A METHOD FOR COMPARING CONCEPTS WITH RESPECT TO SUSTAINABILITY AND OTHER VALUES (AS SUBMITTED TO TOOLS AND METHODS FOR COMPETITIVE ENGINEERING 2014 CONFERENCE)

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Abstract

Selecting concepts involves challenging decisions because decision-makers must consider many factors and the implications of the selection are far-reaching and unknown. As markets become increasingly sustainability-driven, bringing sustainability considerations into the decision is necessary. This is challenging due to the complexity of the concept of sustainability and it being unfamiliar to many decision-makers. In this work we therefore aimed to develop support for helping decision-makers to consider sustainability when selecting a concept. We undertook a case study where we studied decision-makers selecting a road construction process. Then we developed a method of support to help these decision-makers to select a process. The developed method helps decision-makers consider sustainability aspects when selecting concepts. The method supports decision-makers to compare alternatives by using indicators that are based on the values of actors in the extended value network. Global society is included as an actor who values development that is more sustainable. We modelled and visualised the outputs from the developed method in order to support decision-makers in the case study with their specific decision. Early indications from our testing are that the method and general approach could be useful for decision-makers wanting to consider sustainability in concept selection.

KEYWORDS

Sustainability, sustainable product development, value, value-focused, concept selection, decision-making.

1. INTRODUCTION: DECISION-MAKING IN COMPLEXITY, BASED ON WHAT IS VALUED

Selecting which concepts to invest in can be challenging; even more so when you want to include sustainability in your decision. As the public road authority in Sweden, Trafikverket must face this challenge and include sustainability in their decision-making [1]. The nature of sustainability is complex; it relates to social and ecological systems, and includes considering not only current global issues, but also potential future issues. Wrestling with the complexity of sustainability is also relatively new for decision-makers (compared to cost and risk, for example). In this type of decision-making context - complex and un-familiar - decision-makers are particularly prone to relying on decision heuristics (decision-making shortcuts that are useful for routine decisions), resulting in systematic errors and biases [2, pg 25]. We therefore think that including sustainability in their decision-making is a challenging task for decision-makers and hence they could benefit from support for selecting between concepts.

When providing support to decision-makers, we need to be careful with how decision-makers consider sustainability in relation to other factors. Considering aspects of a selection decision before other aspects can sway a decision-maker's preference. Similarly, the order in which support presents information can also influence decision-makers. [3, 4] For example, if asked to consider risk prior to considering sustainability, decision-makers are susceptible to giving more importance to risk than they would if they were to consider sustainability first. This effect is worse when decision-makers have little experience with the subject, for example, with emerging sustainability considerations. [5] We thus consider it important that sustainab-

ility is considered at the same time as other aspects or concerns during concept selection, and not as an afterthought.

When selecting concepts, decision-makers not only need support to help them include sustainability alongside their other concerns, but also to consider their full range of concerns. When faced with complex trade-offs, such as selecting concepts with respect to sustainability and other considerations, decision-makers generally lack the ability to consider their full range of concerns and therefore tend to base their decisions on only a subset of what they value [6]. Value-focused thinking is an approach designed to help by getting participants to think about all their values and then make the decision based on these values [7]. There are many studies that show that decision-makers often do not make decisions in this value-focused way [8]. It is therefore important that, for these kinds of complex decisions, decision support provides an explicit emphasis on values and value trade-offs [7, 8].

When we use the term *values*, we mean those things that the value network actors want (what they value) that are related to the particular decision under focus. This could include more tangible values such as cost and less tangible values such as perception. We chose to focus on value in order to help decision-makers take a more holistic perspective (focused on what they and others really want [2, pg 6]) and select alternatives that provide greater value to actors within the value network (including intangible values), rather than alternatives only meeting (tangible) requirements. (Value network actors are people or organisations that contribute to the decision or are impacted by it.) Starting with what is valued is in line with value-focused thinking [7] and the value model [9], and is related to value-driven/ centric design [10] and analysis [11].

In summary, we wish to support decision-makers to carefully construct their preferences during the decision-making process and to do so based on what they all value. As part of this support, we intend to help decision-makers to consider sustainability side-by-side with their other values. The challenge therefore becomes: *How could an approach focused on values be used to support decision-makers, who are selecting concepts, to consider sustainability alongside other things that are valued by value network actors?*

2. RESEARCH APPROACH: DESIGN RESEARCH METHODOLOGY WITH A CASE STUDY

We wanted to understand how to support decision-makers with concept selection and we had the opportunity to provide support selecting concepts. We therefore chose Blessing and Chakrabarti's design research methodology [12] because guides researchers to understand the system and situation, to develop support for improving the situation and then to evaluate results.

