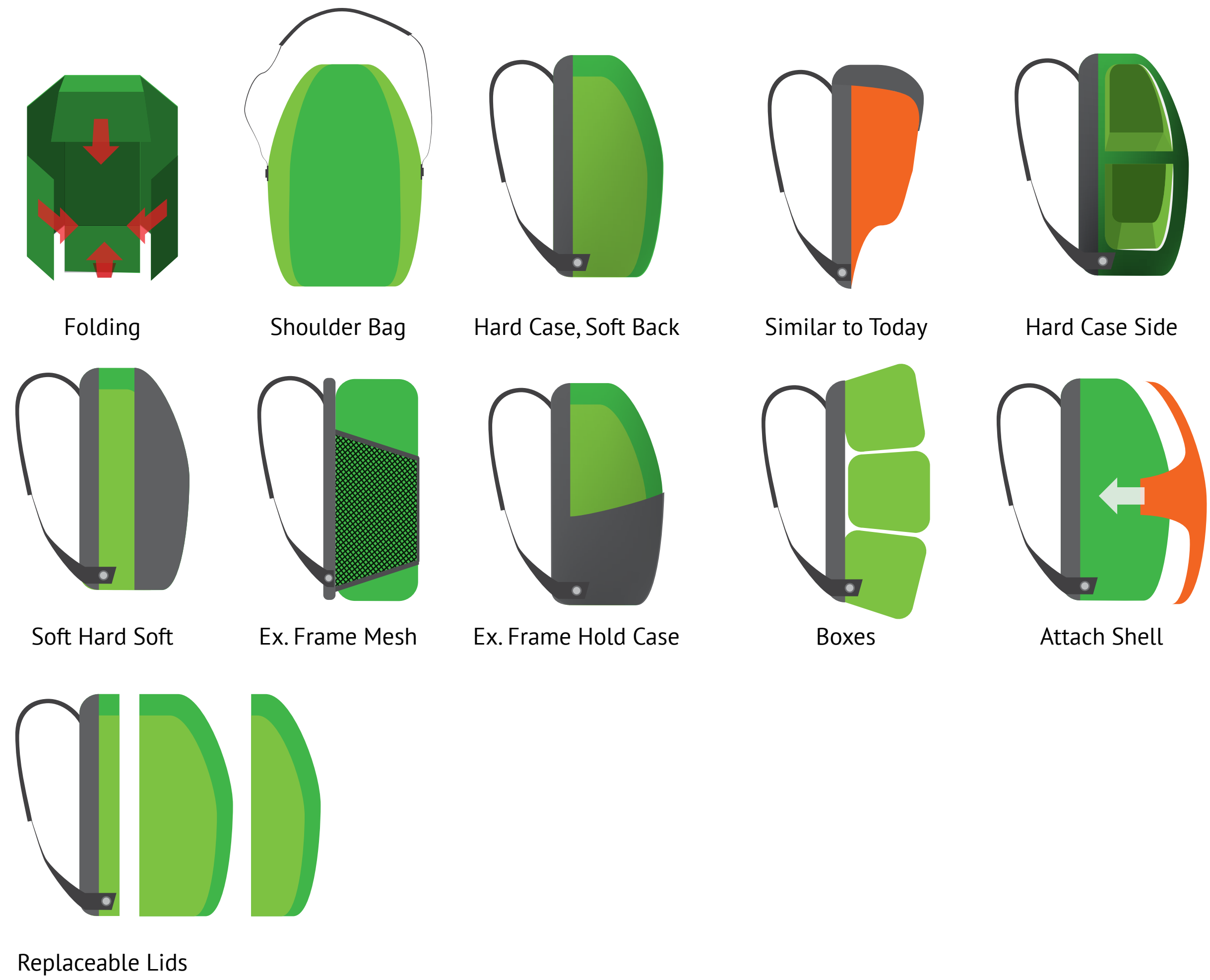


Fig.45 The eleven generated concepts.

8.1.9 Boxes

The boxes concept was based on the arrangement of a set of boxes containing different equipment. The boxes can be attached to each-other, thus enabling personalisation and modification for a specific use situation. The boxes are attached to a backpack harness.

8.1.10 Attach shell

The attach shell concept was inspired from protection in the nature (e.g. tortoises and armadillos). A hard shell is attached to a softer backpack, thereby providing protection. As the protective shells would be offered in various sizes, the protection could be tailored to fit the specific needs of a given situation. Hence, the attach shell concept was intended to be the most flexible solution.

8.1.11 Replaceable Lids

The replaceable lids concept was aimed at creating flexibility and modularity. As such, the concept may be regarded as a combination of the ‘boxes’ and the ‘attach shell’ concepts. The concept consisted of a back-plate and a replaceable lid. Different sizes of the lids would allow for transport and protection of loads of various shapes and sizes.

8.2 Concept evaluation I

The weighted Pugh-matrix, see Appendix 4, revealed two top candidates for further development. These concepts were the hard case, soft back (HCSB) and the soft-hard-soft with 42 and 35 points, respectively. As these two concepts could be regarded as fairly similar, it was decided to add elements from the lower-scoring soft-hard-soft concept to the HCSB as opposed to further developing these two concepts separately. In addition to the HCSB, the folding concept (31p) and the frame hold case concept (30p) were selected for further development. Thereby, one innovative (folding), one neutral (HCSB) and one budget (frame hold case) concept were chosen for additional studies and refinement prior to the concept selection stage. The results of the refinement process are displayed in figure 46-48.

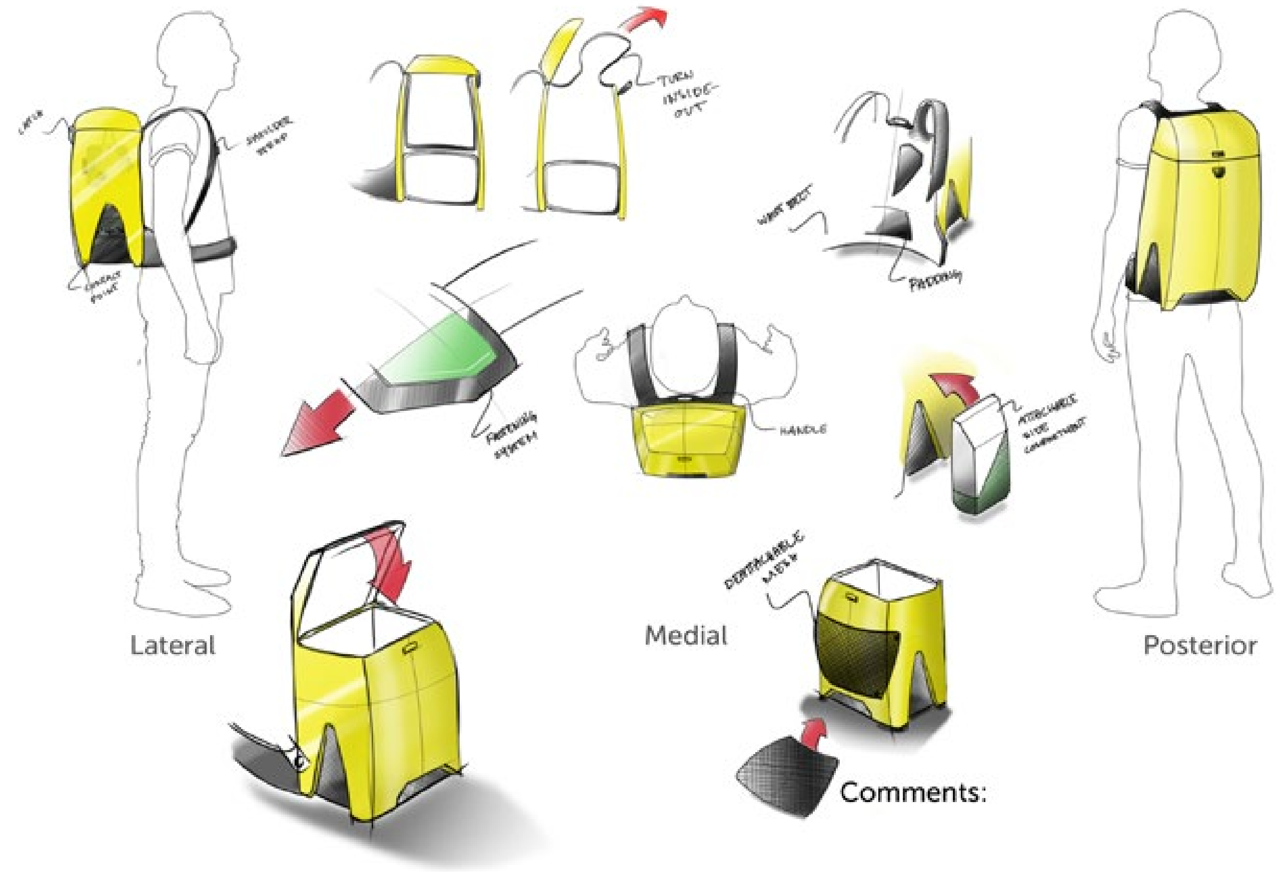


Fig.46 Sketch of the hard case, soft back (HCSB) concept.

8.2.1 HCSB development

As can be seen from figure 46, the HCSB concept featured removable side compartments and an internal flexible pouch attached to the main case. The pouch, in which the tachymeter was to be placed, could be turned inside-out to facilitate cleaning. The hard case was split on the sides and on the back to create a more complex and interesting form. Furthermore, the split served to create four contact points (one in each corner of the case) on which the concept could rest when placed on a horizontal surface. The tachymeter would be accessed by opening a lid located at the top of the concept.

8.2.2 Folding development

The folding concept was the least defined of the three concepts selected for further development. As can be seen from figure 47, the concept featured various folds held in place by multiple latches. The large flat surfaces created during the folding process would allow for stabile placement during transport as well as on the ground. The latches would provide quick access to the necessary equipment and tools.

8.2.3 Frame hold case development

The frame hold case concept was designed to include a well-developed back panel suitable for heavy loads. The tachymeter is carried in its protective case, which is placed in the large pocket. In the pocket, the protective case is secured by a flexible and elastic mesh, see figure 48. As can be seen from figure 48, the possibility of attaching removable compartments for handheld remote control units and radio communication units on the waist belt and shoulder straps were explored in the frame hold case concept.