In order to develop our understanding of the system, we wanted to explore a relevant and contemporary case. We also wanted the opportunity to test our ideas for supporting decision-makers with including sustainability when they select concepts. We therefore used a case study to help us dig into the challenges being faced by a group of decision-makers, to help us create relevant and useful decision support, and then to provide a testing arena for evaluating our decision support. This contemporary and real-life nature of our study, along with the boundaries between decision-makers and decision process being unclear are in line with Yin's reasons [13, ch. 1] for using a case study.

In section 2.1, we outline our research methods, mapped onto the structure of the design research methodology, and in section 2.5, we describe our case study.

2.1. Research methods

In line with Blessing and Chakrabarti's methodology, we carried out the following three types of activity: (1) an initial descriptive study to understand relevant research areas, and the particular decision and surrounding context of the case study, (2) a prescriptive study to develop support for decision-makers in the case study, and (3) a second descriptive study to start evaluating the tool and method. We began with the initial descriptive study and then iterated between all three studies, particularly regularly between developing and evaluating our support. In the following subsections, we outline the methods we used for each type of activity.

2.2. Initial descriptive study - understanding relevant research and the decision system

We reviewed decision science and value innovation literature and read literature and documents on sustainability considerations in road construction. We also looked at popular articles and government reports on the challenges in road construction projects. Within the case study, we studied documents and interviewed

decision-makers and experts in order to develop our understanding of the road construction process, the decision-making and what the decision-makers value.

2.3. Prescriptive study - developing the support

We developed the support by exploring a few alternative designs and learning from relevant research areas. The research areas included decision-making for sustainability, how to visualise information, value focused approaches, sustainability indicators and lifecycle assessment. Our result is support in the form of a *method*, which we explain in section 3.

2.4. Second descriptive study - starting to evaluate the support

We focused this evaluation on assessing usability and applicability, and suggesting improvements, which corresponds to the evaluation of application of the proposed changes in the design research methodology. This evaluation meant we studied how we could make the support easier to use and how to better help users to achieve the longer-term objective of making their concepts and system more sustainable.

In order to assess and improve this developed method we applied the method to the case study. We, the researchers, used the method to support decision-makers for the specific decision in the case study. As explained in section 3, the final step of the method is to model relationships and visualise results in order to support a decision, and so every time we did the last step of the method, we created or evolved those models specific to the case study decision.

As we applied the method, we noted our real-time observations on what worked well, challenges and ideas for improvements. We then incorporated some of these improvements in the next of many small iterations of developing the method. During development, we discussed our method and prototype tool in person with a representative from Atlas Copco and some of the components were discussed via email with a former employee of Trafikverket (who is an expert in the technical aspects of the active design decision). In addition, we presented (in person) the prototype (as described in section 4.2) to the same Atlas Copco representative as before and to the wider project group. We also provided supporting written documentation to Atlas Copco. We solicited feedback from all parties. We included the results of this evaluation in the development of the method and prototype, except for the current set, which are reported in section 5.

2.5. Case study: selecting a road construction process

"The largest causes of loss [in Swedish construction projects] relate to lack of knowledge, lack of geo-information and decision-making processes"
according to respondents of the Swedish Geotechnical Institute's survey [14, p. 19].

In Sweden, Trafikverket are the national authority responsible for providing roads, including managing the construction of new roads. This is a challenging responsibility, as illustrated by the various accidents and their causes captured in the Swedish Geotechnical Institute's recently published report (on construction in general, including road construction) [14]. Due to the large losses associated with these accidents and with project delays, Trafikverket are under pressure to provide higher quality roads that lead to fewer problems during use and to deliver these through construction projects with fewer delays and unexpected costs. Meanwhile, society is also demanding that they do it in a more sustainable way.

Trafikverket have identified a potential solution to the challenge of improving the road construction process: active design. In active design, information gathered in one step of the construction process is used to design the next part. For example, the thickness of the pavement (top layers of the road) can be designed after measuring the strength of the previous layers.

Atlas Copco AB is a Swedish company who, under their Dynapac brand, have developed a tool for measuring, recording and displaying the relative strength of layers as these layers are compacted by a large rolling machine. This tool, the Dynapac Compaction Analyser, is therefore useful in active design, for example for identifying weak areas in layers of the road, which can then be strengthened before moving to the next step in the construction process. Atlas Copco also recognise the importance of sustainable development and see potential in their solution and active design to help make road construction more sustainable.

There thus emerges a decision: whether to use active design, with the Dynapac Compaction Analyser, or keep to the current road construction process. No-one was clear on whether active design would really improve road construction in terms of the various considerations, such as whole life cost, safety and sustainability. This decision is the focus of the case study.

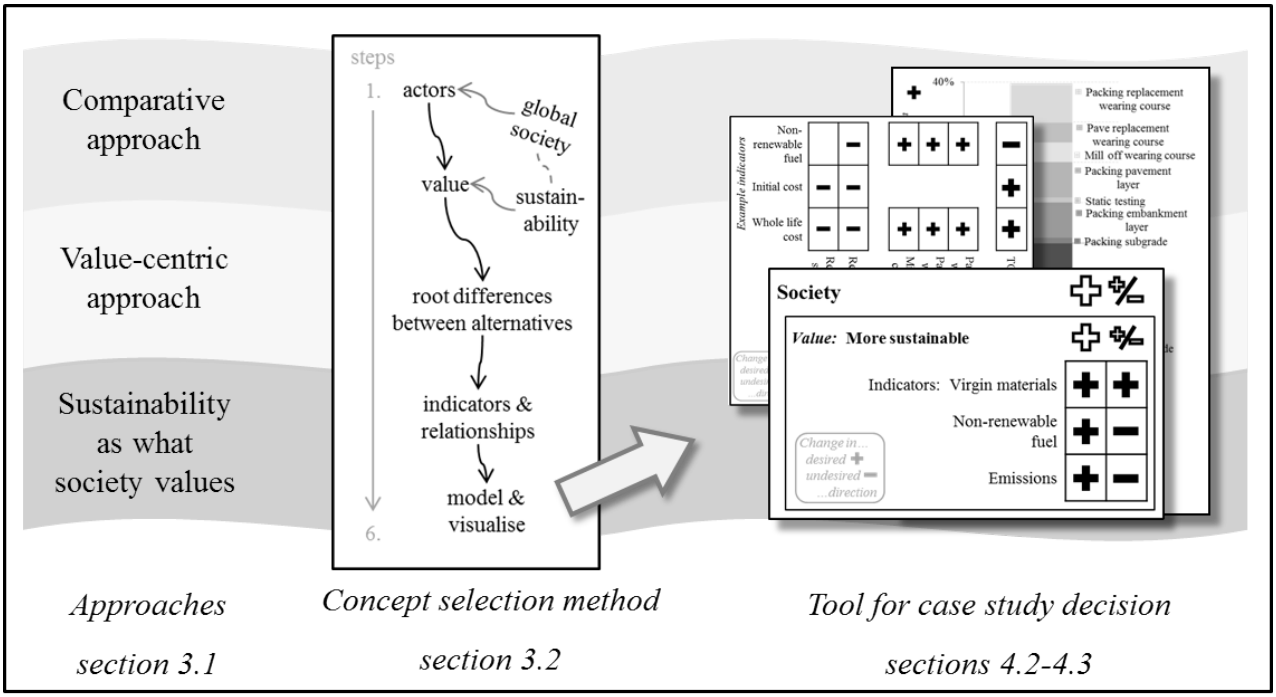

Figure 1 We combined three approaches (section 3.1) to develop our concept selection method (section 3.2). The prototype tool (sections 4.2–**??**) was a result of applying our method for the active design decision.

3. RESULTS: APPROACH AND METHOD

There are three types of result - the method that we developed, the approaches on which we based the method, and the prototype tool resulting from applying our method to the case study - as illustrated in figure 1. In this section, we introduce the approaches (section 3.1) and detail the steps in the method (section 3.2). (There is a further type of result - the evaluation of the method - which we share in section 5.)

3.1. Comparative, value-centric approach that includes global socio-ecological sustainability

Comparative approach

We propose a comparative approach, where applying the method results in a comparison of alternatives, rather than some absolute measurement. For example, the method helps decision-makers to identify and communicate which option is relatively more sustainable and which has relatively lower whole-life cost, rather than some absolute sustainability measurement and the exact whole-life cost.

By taking a comparative approach, decision-makers can scope down the decision to only those things that vary between the alternative concepts. For example, when considering the steps in the road construction process (in the case study), we were able to disregard the early step where the subgrade is cut out because the alternatives do not differ for this step. Furthermore, we urge decision-makers to scope down the system under consideration in order to reduce the number of factors that need to be considered for the comparison.

We also employ a comparative approach to help decision-makers to mitigate their evaluability bias. Decision-makers are prone to focusing more on the easy-to-evaluate attributes (such as cost) than the difficult-to-evaluate attributes (such as long-term sustainability implications), unless they are provided with suitable reference information to help with the difficult-to-evaluate attributes. This bias occurs even when the difficult-to-evaluate attributes are more relevant to the decision, and evaluability bias can lead to the decision-maker preferring the easy-to-evaluate option [15]. We therefore think it important to provide a way of comparing alternatives [5], rather than asking decision-makers for their preference for a lone option.