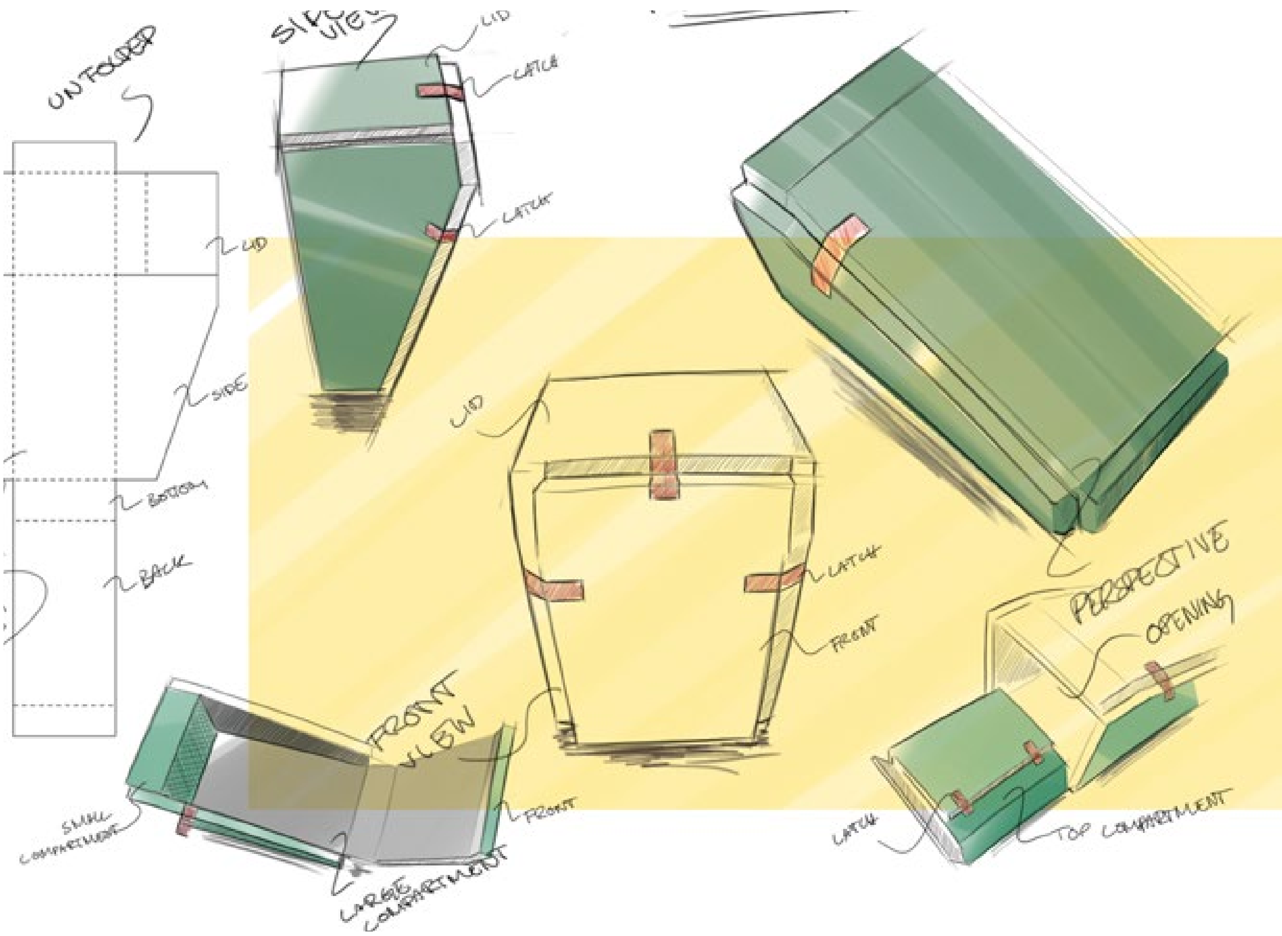


Fig.47 Sketch of the folding concept.

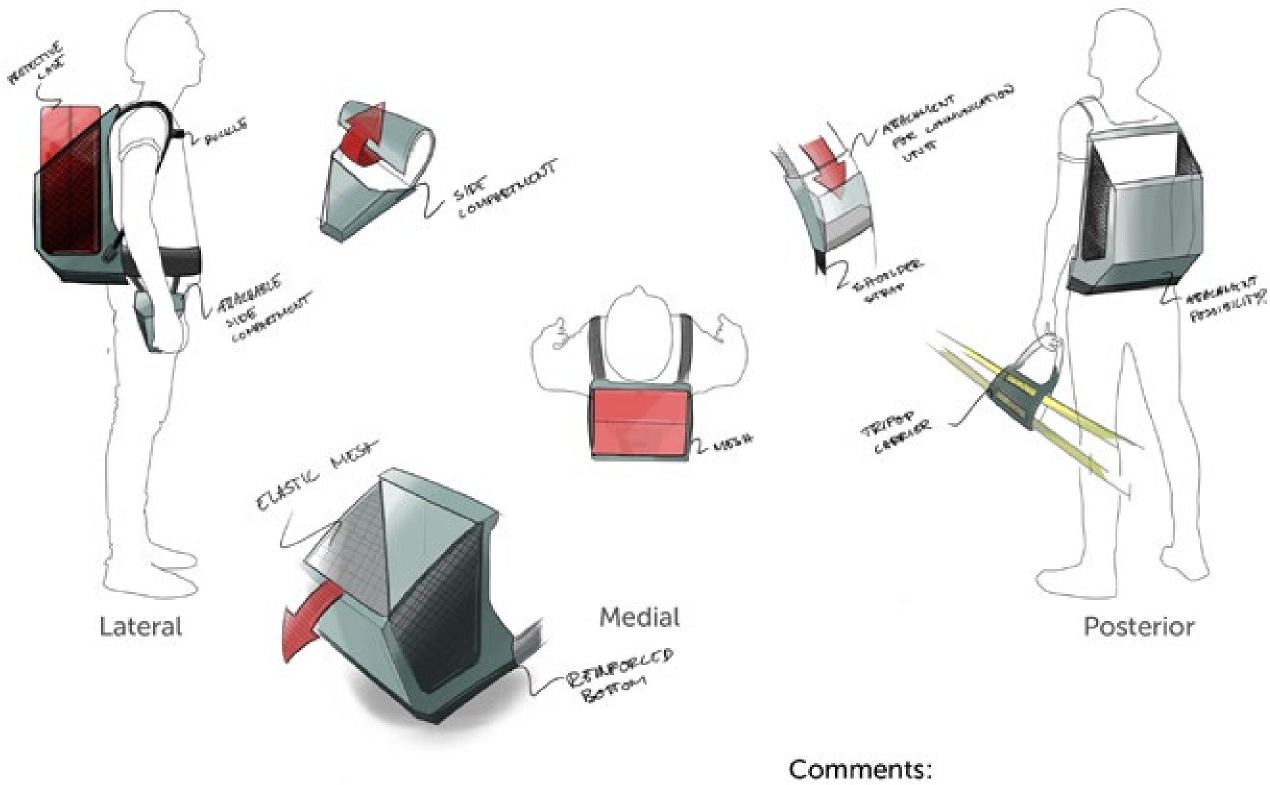


Fig.48 Sketch of the frame hold case concept.

9. Concept Selection

The selection process resulted in a decision to further develop two concepts, the HCSB and the folding concept. The other concepts, which were also presented, were decided to be kept for their potential as part solutions and inspiration. The hard case, soft back (HCSB) concept was deemed suitable for development as it was regarded as realistic and interesting. The folding concept was viewed as innovative yet in need of a more thorough study. Thus, the folding concept was selected for further development - either as a separate concept or as an integrated part or function in the HCSB concept.

10. Concept Refinement

The concept refinement phase resulted in multiple sketches and CAD models exploring different variations on the HCSB and the folding concepts. As can be seen in figures 49-50, elements from the soft-hard-soft concept (see chapter 8.1.6) were considered as a means of dividing the large hard surfaces and thereby further differentiate the concept from the existing protective cases. Alternative methods of accessing the load were studied, see figure 51. However, a combination of two factors revealed that a solution with the lid located at the top of the carrying concept was most beneficial. First of all, tachymeters have an integrated handle at the top; secondly, the height and duration of the lift of the tachymeter (for mounting it onto the tripod) will be reduced if the concept is placed on the ground in an upright position.

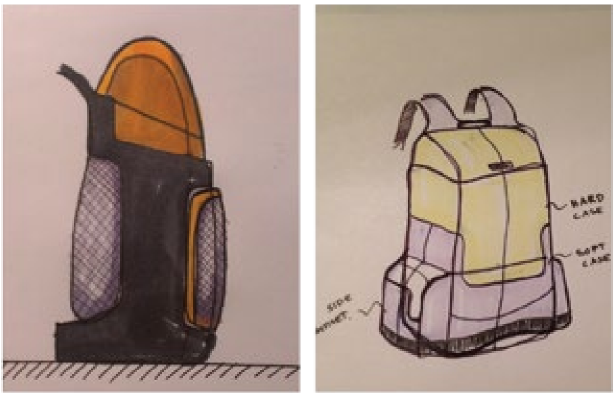


Fig.49 Quick sketching during the concept refinement phase.

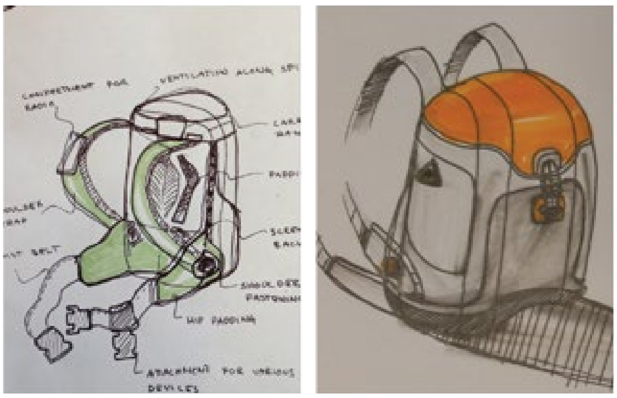


Fig.50 Sketches from the concept refinement phase.

CAD modelling was used for exploring different designs. The digital tachymeter model and the reference cuboid (based on the dimensions of the tachymeter, remote unit and other equipment), see figure 52, ensured that the modelled concepts were neither too large nor too small. Moreover, an evaluation of the reference cuboid against a 5th-percentile female mannequin in Jack 7.1 showed that the concept would be large and prominent, solely due to the dimensions of the sensitive equipment.

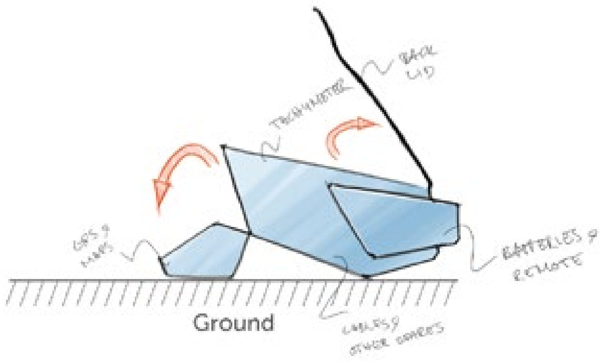


Fig.51 Exploring different alternatives to opening and accessing equipment.

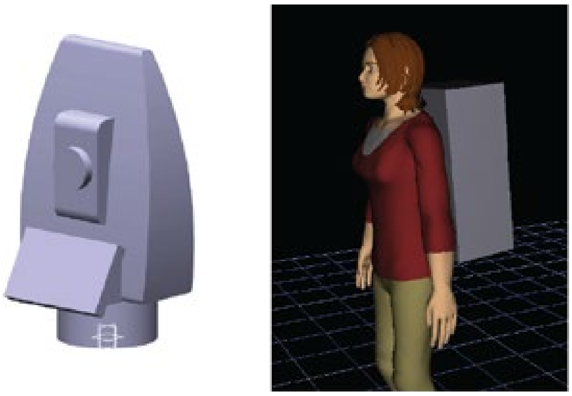


Fig.52 Tachymeter-dummy modelled in Catia V5. Testing of dimensions in ergonomic evaluation software Jack 7.1.

Hence, the concepts developed during the concept refinement process were aimed at minimising the expression of a large and bulky backpack without changing the limiting dimensions.

The CAD models, see figures 53-54 featured removable side compartments, a strong waterproof zipper for opening and closing the top lid, triangular connectors for attaching additional tools and a bottom surface in a rubber material. The rubber reinforced bottom would allow for easy cleaning as well as communicating an expression of reliability in harsh conditions. The use of contrasting colours, grooves in the forms, zippers, side compartments and attachment possibilities served to divide the large surfaces into smaller ones, thereby the reducing the overall perceived size of the carrying concept.

The folding refinement process revealed difficulties in combining the folding principle with the desired expression of a small and versatile carrying concept. Different folds were explored, see figure 55, however, all resulted in large flat surfaces. Folds as a means of adding rigidity and reducing the size of the large surfaces resulted in complex shapes. Furthermore, the folding principle entailed that many screws and latches would be required in order for the concept to maintain its shape.
Finally, the requirements regarding prevention of

Fig.53 Numerous CAD models were made during the concept refinement phase.

Fig.54 CAD models were made as a means to explore different forms of the carrying concept.

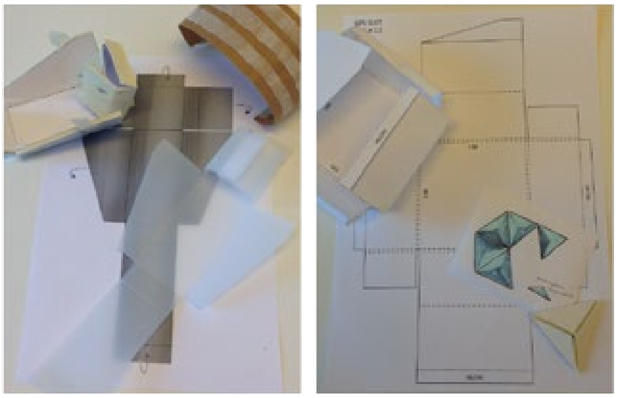


Fig.55 Development of the folding concept.