Value-centric approach

With a value-centric approach, decision-makers create a model of the values in the system and then use it to rate the relative attractiveness of alternatives (our definition based on value-focused thinking [7] and Richardson et al.'s definition of value-centric analysis [11]). It is important for the decision-makers

themselves to decompose the values and relate them to facts/consequences for the various alternatives. Doing this is considered an important cognitive aid [2, pg. 24] and is something that is often missing from simple, traditional matrix-based analysis methods that are often used for concept selection.

We believe that using the identified values to develop indicators (rather than selecting from lists of existing indicators) increases the chance of completeness and helps the user and actors to understand which indicators are interesting to which actors. It also helps the user to scope to only those indicators that are relevant, particularly when considered for only what differs between the alternatives. One limitation is that expert input may be required in order to develop the particular indicators for each type of values. However, expert input is not uncommon, with cost modellers providing specific cost indicators and values, and so hopefully it would not be a big problem.

Value-focused structured decision-making methods have been designed and used for complex decisions that involve sustainability, for example [2, 8, 16]. However, we have not found examples for product development decisions, or for selecting concepts in particular. There is also support for value-driven product development. Linstedt and Burenius' value model [9]aims to support focusing on value creation when running a development project, but it contains very little detail on how to select concepts (pg. 474). Collopy and Hollingsworth's value-driven design [10] aims to encourage engineers to consider monetary value in addition to functional performance, but is limited to monetary value and does not seek to support decision-makers in identifying the full range of what is valued. We have therefore identified a need for value-centric support for integrating more sustainable development into concept selection decision-making.

We developed such a value-centric approach and integrated sustainability by including it as what global society values. Our aim was for decision-makers to incorporate global socio-ecological sustainability in their decision-making and to consider it alongside other factors (see introduction). To achieve this, we include more sustainable development by incorporating global society as an actor and capturing *more sustainable* development as what society values. Although all the actors are members of society, an actor perhaps does not consider their perspective as a member of society when representing their organisation, and so we give them a nudge to do so.

Definition of global socio-ecological sustainability

In order to include *more sustainable* as a value and identify related indicators, we needed a way of identifying what is *more sustainable*. We also needed to find a way that enables decision-makers to compare the alternatives with respect to sustainability as easily as they could with respect to the other factors. Without suitable points of comparison, decision-makers will tend to focus more on the things that are easy-to-evaluate (such as cost) and less on those that are more difficult, even though they may be more important for that particular decision [15]. We therefore needed a way to consider sustainability that is highly usable in the decision-making process.

We chose to use the definition of sustainability provided by the sustainability principles given in Robèrt et al.'s framework for strategic sustainable development [17]. This definition of sustainability is built upon an identification of the upstream causes of unsustainability for the global ecological and social systems. By identifying the upstream causes of unsustainability, rather than downstream impacts of these activities, Robèrt et al. attempt to provide a holistic view that also allows for unknown sustainability impacts. We considered that the holistic and global socio-ecological nature of this definition was well matched to what we needed for a definition of sustainability being what global society values. It has also been developed, tested and refined by researchers and sustainability practitioners for over 20 years [18, pg. 4].

Robèrt et al.'s four sustainability principles are that, in a sustainable society, nature is not subject to systematically increasing... (1) ...concentrations of substances extracted from the Earth's crust, (2) ...concentrations of substances produced by society, (3) ...degradation by physical means, and, in that society, (4) people are not subject to conditions that systematically undermine their capacity to meet their needs [17]. Robèrt et al. also designed the principles in such a way as to enable users to determine how an activity is contributing to unsustainability. We therefore wished to try using them to help decision-makers understand which alternative is *more sustainable*.

Although the principles can be used to determine whether and how an activity is contributing to unsustainability, an analysis must be performed in order to achieve this. The principles are not indicators, but rather a tool for analysing how an activity contributes to the upstream causes of unsustainability. Using them therefore requires effort and, arguably, specialist skills.

We thus needed to find a way of making the use of this definition of sustainability more functional for the value-centric comparison of alternatives, such as developing indicators.

We considered existing indicators associated with the sustainability principles to be unsuitable for inclusion for inclusion in our method. Azar et al. created a set of indicators for the sustainability principles [19]. These indicators are at a societal level and are more complicated than is required for indicators that are used to compare (rather perform an absolute measurement). Others have used the sustainability principles to develop indicators specific to their context or question, for example, Sokka et al. developed indicators for assessing industrial symbiosis [20]. Thompson et al. developed a method that includes listing current sustainability criteria/indicators, using the sustainability principles to add to the list of criteria and then rationalising and converting the list into a sustainability compliance index (steps 1–2 of their method) [21]. Since Thompson et al.'s method starts by collecting whatever indicators are already being used, it does not easily fit a value-centric approach. In addition, Thompson et al.'s method is under development and needs further work before it can be used. In summary, no suitable existing indicators related to Robèrt et al.'s principles were found.

Since no suitable set of indicators existed, we developed our own way of converting *more sustainable* as a value into something more tangible. We propose using the sustainability principles to analyse the differences between the alternatives being compared. This includes performing a sustainability life cycle analysis of physical goods used in the activities being compared. A sustainability life cycle analysis[1] is where the sustainability principles are used to analyse each life cycle stage in turn [22] and is often communicated as a table with life cycle stages along one axis and sustainability principles along the other.

3.2. A six-step method

The developed method centres on identifying and modelling the relationships between the actual things that differ between the alternatives and what the actors value. The method comprises the following steps:

1. Identify the selection decision.
2. Identify the value network actors.
3. Identify the functional, economic and emotional values for each actor.
4. Scope down the things considered in the decision to only what is different between the alternatives.
5. Use the values to analyse the differences between the options and so develop indicators and root variables.
6. Model relationships and visualise the results.

A user is likely to iterate between the steps. In steps 2, 3 and 5, a user will have to make scoping decisions, for example, about how many actors or indicators to include. It would be ideal to include all information, but this is not possible and so a user must limit the scope while trying to include as much as possible.

The six steps

In the following paragraphs, we describe each step in more detail and in section 4.1 we illustrate the steps with examples from the active design case study.

Step 1: Identify the selection decision. **(a)** Identify the concept selection you wish to make. **(b)** Then identify the alternative concepts. There must be at least two concepts, one of which could be the current process, system or product.

Step 2: Identify actors in the value network. **(a)** List individuals, groups or organisations involved in making the decision or are likely to be impacted by it. It may help to consider those actors who influence or are affected by the delivery of each concept. (See Peppard and Rylander's step 2 [23] for inspiration for how to identify value network actors.) **(b)** Add (global) *society* to the list in order to include those who could be affected by the sustainability aspects of the decision. Adding society is an integral part of this method.

Step 3: Identify the functional, economic and emotional values for each actor. **(a)** Use Tan et al.'s [24] approach to identify what each actor values - what they consider most important - in the specific context of this concept selection decision. The statement of the value should include a desired direction. We chose to use Tan et al.'s approach as a means to support users to more completely identify what is valued by value network actors. **(b)** Ensure that *more sustainable* is captured as what the global society values.

Step 4: Scope down the things considered in the decision to only what is different between the alternatives. Delineate the alternatives and

[1] Also known as sustainability/strategic life cycle assessment and strategic life cycle management.

scope down the decision to only comparing what differs between the alternatives. It may be necessary or helpful to break down the alternatives into similar parts such that the comparison can be made for each of these parts.

Step 5: Use the values to analyse the differences between the alternatives and so develop indicators and root variables. Use the sustainability principles to analyse activities, including life cycles. **(a)** Consider each value in turn, and for each part in turn. Identify what causes changes in the value and what might indicate changes in the desired/undesired direction for the value. These things that indicate changes in the desired/undesired direction for the value are your indicators. For the value *more sustainable*, use the sustainability principles and comparative sustainability lifecycle assessment (see section 3.1) to analyse each part. **(b)** Then identify what these indicators are dependent on. Continue until you identify the root things that change - these are your root variables. Record the relationships between the root variables, indicators and values. Various tools could be used to calculate how indicators vary with the root variables, for example cost modelling. Note that in this step you are not analysing the alternatives, but rather analysing the differences with the intention of developing a set of relevant indicators.

Step 6: Model relationships and visualise the results. **(a)** Take the indicators and root variables identified in step 5 and model the relationships between them. Add the required raw data. If you want to be able to sum across different parts, then the data must be quantitative and relative, usually absolute. **(b)** Visualise the results for the indicators, for each comparison being made. Present the indicators simultaneously in order to help mitigate bias towards the first indicator displayed and to make explicit any trade-offs. Decision-makers will then be able to use the output of this step to examine trade-offs and understand how the alternatives compare.

4. RESULTS: CASE STUDY

In this section, we share some examples from applying the above-described method in the active design case study. In section 4.1, we give examples from each step and in section 4.2, we describe the prototype decision support tool we created in step 6.

4.1. Sample of results from using method in active design decision case

The following list gives some of the results from applying each of the six steps of the method.