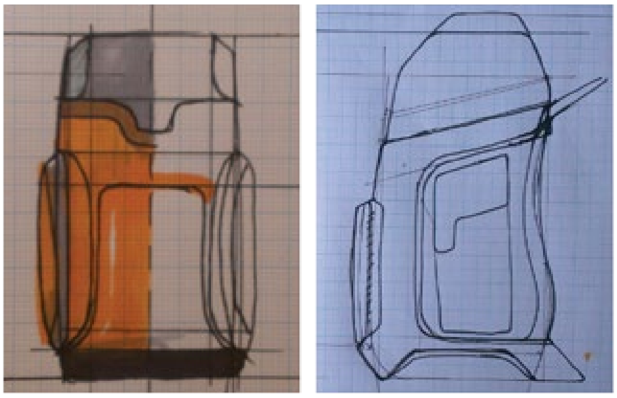


Fig.56 Sketches were used as basis for the CAD modelling.

ingress of fluids and particles would be difficult to combine with a folding concept (see chapter 7.7).

10.1 Concept Evaluation II

The second concept evaluation resulted in a decision to continue to develop and refine the HCSB concept, with added features in a softer material. Blanking at Boblbee mentioned that it is difficult to control the geometry of softer plastics (e.g. EVA-foams) and, consequently, achieving waterproof joining of soft parts is complicated. In addition, Blanking stated that waterproof zippers (i.e. with appropriate IP-classification) are very expensive and that a latch solution would be preferable for the final concept.

The folding concept was deemed more suitable for the protective interior of the backpack than as a separate concept.

10.2 Further Refinement

In the refinement process, more specific and detailed sketches and models of the HCSB concept were produced, see figure 56. Arrangement of curves and surfaces were explored, resulting in a carrying concept that can be described as a combination of a hard and a soft case, see figure 57. In line with the results from the DFA (see chapter 6.2), heavy textiles, contrasting colours and closed shapes were studied during the concept refinement phase. The addition of the identified design cues served two purposes; firstly, the concept would more easily be recognised as a Boblbee product; secondly, the addition of softer materials and contrasting colours would make the concept appear smaller (as the large flat surfaces would be split up, see chapter 6.1.4 and figure 12).

The concept was made to include two removable side compartments and a large sub-dominant pocket on the back. The side compartments were intended to be used for storage of the remote control unit and

Fig.57 CAD modelling aimed at refining the HCSB concept.

spare batteries. In addition, the compartments were intended to be removable, thus allowing attachment of other tools and equipment in their place. The back pocket would be used for transport of maps and notebooks. As the persona, Hans (see chapter 7.8), displays a strong desire for organisation and overview, the necessary equipment were given specific places in the carrying concept.

FINAL REFINEMENT

- Evaluations
- Final concept
- Discussion and conclusions

11. Evaluations

11.1 User response

An evaluation with Per Rubendahl at Lantmäteriet revealed some strengths and weaknesses in the conceptual carrying system. During the evaluation, Rubendahl was presented with a functional model and renderings of the carrying system, see figures 58-59 and 60, respectively.

Fig.58 Front and back view of the functional model.

Fig.59 Details on the functional model.

First of all, Rubendahl expressed an appreciation for the side compartments, more specifically their large size and the possibility to adjust that size through the accordion-like folds on the sides of the compartment, see figure 59. Following the appraisal, Rubendahl stressed the importance of a proper fastening of the lids since accumulation of water and dirt is a problem in the side compartments of the existing backpack. Today, these compartments are used for storing spare batteries and maps. Consequently, Rubendahl would like the side compartments to be as water-resistant as feasible. When asked, Rubendahl stated that he does not see a great benefit in the possibility to remove the side compartments as an empty pocket does not add any (or a negligable) additional weight to the carrying system. Moreover, he continues, there is a risk of losing the side compartments, especially when not using individual packs. However, Rubendahl values the potential of attaching additional tools and equipment (e.g. pipes, spades or spray cans) onto the carrying solution concept.

As mentioned in the previous interview (see chapter 6.8), Rubendahl states that one tries to carry as much as possible at a time in order to reduce the number of trips between the measuring site and the transport vehicle. As the terrain at the measuring location is usually unknown, one brings both a tachymeter and a GPS unit for a measuring task. When prompted how he would use the concept for a measuring session, Rubendahl explains that he would place the tachymeter in the carrying system in the storage room and then place it in the transport vehicle. In addition, he would bring the GPS unit in its protective case and place it alongside the carrying solution. When arrived at the worksite, Rubendahl would mount the GPS and the reflector prism onto the telescopic reflector pole and put the carrying system on his back. Upon walking to the measuring site, he would hang the tripod over one of his shoulders. To facilitate the transport of the tripod, he wishes for a means of attaching the tripod strap to the shoulder strap.

When discussing the potential of the carrying system and its usage, Rubendahl explains that he appreciates the backpack carrying concept as it would enable him to have one hand free. According to him, a free hand is particularly valuable when one is working alone. Compared to the existing backpack (see figure 30), Rubendahl declares that the concept appears to be more comfortable, water-resistant, stabile and robust. Furthermore, the hard shell, according to Rubendahl, instills a sense of trustworthiness. When compared to the existing protective cases, the concept is regarded as more comfortable. Rubendahl mentions that the depth and the large handle on the reference protective case render it difficult to carry close to the body. Due to the high combined weight of the necessary tools and equipment, Rubendahl stresses the importance of a lightweight carrying solution. Thus, he is worried that the carrying concept may be heavier than the existing backpack (3 kg). As the

Fig.60 Renderings of the refined concept used for evaluation.

existing protective cases and backpacks are rarely cleaned - often they are emptied and shaken upside down - Rubendahl would like the carrying system to be produced from materials that dirt does not easily adhere to.

Regarding the appearance of the concept, Rubendahl states that he likes the strong orange colour and that it is beneficial if the backpack is easily distinguished from its surroundings. If produced in a strong colour, Rubendahl continues, the backpack could be used as a temporary road cone to mark the measuring zone. When asked about reflexes, he notes that as one is carrying a backpack the safety clothing is covered and thence an addition of reflective fabric on the backpack would be advantageous.

During a discussion regarding the transport of the carrying concept to the measuring site, Rubendahl explains that adequate padding is essential as the roads are not seldom temporary and/or in poor condition. Moreover, he expresses a desire for an efficient method of securing the carrying solution in the transport vehicle. The presented concept is, Rubendahl notes, not stackable; however, he does not see any apparent benefit in having a stackable carrying system.

When asked about ventilation possibilities, Rubendahl admits that it would be a nice feature but one that is not really needed. In the presented carrying concept, he only misses a handle for lifting and shorter transports.

11.2 Evaluation of expression I

11.2.1 Evaluation of reference case

The evaluation of the reference protective case revealed that it was perceived as active, professional and rather safe. It was, however, not regarded as particularly comfortable, see figure 61. The results correspond well to the results from the interviews and analysis. The protective case is used by professionals to transport equipment safely from one location to another, hence the case may suggest professionalism (the user), activeness (the transport) and safety (protecting the load). As confirmed in the interviews and observations (see Chapter 6.8), the hard cuboid-shaped case is not and does not communicate an expression of comfortable carriage.

11.2.2 Evaluation of concept solution

When presented with renderings of the concept carrying system (see figure 60 and Appendix 5), the respondents judged the concept to express a high level of safety, see figure 62. The expression of safety can, according to some of the respondents, be attributed to the hard plastic shell and the wide base of the carrying solution. The concept was neither perceived as active nor passive, likewise, the concept was not regarded as particularly professional nor notably casual. Ratings of the comfortableness showed that the concept expressed, albeit slightly, more discomfort than comfort. One reason for the low perceived comfort may be that

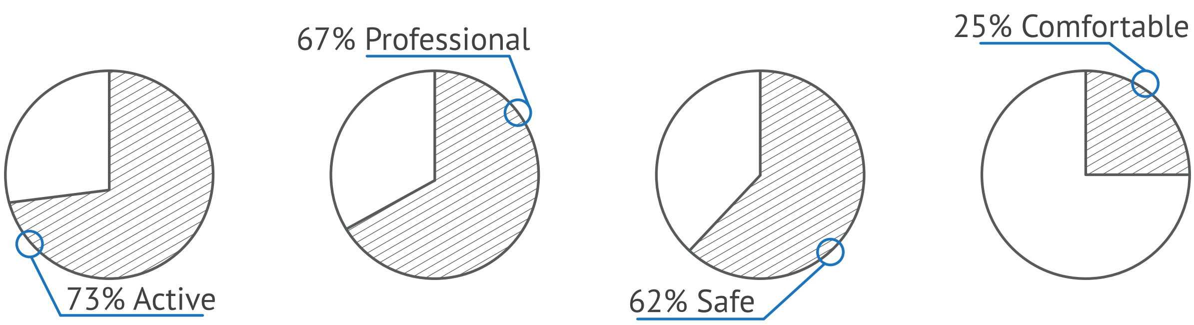


Fig.61 Evaluation of the reference protective case.

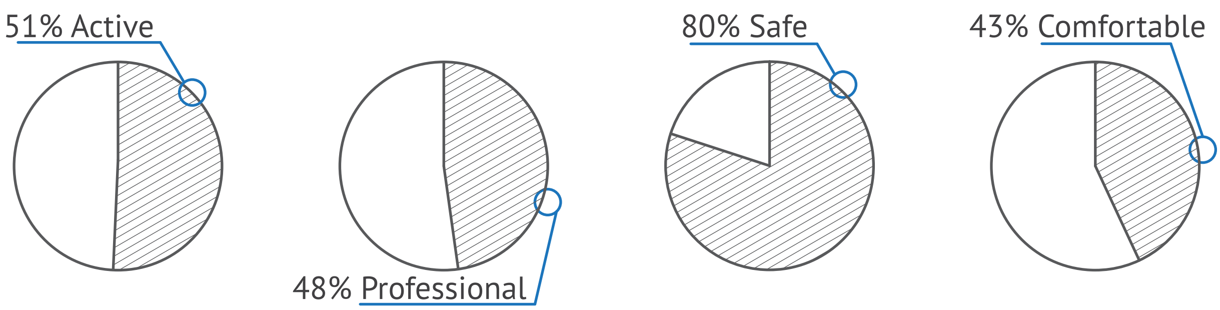


Fig.62 Evaluation of the concept carrying system.

the shoulder straps and hip belt were not completely finished at the time of the evaluation, see figure 60. The subjects were informed of this prior to the evaluation.

11.3 REBA analysis II

A REBA analysis was conducted with the functional model. The more well-developed back panel, see figure 58 provided a more comfortable coupling. The lift from ground level, see figure 63 resulted, as in the previous evaluation (see chapter 6.9), in a score of 8. This score corresponds to a high risk of injuries (see Hignett & McAtamney 2005). For the functional model, the lift from the ground still entails a twisted trunk with a forward inclination of approximately 20 degrees. Other factors that had significant negative impact on the score (i.e. the risk for injuries) were the high weight of the load (12kg) and the support on one leg during lifting.

The back carrying was improved in the functional model. The aggregate score for the back carrying was 4 in the carrying concept compared to 5 for the reference protective case. However, the back carrying still entails a medium risk for injuries. Compared to the back carrying of the protective case, the carrying concept was perceived as much more comfortable and allowed for a more upright posture, see figure 63 and 36.