1. Which *road construction process* do we prefer? Alternatives: active design and the current road construction process.
2. Atlas Copco, road builders, Trafikverket, road users and society.
3. Society: More sustainable. Trafikverket: Lower or constant initial cost; . . . increased perception by society of how sustainable are Trafikverket.
4. We excluded the early steps of the road construction process that were the same in both the current process and in an active design process. We chose how to break down the process into steps by identifying 'natural' steps in the process and by understanding (during step 5) how far the process needed to be broken down into steps such that participants could consider that step in isolation.
5. The difference in initial construction cost between the two alternatives is given by summing the differences (between the alternatives) for all the costs included in the initial constructions phase, such as personnel costs and fuel costs. The difference in man hours and in fuel usage (between the alternatives) are directly proportional to the difference in time spent on an activity and difference in cost of fuel, among other things. These are then given by:

$$\begin{aligned} &\Delta fuel\_costs_{step} \\ &= cost_{unit\_of\_fuel} \cdot \Delta amount\_used_{step} \\ &= cost_{unit\_of\_fuel} \cdot fuel\_usage\_rate \\ &\quad \cdot \Delta activity\_duration_{step}. \end{aligned} \tag{1}$$

Here, $\Delta activity\_duration$ is a root variable, $cost_{unit\_of\_fuel}$ is a coefficient and $\Delta Initial\_construction\_cost$ is an indicator.
We had to find ways of facing the challenge of missing data. For example, considering the value *more sustainable* for the paving step. The paver (machine) would be used more for active design than it is for the current process. Therefore, there are more of all the paver lifecycle issues because more pavers are used. For example, more virgin materials used due to the construction of more pavers and more CO_2 emissions from increased usage. Turning the second example

into something measurable was easy (easy to sum with emissions due to other sources). The first was a little more difficult because we needed to have data that it is not readily available. Rather than measure it directly, we calculated the change in the proportion of the usable lifetime of the machine that is 'used up' in a particular step. And then, we could use the relative weight of the machines and an assumption that the machines have an equal proportion of material that is virgin to indicate relative use of virgin materials and thus sum across different machines and steps.

6. We modelled the relationships and visualised the results in a simple Microsoft Excel file, thus creating a prototype decision support tool for this decision. Figure 2 is a simple representation of the prototype, where the boxes represent modules that perform simple operations on the inputs (shown as lines). Example operations are summing together and multiplying by a coefficient.

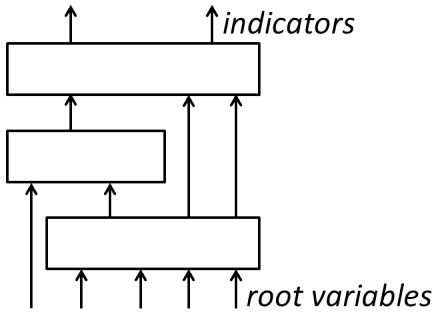

Figure 2 Architecture of the case study prototype.

4.2. Four views for comparing the road construction process options

We created the following four views, which show increasing levels of detail to the decision-makers:

- Dashboard (summary)
- Time breakdown
- Proportional breakdown
- Time and indicator breakdown.

The dashboard is a summary view from the perspective of each actor. This is a summary of what is important to them, and so a starting point for discussion. Under the heading of each value, names of related indicators are listed. The symbol in the box next to each name indicates a change in the desired direction ('+') or the undesired direction ('-') with respect to a move from the current construction process to active design. There are also symbols next to the value titles. These symbols represent a compilation of the related indicators, where '+' shows that all related indicators are '+', '-' shows that all related indicators are '-' and '+/-' shows that the related indicators are a mixture of '+' and '-'. This middle, '+/-', state is required because many indicators cannot be summed together into another indicator (for example, emissions cannot be summed with uncertainty), but it is possible to use the symbols to communicate whether all the indicators show a change in a particular direction (that is, it is all good news, all bad news, or something in between). In a similar way, the symbols next to the actor name show a compilation of the values for that particular actor. An example dashboard (simplified for this paper) is shown in figure 3.

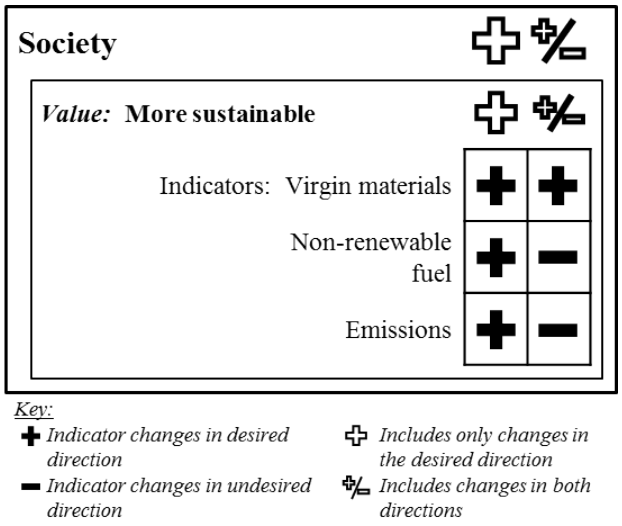

Figure 3 Simplified dashboard view for society: changes in the desired or undesired direction of the indicators that are related to what society values - being more sustainable. The two columns of indicators are for the two types of active design.