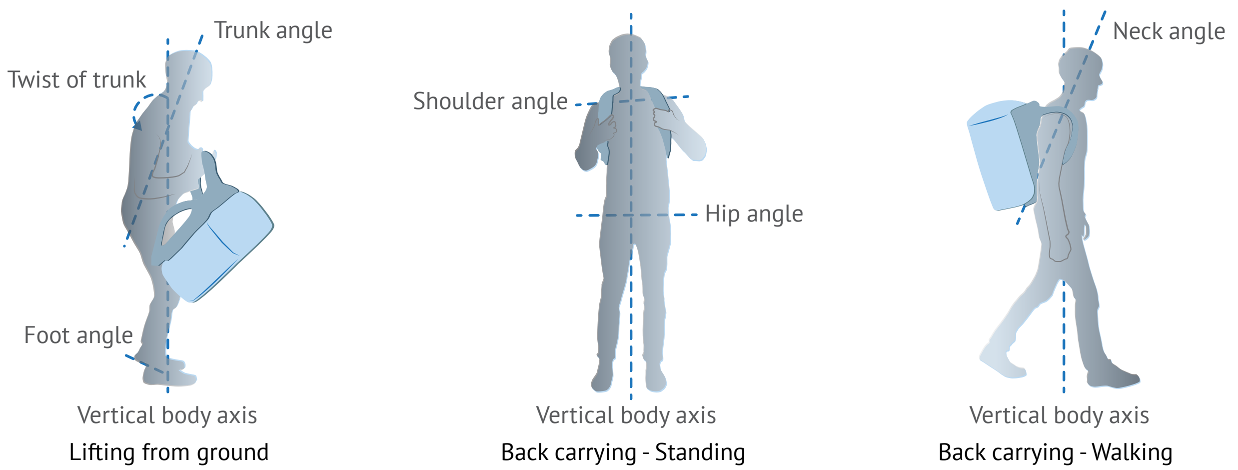


Fig.63 Illustration of the REBA analysis of the functional model.

12. Final concept

12.1 Overview

The final concept, see figure 64, is designed as a transport solution for sensitive equipment in general and for tachymeters in particular. The concept, named Tortoise, is an internal frame backpack designed and constructed to provide a comfortable and reliable carrying experience in the most harsh conditions. The carrying concept is a transmitter of Boblbee's design cues and is easily distinguished from the existing protective cases on the market.

Fig.64 Visualisation of the final concept.

12.2 Usage

12.2.1 Concept layout

The Tortoise is designed as a fusion between a soft and a hard backpack. The layout of the concept is based on the findings from the interviews and observations in combination with the results from the literature review and ergonomic analysis. Sensitive equipment (e.g. a tachymeter) is stored upright in the large water and dust protected container. In the container, the equipment is protected by a removable padded insert and secured with a padded velcro strap, see figure 66. The sensitive equipment is placed as high as possible in the pack and is accessed through the top lid to reduce the height of the lift when unloading. Cables, pencils, notebooks and maps may be placed in the compartment beneath the hard container, accessed through the prominent pocket on the back, see figure 65. Items that require fast access or frequent usage can be placed in the elastic fold-out on the inside of the back pocket, see figure 65. The carrying concept features two removable side compartments that may be used for transporting batteries and the remote control unit. The side compartments are removable to allow for a greater range of variation and personalisation, see figure 73. In order to enhance the personalisation possibilities, the Tortoise concept is equipped with triangular Boblbee connectors, see figure 64, to enable modifications depending on the use situation and context. For instance, the triangular connectors may be used to attach a mesh for external storage of less sensitive instruments and tools. If the tools and instruments are large, the side compartments may be removed thereby providing storage opportunities along the sides of concept. The shoulder straps are equipped with attachment possibilities for a mobile phone or a radio communication unit, see figure 74.

Fig.65 Storage possibilities in the Tortoise concept.

In line with the desires of the persona (see chapter 7.8), the layout of the concept is arranged to provide each item with a dedicated location to ensure a good overview and an efficient compilation of the necessary equipment.

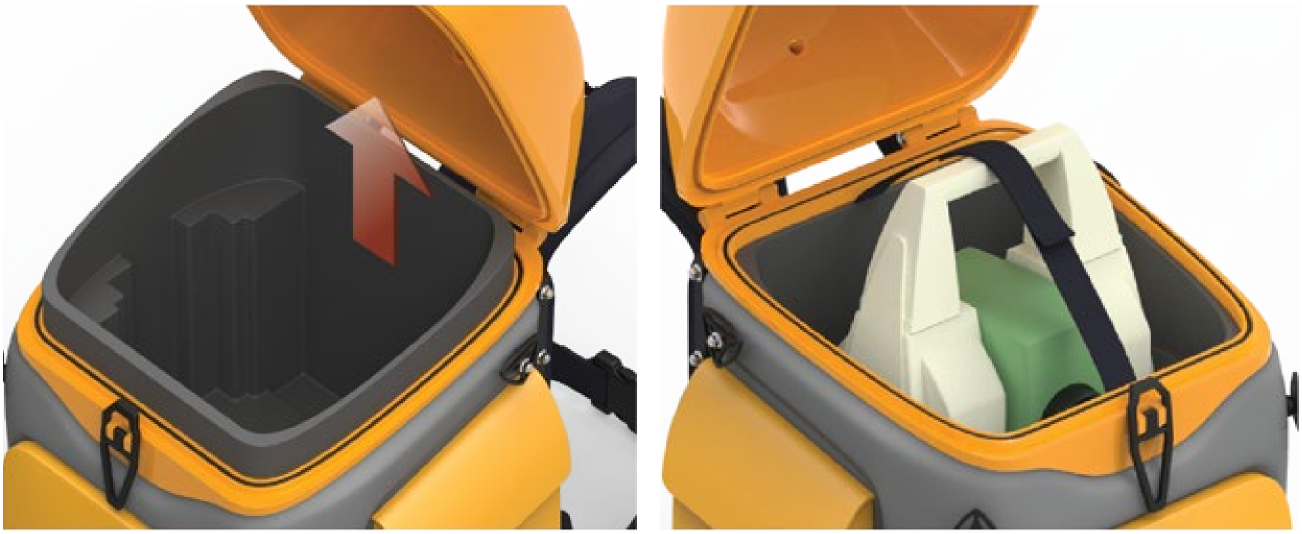


Fig.66 Removable padded insert and securement of sensitive instruments through a velcro strap.

12.2.2 Carrying experience

The final concept is designed to place the heaviest load (i.e. the sensitive equipment) high on the back and close to the carrier's centre of gravity. The backpack carrying solution facilitates a symmetrical placement of the load, thus reducing the risk for discomfort and injuries. To further reduce the perceived discomfort during long hikes with heavy loads, the back panel is S-shaped (like the vertebral column) to transfer weight to the sturdier vertebrae and pelvic girdle, see figure 70. Moreover, the waist belt serves to shift the load from the shoulders to the stronger and less sensitive hip region. The two shoulder straps are well padded and follow the curvature of the shoulders and chest, thereby reducing the pressure by distributing the force over a larger area, see figure 67. Implementing the results from the literature study, the shoulder straps have a lower attachment angle of approximately 30 degrees. The length of the shoulder straps and the waist belt can be adjusted to fit potential users in the range from the 5th-percentile women to the 95th-percentile men, see figure 68. The length of the straps and belt may be adjusted using the buckle on the straps and belt, respectively. The shoulder straps and waist belt firmly secures the load to the carrier's body. As can be seen from figure 68, the fit of the Tortoise concept is not optimal for the 5th percentile women and the 95th percentile men since the S-shape of the back panel does not follow the curvature of the carrier's vertebral column to a satisfactory level. To increase the comfort and the carrying experience for the shortest and the tallest, the back panel can be detached and replaced with a smaller or a larger one, respectively.

Fig.67 Shoulder straps that follow the curvature of the upper body.

Although the load is secured to the user's trunk, the design of the back panel allows for movement and ventilation. The padding consist of several small cushions placed to follow the curvature of the carrier's back, see figure 64. At regions with high identified levels of sweating, the padding is intentionally omitted to allow for ventilation. The back panel is constructed with a pyramid microstructure to enhance the ventilation, see figure 69.

The tortoise concept is equipped with a handle to facilitate lifting and carrying over shorter distances. The bottom of the backpack is wide and reinforced to allow for placement on wet or slippery surfaces. When placed inside a transport vehicle, the wide base provides a balance. By pulling the safety-belt between the shoulder straps, the backpack can be secured during transport.

When closing or opening the latch of the waterproof container, the user is provided with visual and audial feedback ('click'). As the side compartments are opened, the velcro hoops and loops are separated transmitting a characteristic sound. The protective padded interior in the main compartment is easily removed by pulling it upwards, thereby it may be cleaned or replaced to accommodate for another need, see figure 66.

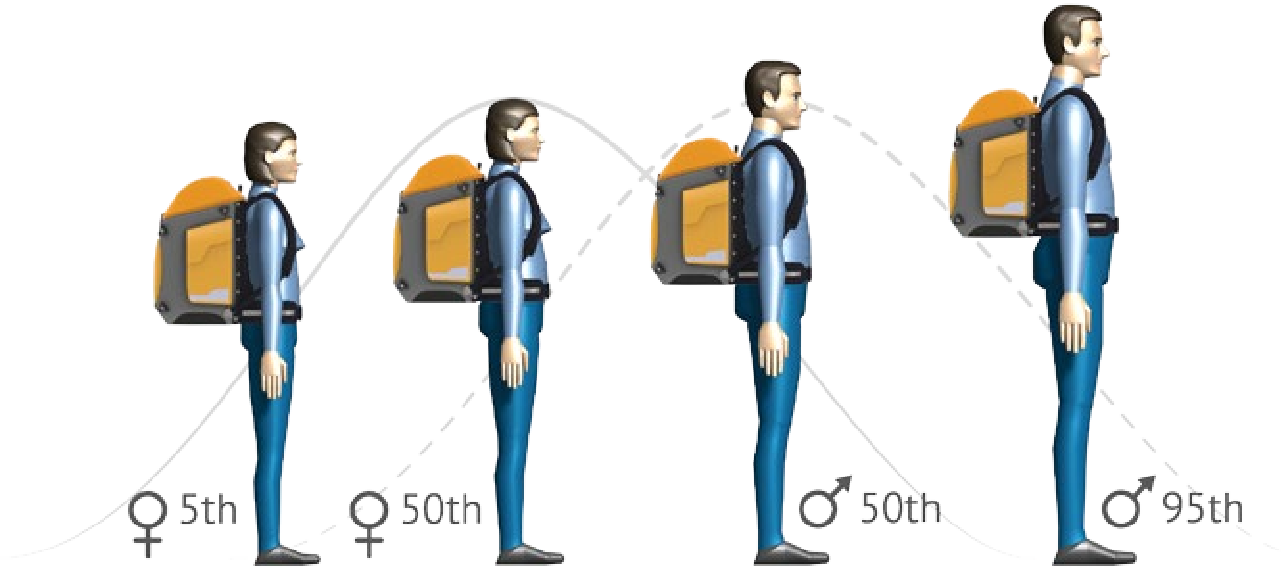


Fig.68 Size of the Tortoise concept displayed in relation to 5th percentile women, 50th percentile men and women, and 95th percentile men.

Following the scenario (chapter 7.9), the Tortoise concept is designed to provide a stabile transport inside the car, a comfortable carrying experience that transfers weight from the shoulders to the waist, a well-ventilated back panel to reduce sweating and heat accumulation, and a reinforced bottom for placement on a muddy ground.

Compared to the reference protective case with two shoulder straps, the tortoise is more time-consuming to put on and take off due to the addition of a waist belt.

12.3 Materials and construction

The dimensions of the concept, see figure 71, are set to fit the largest tachymeter identified - Leica TS/TM 30. The water and dust proof compartment is sealed with a strong latch. To further enhance the fit between the lid and the container, a rubber gasket is placed along the rim of the opening, see figure 66. To enable evaporation and functionality after atmospheric pressure changes a pressure valve is placed on the lid of the main compartment, see figure 68. The soft water resistant exterior of the carrying solution is made from an impact resistant and dampening PEBA foam (which is fairly rigid, like a shoe sole). Thus, the soft shell serves to reduce the first impact if the backpack were to be dropped. The soft shell is attached to the main compartment by a number of screws, see figure 72. The hard container is made from ASA/PC, a plastic with high impact strength and UV-resistance, see Appendix 7. The surface of the ASA/PC plastic is smooth to facilitate cleaning and allow water to run off. The structural stability of lid of the container is reinforced by a large groove in the form, see figure 64. The back panel is joined to the hard case by a series of screws, thus enabling replacement and repair of worn elements. Additionally, this construction allows for personalisation in terms of selecting the appropriate size of the back panel. The back panel is made in three different sizes

Fig.69 Pyramid microstructure on back panel to increase the ventilation.

Fig.70 S-shape of the back panel to follow the curvature of the vertebral column. Split view of the Tortoise carrying concept.

as opposed to one adjustable size. Thereby, the number of movable components (and the weight of the carrying concept) is minimised. Although the soft shell and the back panel are joined by screws to the hard compartment, none of the screws are placed so they penetrate the waterproof container. The back panel is made from the same materials as in the current Boblbee products, i.e. EVA-foam and nylon.

The removable side compartments are attached to the outer shell by a keyhole suspension system, i.e. the side compartments are hung from the outer shell, see figure 73. The body of the side compartment is made from PEBA and the lid is made from a waterproof textile. The lid is fabric to allow a tight fit and some stretch of the material. The large back pocket in made in PEBA and opened and closed by a water resistant zipper. The bottom of the carrying concept is reinforced with rubber to create a waterproof surface with high friction. The rubber is sewn to the outer shell. The back, the side compartments and shoulder straps are equipped with reflective patches for increased visibility, see figure 64.

The suggested materials fulfil the necessary requirements regarding storage and service temperatures (see chapter 7.7). The materials proposed, in combination with the construction of the Tortoise concept with a water and dust proof container and a pressure valve will allow for a global usage with respect to temperatures, weather conditions and terrains. Furthermore, ASA/PC and PEBA exhibit adequate resistance to salt water and UV radiation. Hence, the materials can be cleaned with water. All materials used in the Tortoise concept are labelled according to ISO-standards to facilitate identification and organisation during disassembly.

In line with the information provided from Boblbee, the soft parts of the concept (e.g. the back panel) are modelled only as a visual reference, whereas the hard container is more accurately modelled and given draft angles. The hard container is suggestively manufactured using injection moulding and the outer shell is preferably made by thermoforming of a foam sheet.

The weight of the carrying concept is 3200g without padding and 3900 grams with padding. The weight of the backpack used by Skanska and Lantmäteriet (see figure 30) is 3000g and the weight of the

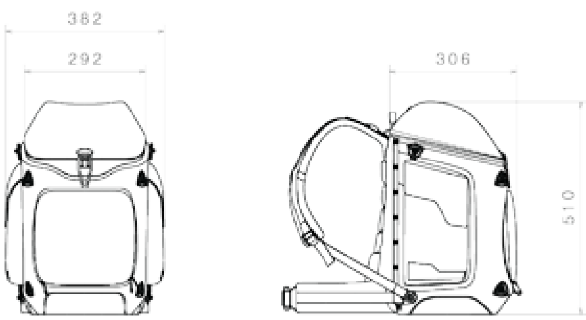


Fig.71 Dimensions of the Tortoise concept.

Fig.72 The container with visible holes for screws for attachment of the softer shell.

Fig.73 Removing the side compartments allows for attachment of external loads using the Boblbee connectors.

reference protective case (see figure 3) is 2900g. Thus, the presented concept is heavier than both the reference protective case and the backpack. The reason for the increased weight compared to the reference case is the more ergonomically developed back panel; a panel which will enhance the comfort experienced during load carrying using the concept solution. The presented concept is heavier than the backpack due to the usage of plastic for the waterproof container. As the existing backpack is made from canvas textile (and is not waterproof) with a lower density than ASA/PC plastic, the backpack is lighter than the Tortoise concept.

12.4 Form design

The final concept is designed to fulfil four aesthetic demands. First of all, the concept should not be perceived as large and/or heavy. Secondly, the concept should fit Boblbee's brand identity and be a transmitter of the company's design cues. Thirdly, the Tortoise concept should communicate an expression of safety, comfort, professionalism and activeness. Finally, the form of the concept should be differentiated from the existing carrying solutions for sensitive equipment on the market.

By using a number of elements to split the form and create complexity, the backpack concept is perceived as smaller than it would if it were to be a solid cuboid from hard plastic. The addition of a soft shell divides the form horisontally, creating a lower (soft) and a top (hard) form that are viewed as two separate elements. The addition of a large back pocket further divides the soft shell and serves to decrease its perceived size. The removable side compartments add a width and complexity, resulting in an aggregate form that is not fully perceived as cuboid. The divergence of the soft shell into four contact points angled towards the centre of the backpack in combination with the dark contrasting bottom surface serve to create an expression of lightness.

In order for the Tortoise concept to fit within Boblbee's product portfolio a number of the company's identified design cues have been implemented in the final concept. As can be seen from figure 64, the concept feature contrasting colours, heavy textiles, a Boblbee logo, visible construction details, triangular Boblbee connectors, diagonal lines on the sides, a large closed shape in the back pocket, a lid from hard glossy plastic and a mesh structure on the textiles. Consequently, the Tortoise carrying concept is a transmitter of Boblbee's design cues.

The expression of safety in the Tortoise concept is communicated through the well-padded container in hard plastic. The expression is enhanced by the strong latch used for opening and closing and the rubber gasket that ensures a waterproof fit between the lid and the container. The expression of professionalism is transmitted by the elaborate waterproof construction and the dimensions of the backpack. The removable interior padding that can tailored to fit specific instruments further amplifies

Fig.74 Attachment possibility for a communication device (e.g. walkie talkie) on the shoulder straps.

the expression of professionalism. The activeness is communicated through the possibilities to modify the carrying concept and attach additional tools on the backpack using the triangular Boblbee connectors. The reinforced rubber bottom and the protective container reveals that the carrying concept can be subject to and withstand various activities in harsh environments. The padded waist belt and shoulder straps in combination with the S-shaped back panel convey an expression of comfortable carriage.

The presented concept is differentiated from the existing protective carrying solutions on the market as it is an ergonomically well-developed backpack system made for longer transports by foot.
The combination of soft and hard materials result in a concept that may be regarded as a fusion between a protective case and a hiking backpack, a product currently unavailable on the market.

Relating to semantic 'sign', it is assumed that the shoulder straps will enable the user(s) to understand the intended function and usage of the final concept.

12.5 Sustainability

The sustainability of the final concept is related to the choice of materials and joining techniques. The Tortoise concept is designed with materials that may be recycled. The main body of the concept (i.e. the container, the soft shell and the back panel) are joined by screws to facilitate disassembly for repairing or replacing components. Like the existing carrying systems from Boblbee, the back plate is constructed with seams. This method of joining results in a more complicated disassembly and, consequently, the materials in the back panel will be more difficult to recycle. Nonetheless, heavy seams are a common means of textile joining that provide durability as well as comfort. Furthermore, there is a well-developed market in place (e.g. shoe repair shops) for repairing this type of constructions, thereby increasing the lifespan and sustainability of the Tortoise carrying concept.

Fig.76 White-coloured Tortoise carrying system.

Fig.77 Black-coloured Tortoise carrying system.

Fig.75 Sand-coloured Tortoise carrying system.

Fig.78 Grey and green-coloured Tortoise carrying system.

12.6 Colour variations

Figures 75-78 display the Tortoise carrying concept in different colour schemes. Depending on the usage context, the need for visibility is dissimilar. For instance, at a construction site with crossing vehicles visibility is required whereas during wildlife photography strong colours may be rather detrimental. From a sustainability perspective, the colour(s) should be integrated in the plastic(s) and not painted on following manufacturing. Moreover, moulded-in colours are generally more cost-effective compared to post-manufacture painting and coating (Kellner 2009).

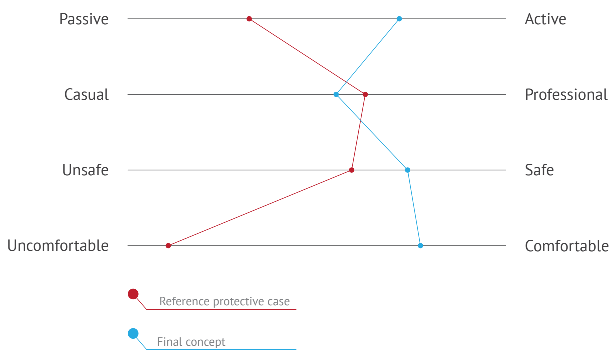


Fig.79 Result from the comparison of the expressions of the reference protective case and the Tortoise concept.

12.7 Evaluation of expression II

The comparison between the expressions of the reference protective case and the final concept showed that the concept was perceived as more active, safe and comfortable than the reference case. The concept was, however, regarded as less professional, see figure 79. An explanation for the higher rating of the activeness in the concept may be that the carrying concept allows for a wider range of movements and, in connection with the high perceived comfort, more and longer activities. The significant difference in the comfort communicated by the two carrying solutions is most probably related to the more developed shoulder straps and the addition of a soft back panel and waist belt in the concept. Since both the reference protective case and the presented concept feature tailored padded interiors, its impact on the perception of safety is probably minor. Thus, the comparatively higher identified expression of safety in the concept solution may be attributed to its wide rubber reinforced bottom and the standing positioning of the sensitive tachymeter. The lower perceived professionalism in the concept solution than in the reference protective case may be related to the more task specific design of the protective case. The reference case is unambiguously designed to be used by professionals to transport a sensitive instrument from one location to another whereas the concept is a less-defined carrying solution in between a protective case and a sports backpack with a less evident usage context. Hence, the vagueness in the design of the concept may result in a lower perceived professionalism.

13. Discussion

13.1 Problem description

The problem description consisted of two parts that were similar yet only to a certain extent. At the start of the project a brief was provided to the researchers. This brief had been sent to Boblbee as a basis for a carrying solution project by one of the larger producers of measuring instruments. The project was, however, not realised. The brief consisted of relevant technical information for the development of a carrying system for three different tachymeters. Boblbee, on the other hand, expressed a wish for a more general solution that could be used for transporting other sensitive equipment (e.g. cameras and medical devices) as well. The reference product to transport in the carrying concept was nevertheless set to be a tachymeter and the reference protective case was one used for transporting tachymeters and other measuring equipment. Consequently, there was some initial confusion regarding the focus and stakeholders in the project - was it a project aimed at developing a carrying concept for sensitive equipment for Boblbee or was it a project aimed at developing a carrying system for tachymeters as a business-to-business project between Boblbee and the manufacturer of measuring instruments? Until the project and its stakeholders were adequately specified it proved difficult to plan the execution of the project. Finally, it was decided together with Boblbee to focus on developing a carrying concept for tachymeters. As tachymeters are sensitive and expensive, a carrying solution for tachymeters would be suitable for other sensitive equipment as well. Thus, the project was aimed at developing a carrying concept for tachymeters for Boblbee. However, the dual focus of the project latently persisted only to surface when discrepancies between the requirements for a carrying concept for tachymeters and a carrying concept for sensitive equipment emerged, see chapter 13.3.1.

13.2 Methods and process

The project consisted of two phases: an initial research phase, followed by a concept development ditto. Since the project had been defined in an open manner, the first stage of the process was to try and assess what possible methods to use and what steps that would be required in order to develop a suitable final result. The complexity of the project demanded development of a detailed process plan. This resulted in in a flowchart (see figure 4) that would serve as a guide throughout the project. The flowchart proved to be of great use even though it was, at many stages, hard to follow.

The planning also concerned what methods to be used in the project. Based on the researchers' earlier experiences of project development, a number of methods were decided upon. With little previous knowledge regarding surveying and carrying systems, the literature review and the observations were highly valuable. These parts provided an understanding of the actual user-needs. Based on the information concerning the users, a persona and a scenario were created. This clear description of the intended user and use situation was revealed to be a helpful resource during the concept development process.

The research gave many insights regarding human anatomy and optimal load placements. Whereas the theoretical research was relatively straightforward, the interviews and observations were more demanding. Since many of the companies that use tachymeters are small and have tight schedules, it was difficult to book interviews. Discrepancies between the planned and the actual process arose when scheduled interviews and observations were postponed prompting a need to commence the ideation phase prior to the conclusion of the information gathering. Thus, at the start of the ideation phase, not all data from the interviews and observations had been collected. Its result on the outcome of the project is difficult to assess, it was, however a source of frustration. Another problem with the observations was that only men were observed and interviewed. Due to this unlucky situation, only secondary source information regarding womens' experience from surveying work was obtained. This situation occurred partly due to the (reported) male dominance in the industry and partly due to the lack of specific requests regarding gender distribution from the researches. Finally, it must be noted that the interviews and observations were conducted with Swedish professionals although the stated target group is global. The selection of subjects was based on the location for the research (Gothenburg, Sweden) and the lack of time and funding for executing similar interviews and observations abroad. Consequently, problems that are specific to some regions or work contexts may well be absent in this project. However, the construction and choice of materials would, theoretically, ensure functionality in almost all climates.