On some dashboards, an indirect value is included. A value is indirect when an actor values what another actor perceives or experiences. For example, if all of Trafikverket's indicators are '+', then the symbol for the road users' indirect value *constant or lower taxes* would also be '+'. (The setup of indirect values is relevant to the current arrangement of value actors. This could change in the future through changes in the value flow between actors.)

The time breakdown view provides more detail for the indicators shown on the dashboard. An example (simplified for this paper) is shown in figure 4. This view shows whether the change for an indicator is in

the desired or undesired direction for each construction process step. A user can thus see when initial investment (of, for example, materials, energy or money) pays off in the repair steps. Note that the '+'/'-' shows only a change the desired/undesired direction for that specific indicator and for that specific step and does not show the magnitude of the change. Therefore, a '+' does not automatically cancel a '-'. This view is designed to help users to start to understand why an indicator on the dashboard is '+' or '-'.

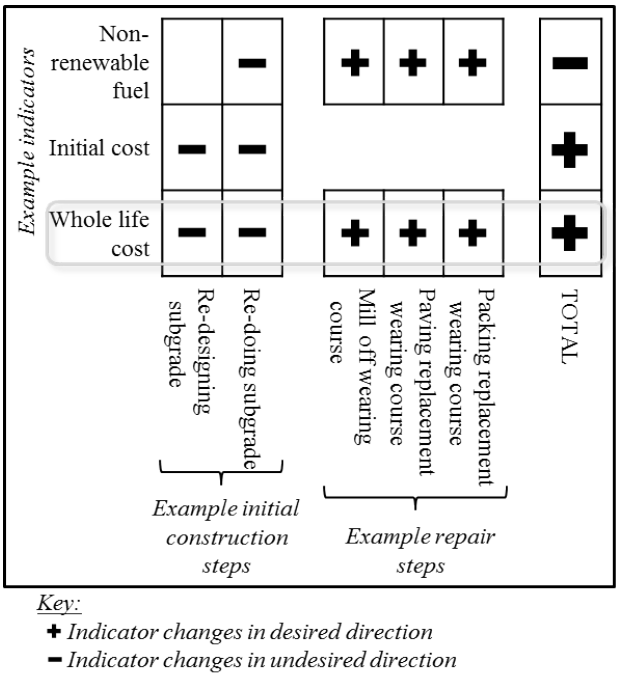

Figure 4 Simplified time breakdown view: example indicators broken down over example steps.

The proportional breakdown view provides yet more detail. An example (simplified for this paper) is shown in figure 5. Whereas the time breakdown view showed whether or not the contribution from each construction process step was in the desired direction, this view shows the proportional contribution of each step, that is, this view shows the magnitude of each '+' or '-' in the time breakdown view. For example, from figure 5, a user could understand that figure 4 showed non-renewable fuel as '-' for only one step (redoing the subgrade) and yet had a '-' total because the additional non-renewable fuel used in redoing the subgrade is larger than the sum of all the reductions achieved in the other steps ($\sim -60\%$ versus $\sim +40\%$). This view can help users to further understand and support discussions of the trade-offs (within indicators) between different steps of the process.