Since the aim of the project was to create a carrying system, much of the early ideation process was concerned with various methods of carrying or transporting a load. In hindsight, with the final concept being a backpack, this time-consuming task may be viewed as a waste, yet it provided a firm base when motivating this direction for the project (i.e. to develop backpack system).

When developing a carrying system, much of the work concern ergonomics and user experience.

With a limited budget and a tight time-schedule, the construction of simple mock-ups and the use of REBA analysis were useful tools for creating an understanding of the functionality of the concepts. Although the mock-ups looked far from the intended final result, these models constituted a practical means of illustrating and communicating the dimensions of a concept as well as for getting a perception of the carrying experience. The REBA analysis of the Tortoise concept only showed a slight decrease in the risk for injuries yet it was perceived as much more comfortable during carriage. A method for evaluating the comfort (or perhaps perceived exertion) during carriage may have been beneficial for analysing the difference in carrying comfort between the concept solution and the reference protective case.

During the final development phase, the complexity of the project became evident. In the process of fulfilling all the demands regarding form and function, collisions between different constraints constantly emerged. As a result, many iterations with new CAD models had to be performed until a satisfying concept was realised. In this process, Catia Imagine and Shape was useful, as the virtual models could be modified without having to rebuild the whole geometry.

Due to the difficulties in scheduling appointments with the interviewed professionals, the user response session (see chapter 11.1) only comprised one subject. Although the session provided many insights, the fact that the evaluation is based on the views of one person must be stressed. In order to fully assess the professionals' opinions regarding the Tortoise concept more evaluations with professionals should be conducted. As mentioned in the paragraph concerning the interviews and observations, the evaluation sessions should preferably include men and women working in different regions of the world.

Despite the fact that the aim of the project was rather undefined at the start, the use of a detailed process allowed for the development of a clear and realistic concept that fulfils the relevant requirements placed on a carrying system for sensitive equipment.

13.3 Final concept

13.3.1 Usage

As mentioned in the paragraph regarding the problem description, a difference in the demands from the interviewed professionals and from Boblbee was identified. The subjects interviewed expressed a wish for a lightweight carrying system and did not see any apparent advantages in having a highly waterproof container as the tachymeters themselves are water and dust proof. In contrast, Boblbee wanted a waterproof carrying solution that was sealed with a latch as IP-classed zippers are costly (see chapter 10.1). Although not fully supported by the interviews, a decision to develop a waterproof carrying system was made. Making a carrying concept waterproof will increase its weight as overlapping and gaskets are necessary. As a compromise and a means to reduce the weight of the concept, the final carrying solution was constructed with a waterproof container and lighter, water resistant compartments. Adding lighter elements to the carrying concept was essential as the results from the literature review and the REBA analysis revealed that the weight of a load is a determinant for injury incidence.

The addition of a waterproof container was deemed beneficial as it would provide a safe transport for sensitive equipment that are not waterproof. Since all optical and electrical equipment are sensitive to vapour (a frequent problem reported by the survey engineers), a ventilation valve was added. A safe transport of various sensitive equipment would be realised by optimising the interior padding of the waterproof container. This optimisation would be achieved by replacing the padding for tachymeters with, for instance, padding for a camera house and lenses. Thus, the carrying concept would be capable and useful for the transport of other sensitive equipment. However, the dimensions of the presented Tortoise concept are determined by the size of the largest tachymeter identified. Nonetheless, the underlying principle of combining a soft shell for attenuating an impact with a padded water and dust proof container is functional independent of the size of the carrying solution. Hence, the presented carrying concept is scalable to fit various sensitive equipment that require a safe transport. Despite the fact that the user response session did not reveal any demand for removable side compartments, the pockets were designed to be detachable. This decision was based on the identified wish for transporting various loads on the carrying solution. By removing the side compartments, the user would be able to attach tools on the sides of the backpack.

Although the presented carrying concept is intended to be used by professionals from countries all over the world, anthropometric measurements for Swedish adults were used as reference during the concept development. The usage of Swedish data provided an opportunity for testing and evaluation in Sweden. In addition, using international measurements would imply collecting and calculating averages for a global population - an operation that the researchers judged to take too much time in relation to its expected benefit. The global usage potential of the carrying concept is reflected in the usage and storage temperatures of the suggested materials as well as in the water and dust proof construction of the main compartment.

Thereby, usage in regions with high or low temperatures and dry or humid climates would be possible.

13.3.2 Materials and Sustainability

There was a wish from Boblbee to explore the possibilities of using alternative materials for the carrying concept. Based on the test values, service temperatures and resistance to UV-radiation from CES, the hard container should suggestively be made from an ASA/PC thermoplastic compound and the softer shell should be manufactured from the thermoplastic elastomer PEBA. However, if Boblbee can accept a trade-off in the storage temperature range (from -40 to -32 degrees C) for the carrying concept they may use a combination of ABS for the waterproof container and EVA foam for the softer shell, i.e. materials from which the company has experience.

During the project it has proved difficult to assess the properties of the plastics used by Boblbee as well as by the leading companies in the industry for protective cases. The reason for the perceived difficulty is that the companies keep the specific contents (or the percentages of each content) secret and prefer to use labels such as 'impact modified' or 'high impact' (see Chapter 6.5). Consequently, the combination of the ASA/PC compound and the PEBA foam should be regarded as a suggestion based on the retrieved information and the test values from CES.

The sustainability of the Tortoise concept is achieved not through the material suggestions but through the joining of the different parts. As mentioned, the ability to separate the materials and replace worn out or damaged elements will serve to increase the functional life of the carrying concept.

13.3.3 Concept expression

As can be seen from figure 79, the Tortoise concept is perceived as less professional yet more active, safe and comfortable compared to the reference protective case. Although the results appear promising considering the aim at developing a carrying solution for professionals to be used in a work context, it must be noted that the subjects for the study do not adequately represent the intended target group for the Tortoise concept. The subjects were industrial design engineering students and not, as in an ideal case, professionals with experience from tachymeters. Additionally, all but one of the participants were Swedish. The selection of test persons was based on a trade-off between a suitable number of subjects and time available. To conduct the evaluation with professionals, substantial time would have had to be allocated to the study. Consequently, it was judged that - for a project of this scale - it would be satisfactory to execute an evaluation with industrial design engineering students; students who, from their education, have experience from form evaluations. Hence, the result from the evaluation should be regarded as an indication of the concept expression based on the views of the subject group. To ensure that the concept is similarly perceived by the intended target group, testing within that group is necessary.

Fig.80 Rendering of the Tortoise carrying concept worn on a 185 cm tall model.

14. Conclusions and recommendations

The aim of this master project was to design, develop and present a product concept that ensures a safe and comfortable transport of tachymeters (see chapter 1.2). The final concept, Tortoise, is a fusion between a protective case and a hiking backpack. The combination of soft and hard plastics serves to protect the load during transport. The replaceable interior padding enables the concept to be used for carrying various sensitive equipment. A well-ventilated and padded back panel, two ergonomically designed shoulder straps and a wide waist belt serve to create a comfortable carrying experience for users all over the globe.

The research questions for the project were:

With regards to human physiology and the usage context, what is the optimal method of transporting a tachymeter from the storage room to the measuring site(s) and back?
- Based on this study it appears that the most optimal method of transporting a tachymeter from the storage room to the measuring site is through a backpack with an internal frame that places the load high on the back and shifts weight from the shoulders to the hips. A wide base provides a stabile placement and a rubber reinforced bottom increases the friction against the surface on which the backpack is placed.

How should a carrying solution for sensitive equipment be designed in order to express safety and professionalism and fit Boblbee's product portfolio?
- By using tailored protective padding and creating a waterproof container an expression of safety and professionalism can be communicated. Through the use of heavy textiles, contrasting colours, Boblbee's logo, closed shapes and the Boblbee specific triangular connectors, a carrying system for sensitive equipment that fits Boblbee's product portfolio can be developed.

How could a carrying system for tachymeters be designed to be differentiated from the existing products on the market?
- As the products on the market are unicoloured cuboid-shaped protective cases made from hard plastics and primarily designed for hand carrying, a carrying system for tachymeters can, for instance, be differentiated through the method of carriage (e.g. on the back), through the use of alternative materials (or a combination of materials) or by providing an ergonomically comfortable carrying experience.

What materials appear promising to be used in a carrying solution for sensitive equipment?
- Based on data from CES, two materials that appears to be promising for heavy usage under harsh conditions are ASA/PC and PEBA. The former is a thermoplastic compound and the latter is a thermoplastic elastomer.

The recommendations for the further development of the Tortoise concept concern the verification of its ergonomics and functionality. In order to allow for an 8-hour carrying test and an evaluation of the water and dust protection, a prototype must be constructed. Prior to producing a prototype, wishes and demands from female professionals must be collected and analysed. When developing replaceable interior paddings and options for the external storage (the add-ons), data from other potential users (e.g. emergency medical personnel and photographers) should be assessed. The same is true when evaluating the scaling possibilities of the Tortoise concept.

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APPENDICES

1. Interview questions

1. Vilken utrustning används vid mätningar?
2. Förekommer det olika konfigurationer vid olika typer av uppdrag?
3. Hur många arbetar ihop, är man själv eller i grupp?
4. Förekommer det att man måste bära utrustningen långa sträckor? I så fall, när och hur vanligt förekommande är detta?
5. Brukar man utföra mätningen på en specifik plats eller måste utrustningen packas ihop och förflyttas under mätningen/ arbetsdagen?
6. Vilken typ av låda/väska används under transport och förvaring?
7. Saknar du något hos er transport- och förvaringsutrustning?
8. Hur påverkas arbetet av olika typer av väder?
9. Förekommer det någon typ av arbetsskador vid mätarbete?
10. Hur mycket påverkas ert arbete av den bärutrustning ni använder? Skulle en förbättrad funktion kunna motivera till att investera i ny utrustning?
11. Har det förekommit att mätutrustningen skadats under transport/ förvaring/användning?
13. Hur sker inköp och val av utrustning?
14. Är det någon som har en egen variant/lösning på transport av utrustningen?
15. Vilka märken har du använt utrustning från?
16. Hur upplever du utrustningen i fråga om användarvänlighet?
17. Hur upplever du utrustningens i fråga om ändamålsenlighet, effektivitet och tillfredsställning?
18. Upplever du det uppenbart hur utrustningen ska hanteras, eller har något moment känts överraskande?
19. Hur bärs utrustningen?
20. Om du bär en väska, lägger du då tid på att ställa in och anpassa den så den sitter bekvämt eller hänger du bara på dig den?
21. Är utrustningen personlig?
22. Hur många arbetar med mätning?
23. Vad är det vanligaste klagomålet på utrustningen från dina kollegor?
24. Vad är det vanligaste positiva du hör om utrustningen från dina kollegor?
25. Har du arbetat med olika typer av totalstationer och vad har du då upplevt för skillnader mellan dessa?
26. Hur ofta byts utrustningen ut? Är det några delar som slits mer än andra?
27. Förekommer det att saker glöms kvar på mätplatsen eller på kontoret? I så fall hur vanligt är detta?
28. Upplever du att det är av betydelse hur arbetskläder och utrustning ser ut eller är det viktigare att sakerna är praktiska?
29. Vilken typ av klädsel används i arbetet? Bekväm? Arbetshandskar?
30. Upplever du att arbetet är obekvämt på något sätt? (att det är varmt, att man blir svettig, att det är tungt, att det är stressigt.)
31. Är det någon utrustning du saknar ute i fält? Skulle du ha nytta av en dator etc?
32. Är det något du önskar?
33. Behövs det ytterligare kringutrustning?
34. Används både totalstation och GPS ihop?
35. Hur många mätningar görs per dag och vecka?

2. Benchmarking

Brand 1 - Nanuk - 925

Specifications

- Temp at least -28 -> +60
- Drop, impact, vibration, rainfall, immersion, ingress protection tested.
- ATA300, ASTM D-4169 DC 18, MIL-STD-810F, IP67 certified
- Lifetime warranty
- No sustainability plan

Features

◀ The latch is more advanced compared to other brands on the market. It is easy to handle, but might be a little hard to use with gloves.

◀ The handle has a good size and has a rubber cover that helps getting a good grip

◀ The hinges on the case are rigid and are also constructed in a way that makes the lid stand open on its own.

◀ The case is made from NK-7 resin based on PP. The overall design is soft and rounded. Hardware made from marine grade 304 stainless steel.

◀ The case has an automatic pressure valve.

Brand 2 - Peli Case - iM2450

Specifications

- Temp at least -29 -> +60
- Protection against knocks, immersion, humidity, corrosion, stacking and drop resistance tested.
- ATA300, STANAG 4280 - DEF STAN 81-41, IP67, MIL C-4150-J certified
- Lifetime warranty
- No sustainability plan

Features

◀ The latches have a good quality feel and a relatively easy to open and close. The new model offers a safety lock.

◀ The handle offers a good grip and is made from the same material as the case, with a rubber cover.

◀ The hinges are very rigid and run along most of the edge between lid and bottom case.

◀ The basic construction is very rigid and made from a PP based copolymer.

◀ The case is fitted with an automatic pressure valve.

Brand 2 - Peli Case

◀ Besides the ordinary hard cases, Peli Cases have a line of backpacks with a built in hard case. This solution has a good quality look to it, but the hard case part only has room for a laptop. It's hard to know if it would work as good with a bigger hard case, but the basic idea is interesting.
modnr. U100

Brand 3 - Explorer - 4419BE

Specifications

- Temp at least -33 -> +90
- Shock, immersion, humidity, corrosion, stacking and drop resistance tested.
- STANAG 4280 - DEF STAN 81-41, IP67, MIL C-4150-J certified
- Lifetime warranty
- No sustainability plan

Features

◀ The latches feel cheap and are of the simpler kind. They are also a little harder to open and close compared to the other brands.

◀ The handle has a good size for our hands, but gives a plastic feel.

◀ The hinges on the case are robust, but not very wide. They are joined with a metal pin.

◀ The Explorer cases are made from a PP copolymer which gives a rigid feel. The material is relatively thick.

◀ The Explorer cases are fitted with a manual pressure valve. This solution might be more reliable than the automatic ones, but at the same time one might forget to close it.

Brand 3 - Explorer

◀ The Explorer Case solution for longer stretches of carrying is a backpack harness solution. By the look of it one get the impression that it doesn't stabilize enough against the back of the user and by that producing too much pressure on the lower back.

Brand 4 - HPRC - 2550W

Specifications

- Temp -40 -> +80
- Drop, impact, handle, water tight, UV tested.
- ATA300, IP67, STANAG4280, DS81-41 approved.
- Lifetime warranty
- Have a sustainability plan

Features

◀ The latches on the case are more basic than the other brands, e.g., Nanuk, but are easy to open and close.

◀ The handle on the case is molded in the same material as the case, with an added rubber grip. It gives a firm and good grip.

◀ HPRC uses hinges that are molded together with the base and the lid, and joined together with a stainless steel pin.

◀ The case is made from PP with an added resin branded TTX01. The material is thinner and more flexible than the competitors'.

◀ The case has an automatic purge valve. The look of it gives the impression of quality.

Brand 4 - HPRC

◀ Besides the ordinary handheld cases, HPRC offers two solutions for more ergonomic carrying. One is backpack type of hard case and the other one is a soft backpack cover for the ordinary hard cases.

◀ The special backpack model has a waist belt and looks like it can offer a user experience close to an ordinary hiking backpack. 3500 mod.

◀ The soft backpack case on the other hand looks more like a solution for shorter use cycles, while it's missing the waistband and has less padded shoulder straps

Brand 5 - B&W - Type20

Specifications

- Temp -40 -> +80
- Watertight, dustproof, airtight, shock resistant, virtually indestructible, chemical resistant and corrosion proof.
- Lifetime warranty

Features

◀ The latches are simple and a little hard to handle.

◀ The handle has a plastic feel to it. The size of the grip is good, but a little slippery and hard.

◀ The hinges are rigid, but don't stabilize the construction much.

◀ The case is made from a glossy Ultra High-Impact ABS Plastic.

◀ The case has a manual pressure valve.

Brand 5 - B&W

◀ Just like some of the other brands, B&W offer backpack solutions for their cases. One solution uses straps to fixate an ordinary case to a back plate. The other one is a soft case to put a hard case into. The one using the straps looks like a good idea, but has a low quality feel. The picture to the left shows how the hard case seams to hang a little lose.

◀ This soft case model looks stable and offers padded shoulder straps. From an ergonomic point of view the lack of back plate and the placement of the load could be questioned.

Inspiration - Backcarrying solutions

- The following pictures have mostly been taken from the internet, but some are also taken at the Photokina fair. All of them show solutions that we find inspirational for the project.

◀ This army harness offers an interesting way of flexible attachment, a solution for modularity.

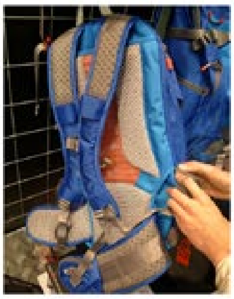
◀ One way of implementing stiffeners in a soft construction

◀ Maybe a backplate like this could be an approach for a flexible and ergonomic carrying solution.

◀ The combination of hard en soft materials creates a light and rigid construction.

◀ A well developed harness construction might be a good way to carry any type of hard case.

◀ There are also soft bags like this, that still offers water protection.



◀ This backpack has and iteresting back plate, that looks like it's offering good airflow.

◀ This bag has an iteresting handle construction, using just soft material

Inspiration - Backcarrying solutions

◀ Both these bags ▶ shows how padding can be used to create a relatively stabel and shock resistant construction.

◀ The shape of the shoulder straps on backpacks vary a lot between models, something we need to look into during our R&D.

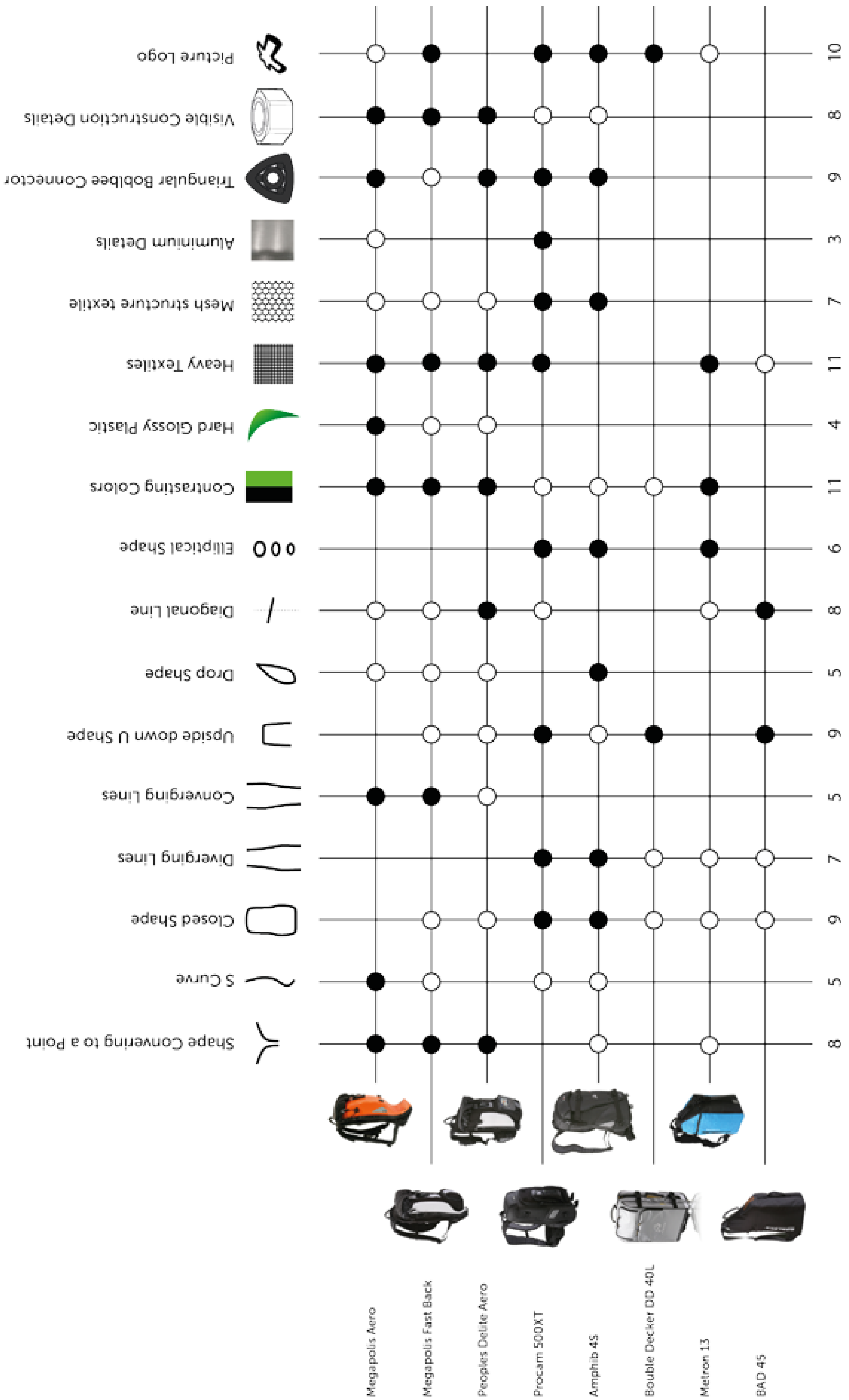
◀ This backpack uses a hard cover, but still looks very soft.

◀ • The way a backpack is attached to the body can be altered in many ways. Here is an interesting example.

◀ • This picture shows how airflow can be incorporated in the design.

◀ • Two more ▶ semihard backpacks, offering good protection, but still providing a softer user experience.

3. Design format analysis (DFA)



4. Pugh elimination matrix

PUGH MATRIX		CARRYING SOLUTION		19 nov 2012									
REQUIREMENT	**WEIGHT**	REFERENCE	FOLDING (1)	SHOULDER BAG (2)	HARD CASE, SOFT BACK (3)	SIMILAR TO TODAY (4)	HARDCASE SIDE (5)	SOFT-HARD-SOFT (6)	EX. FRAME MESH (7)	FRAME HOLD CASE (8)	BOXES (9)	ATTACH SHELL (10)	REPLACEABLE LIDS (11)
Minimise offset (5p)	5	*Existing case*	5	5	5	5	5	0	−5	−5	5	5	5
Minimise weight (5p)	5	*Existing case*	5	5	5	5	−5	−5	−5	−5	−5	5	−5
Load placement T1-T6 (3p)	3	*Existing case*	0	0	0	0	0	0	0	0	0	0	0
Ability to transfer weight (5p)	5	*Existing case*	5	5	5	5	5	5	5	5	5	5	5
Minimise lifts from ground level (3p)	3	*Existing case*	0	0	0	0	0	0	0	0	0	0	0
Allow load placement on back (3p)	3	*Existing case*	0	0	0	0	0	0	0	0	0	0	0
Minimise pressure on skin (3p)	3	*Existing case*	3	3	3	3	3	3	3	3	3	3	3
Minimise heat accumulation (1p)	1	*Existing case*	1	1	1	1	1	1	1	1	1	1	1
Carry all equipment easily (3p)	3	*Existing case*	3	0	3	3	3	0	3	3	3	0	3
Minimise risk of forgetting (3p)	3	*Existing case*	−3	−3	−3	−3	0	−3	3	0	3	−3	−3
Protect equipment from moisture (5p)	5	*Existing case*	−5	−5	0	−5	0	5	0	0	0	−5	0
Steady placement in vehicle (3p)	3	*Existing case*	0	−3	0	−3	0	0	0	0	0	−3	0
Maintain equipment upright (1p)	1	*Existing case*	0	0	1	1	0	1	1	1	1	1	1
Comfortable all types of clothing (5p)	5	*Existing case*	5	5	5	5	5	5	5	5	5	5	5
Comfortable seating opportunity (1p)	1	*Existing case*	−1	−1	0	−1	0	1	0	0	−1	−1	0
Attachment of additional equipment (3p)	3	*Existing case*	3	0	3	3	3	3	3	3	3	3	3
Quick individual adjustment (3p)	3	*Existing case*	3	3	3	3	3	3	3	3	3	3	3
Comfortable 5-95 percentile (5p)	5	*Existing case*	5	5	5	5	5	5	5	5	5	5	5
Minimise sweating (1p)	1	*Existing case*	1	1	1	1	1	1	1	1	1	1	1
Easy access to equipment (3p)	3	*Existing case*	−3	3	−3	−3	−3	−3	−3	−3	−3	−3	−3
Good usability (3p)	3	*Existing case*	3	3	3	3	0	3	0	3	0	0	3
Resist pressure changes (5p)	5	*Existing case*	5	5	5	5	5	5	5	5	5	5	5
Fit brand identity (3p)	3	*Existing case*	3	3	3	3	3	3	0	3	3	3	3
Easy disassembly (3p)	3	*Existing case*	3	−3	−3	−3	−3	−3	−3	−3	−3	−3	−3
Materials up-cycled (3p)	3	*Existing case*	0	0	0	0	0	0	0	0	0	0	0
Express safety, professionalism, comfort, active lifestyle (5p)	5	*Existing case*	−5	−5	5	0	5	5	5	5	5	5	5
Easy to put on and take off (5p)	5	*Existing case*	0	5	0	0	−5	0	−5	−5	−5	−5	−5
Total		***0***	***31***	***27***	***42***	***28***	***26***	***35***	***27***	***30***	***29***	***22***	***27***
Comment			Large flat surface for safer transport. Easy disassembly.	Quick to put on and take off. Cross stap for stability. Ability to swing around to the front (anterior).	Result very dependent on the final design of the product. Organic or cuboid shape? Materials?	Design to provide a good overview. Ability to place additional equipment on pack or hip belt.	Horizontal storage of equipment. Flat surface for steady placement. Rather heavy. Difficult to take out case from side? Less usability.	Hard case and soft cases. Allow easy access to equipment. Equipment stored upright. Ensure not too similar to Pelicase solution.	Heavy? Must be easy to adjust. External frames not used by Bobibee. Too military? Easy to attach various tools and equipment.	Difficult to deattach case? Load too far from back?	Boxes yield less risk of forgetting equipment. Difficult to access cases?	Highly dependent on design of the backpack. Shield makes access to equipment more difficult. Replace shield or pack when worn out.	Various solutions. Box in box. Allow for personalisation. Protect when needed, minimise weight by reducing protective hard shell.

5. Evaluation sheet

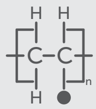
Evaluation of expression

Study the illustrations and rate your perceived impression of the product's expression

Passive	Active
Casual	Professional
Unsafe	Safe
Uncomfortable	Comfortable

6. Properties of some common plastics

PROPERTIES OF COMMON PLASTICS



POLYSTYRENE (PS)

+ Good hardness and stiffness
+ Available in many qualities
+ Low water absoption
+ Low mold shrinkage
+ Low price

- Brittle
- Low softening point
- Low resistance against oils and solvents
- Low UV resistance

ACRYLONITRILE BUTADIENE STYRENE (ABS)

+ Good mechanical properties
+ High fracture toughness and hardness
+ Possible to reinforce with glass fiber
+ Low mold shrinkage
+ Relatively low price

- Limited weather resistance
- Fracture toughness reduced when used outdoors
- Low resistance against some solvents

POLY(METHYL METHACRYLATE) (PMMA)

+ High hardness
+ Good weather resistance
+ Good resistance against oils

- Low resistance against strong acids, alcohols and acetone

POLYETHYLENE (PE)

+ High toughness in various temperatures
+ Low water absorption
+ Available in many qualities
+ Good resistance against most chemicals
+ Low price

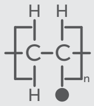
- High mold shrinkage
- Limited weather resistance
- Meachnical properties highly temperature-dependent
- Significant creep under load

ACRYLONITRILE STYRENE ACRYLATE (ASA)

+ Good mechanical properties
+ High fracture toughness and hardness
+ Good for outdoor usage

- Low resistance against solvents
- Reduced fracture toughness in cold

PROPERTIES OF COMMON PLASTICS



POLYPROPYLENE (PP)

+ High fatigue strength
+ Relatively high stiffness
+ Low density
+ Possible to reinforce with glass fiber

- Brittle below -20°C
- Poor UV resistance
- Poor resistance to oxidising acids
- Difficult to join to other PP parts using adhesive bonding

POLYOXYMETHYLENE (POM)

+ Good combination of toughness, stiffness, fatigue strength and creep resistance
+ Good resistance against moisture and chemicals
+ Close tolerances and good dimensional stability of POM products
+ Low gas and vapour permeability

- Low UV resistance
- Sensitive to cracks
- Difficult to join by adhesive bonding
- Low resistance to strong inorganic acids

POLYAMIDE (PA)

+ High fatigue strength and creep resistance
+ High wear resistance
+ Possible to use at high temperatures
+ Possible to reinforce with glass fiber
+ Good resistance against hydrocarbons, alcohols and most bases

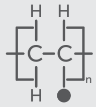
- High absorption of moisture
- Presence of moisture reduce tensile strength and stiffness
- Poor UV resistance
- Elongation varies with temperature and moisture content

POLYETHYLENE TEREPHTHALATE (PET)

+ High stiffness and hardness
+ High wear resistance
+ Good chemical resistance
+ Low water absorption
+ Good UV resistance
+ Possible to use at high temperatures

- Low fracture toughness
- Electostatic charge attracts small particles
- Warpage tendency
- Significant mold shrinkage

PROPERTIES OF COMMON PLASTICS



POLYAMIDE-IMIDE (PAI)

+ Possible to use at high temperatures
+ Good chemical resistance
+ Very low thermal expansion
+ High tensile strength, toughness and creep resistance

- Difficult manufacturing
- Some absorption of moisture
- Expensive
- Low resistance to warm acids and alkalis

STYRENE-ACRYLONITRILE RESIN (SAN)

+ Low mold shrinkage
+ High hardness and stiffness

- Some water absorption
- Discolouration when exposed to UV radiation and heat

POLYURETHANE (PUR)

+ Available in many forms and qualities
+ High wear resistance
+ High toughness
+ Flexible at high hardness
+ Good resistance against UV radiation, oils and oxygene
+ Can be combined and joined with many materials
+ Possible to manufacture at low temperature and pressure

- Curing at an elevated temperature
- Formation of toxic gases when burned

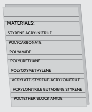
POLYETHER BLOCK AMIDE (PEBA)

+ Good mechanical properties
+ High wear resistance
+ Good chemical resistance
+ Maintained flexibility from -40 to +80°C

- Low UV resistance
- Limited resistance to acids

7. Properties of suggested plastics

PROPERTIES OF SUGGESTED PLASTICS



POM, UV-STABLISED/ SEMI-CRYSTALLINE THERMOPLASTIC

Price: 15,75 SEK/kg
Density: 1420 kg/m³
Young's modulus: 2,93 GPa
Shear modulus: 1,1 GPa
Yield strength: 69,1 MPa
Hardness (Vickers): 20,7 HV
Fracture toughness: 2,93 MPa√m

Impact strength (notced 23°C): 11,3 kJ/m²
Mold shrinkage: 2,2%
Melt temperature (injection moulding): 227°C

Additional information: opaque, used in the automotive industry, for toys, garden sprayers, telephone components and gears.

SAN, IMPACT MODIFIED/ AMORPHOUS THERMOPLASTIC

Price: 24,35 SEK/kg
Density: 1020 kg/m³
Young's modulus: 2,07 GPa
Shear modulus: 0,8 GPa
Yield strength: 37,9 MPa
Hardness (Vickers): 11,4 HV
Fracture toughness: 4,17 MPa√m

Impact strength (notced 23°C): 74 kJ/m²
Mold shrinkage: 0,6%
Melt temperature (injection moulding): 277°C

Additional information: opaque, used for cups, containers, knobs, covers and cassette cases.

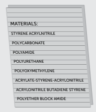
PUR, UNREINFORCED/ AMORPHOUS THERMOPLASTIC

Price: 25,85 SEK/kg
Density: 1180 kg/m³
Young's modulus: 1,69 GPa
Shear modulus: 0,6 GPa
Yield strength: 46,9 MPa
Hardness (Vickers): 19,4 HV
Fracture toughness: 3,41 MPa√m

Impact strength (notced 23°C): 24,2 kJ/m²
Mold shrinkage: 0,7%
Melt temperature (injection moulding): 260°C

Additional information: transparent, used in the automotive industry, for footwear and furniture.

PROPERTIES OF SUGGESTED PLASTICS



PC, HIGH HEAT/ AMORPHOUS THERMOPLASTIC

Price: 31,5 SEK/kg

Density: 1160 kg/m³

Young's modulus: 2,31 GPa

Shear modulus: 0,8 GPa

Yield strength: 70,1 MPa

Hardness (Vickers): 20,5 HV

Fracture toughness: 4,22 MPa√m

Impact strength (notced 23°C): 11,3 kJ/m²

Mold shrinkage: 0,8%

Melt temperature (injection moulding): 350°C

Additional information: transparent, used for safety shields, instrument castings, tableware and medical components.

ABS/PC, INJECTION MOULDING/ AMORPHOUS THERMOPLASTIC

Price: 31,75 SEK/kg

Density: 1110 kg/m³

Young's modulus: 2,52 GPa

Shear modulus: 0,9 GPa

Yield strength: 37,6 MPa

Hardness (Vickers): 11,3 HV

Fracture toughness: 2,82 MPa√m

Impact strength (notced 23°C): 36,4 kJ/m²

Mold shrinkage: 0,7%

Melt temperature (injection moulding): 282°C

Additional information: opaque, used for helmets, instrument panels and housings.

ASA/PC, UNFILLED/ AMORPHOUS THERMOPLASTIC

Price: 32,8 SEK/kg

Density: 1110 kg/m³

Young's modulus: 2,45 GPa

Shear modulus: 0,9 GPa

Yield strength: 52,8 MPa

Hardness (Vickers): 15,9 HV

Fracture toughness: 4,24 MPa√m

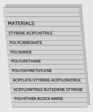
Impact strength (notced 23°C): 49,9 kJ/m²

Mold shrinkage: 0,4%

Melt temperature (injection moulding): 249°C

Additional information: opaque, used for outdoor signs, garden furniture and exterior panels.

PROPERTIES OF SUGGESTED PLASTICS



PA, 46 GENERAL PURPOSE/ SEMI-CRYSTALLINE THERMOPLASTIC

Price: 45,2 SEK/kg

Density: 1200 kg/m³

Young's modulus: 1,0 GPa

Shear modulus: 0,4 GPa

Yield strength: 54,1 MPa

Hardness (Vickers): 16,2 HV

Fracture toughness: 3,22 MPa√m

Impact strength (notced 23ºC): 31,8 kJ/m²

Mold shrinkage: 1,9%

Melt temperature (injection moulding): 316ºC

Additional information: opaque, used for power tool housing, kitchen utensils, gears and combs.

PEBA, SHORE D65/ THERMOPLASTIC ELASTOMER

Price: 52,9 SEK/kg

Density: 1010 kg/m³

Young's modulus: 0,41 GPa

Shear modulus: 0,1 GPa

Yield strength: 17,0 MPa

Hardness (Vickers): 5,1 HV

Fracture toughness: 2,53 MPa√m

Impact strength (notced 23ºC): 595 kJ/m²

Mold shrinkage: 1,2%

Melt temperature (injection moulding): 261ºC

Additional information: transparent, used for soles, shells for boots, shock-absorber parts and breathable films.

8. Moodboard