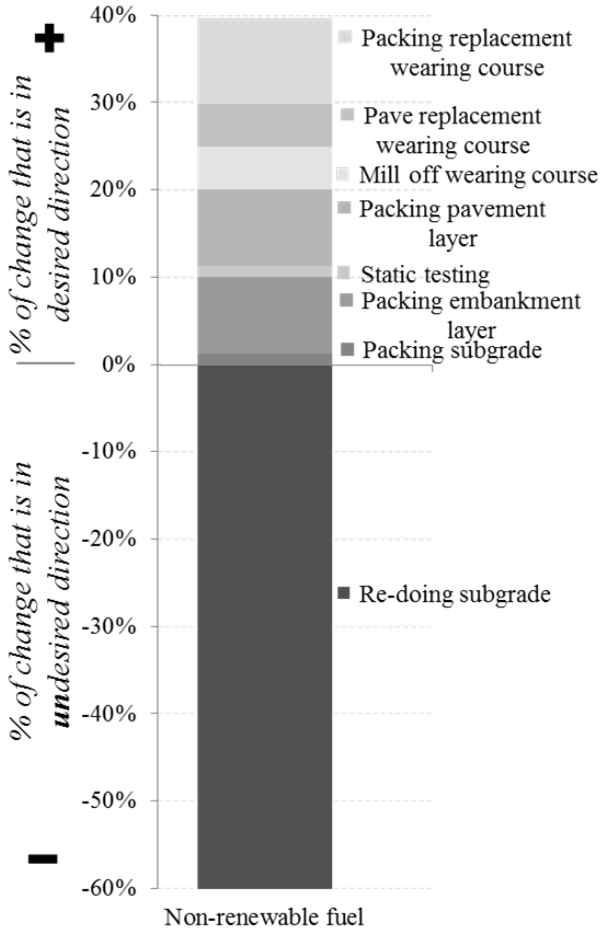

Figure 5 Simplified proportional breakdown view: proportional contribution of each step to the total for an example indicator.

The time and indicator breakdown view provides more detail on the indicators. It is similar to the time breakdown view, but here the indicators are also broken down into their component indicators. For example, this view shows the different cost indicators that are summed to give whole life cost. This view thus helps users to further understand why the dashboard view indicates that they get higher or lower value from the proposed change.

4.3. Using the prototype

The result of the case study was the above described prototype decision support tool. This prototype has since been used by Atlas Copco to facilitate internal explorations and for supporting a meeting with their customers' customer (in Sweden), Trafikverket. They were able to explore and discover, for example, that in a case where little of the initial subgrade is weaker than desired, both types of active design deliver more value than the current construction process, whereas in the

case where a large proportion of the initial subgrade is weaker than desired, the type of active design where the subgrade is re-done is less sustainable and causes more disruption to the road user, but is still more valuable in all other ways. More importantly, Atlas Copco saw the explicit trade-offs and how design choices were related to values (through the modelled relationships) and were able to use that in their discussions.

5. EVALUATION RESULTS AND SUGGESTIONS FOR IMPROVEMENT

We learnt that our method is highly usable in some regards and not so usable in others. From applying the method on the active design decision, we found evidence that it was straightforward to follow the steps and the general approach. For example, one stakeholder in the case study said "the systematic and comparative approach is pragmatic". However, we also experienced that it could be difficult to get data and understand the relationships for less tangible aspects. Indeed, the main negative feedback on our prototype tool was that the inputs were too complicated. Despite these difficulties with complicated data sets and relationships, we believe that, through trying to find this data and define relationships based on what actors value, decision-makers could develop a deeper understanding of the less tangible aspects of the system(s) surrounding their concept selection. For example, they might gain a deeper understanding of risks and sustainability considerations. We think that this deeper understanding, even if the model is not 'complete', would support improved decision-making.

Regarding applicability, we found indications that our method helps users to do what we think will help them to improve their decision-making with respect to sustainability and other things that they value. In the case study, the method did help us to compare alternatives and it helped us to compare with respect to sustainability, safety and whole life cost, for example. The method urged us to consider the sustainability aspects alongside the other factors, including encouraging us to display the indicators side-by-side. One stakeholder from the case study said that the way the results were displayed in the prototype tool allows users to make their own assessment of what an indicator means to them and how they value the indicator result in comparison to the other indicators.

In feedback, case study stakeholders emphasised that they think our method supports improved decision-making with respect to sustainability because the method helps decision-makers to highlight more than just economic benefits and to "get all stakeholders in the spotlight". After testing with the case study, we believe it is useful that the method works at a general enough level to be adapted to an organisation's cultural and operational needs. However, this means that users always have to put in effort to reach tangible and functional results for a specific concept selection.

6. DISCUSSION AND CONCLUSION

6.1. A promising method that addresses the research aim

In line with our research aim, we developed a method that centres on what is valued by decision-makers and other value network actors. We believe this method could support decision-makers who are selecting concepts to consider sustainability alongside other factors, which is also in line with our aim. The method provides this support by asking decision-makers to:

- *compare alternatives*,
- develop *indicators* that are both based on what value network actors *value* and relate the differences between the alternatives to what the actors value, and
- incorporate global society as an actor who values *more sustainable* development.

By comparing alternatives, rather than considering a concept in isolation, we aim to persuade decision-makers to reduce the scope of their decision to only what differs between the alternatives and to avoid some of their bias for the information they consider first. By developing indicators based on what they and other actors value, rather than choosing from a (very long) list of existing indicators, we want decision-makers to create indicators that are relevant to them and their particular decision, thus limiting the set of indicators to include only what is important to these value network actors. By incorporating 'more sustainable' as a value, we seek to encourage decision-makers to consider sustainability in the same way as the (other) things that they value. We wish to encourage decision-makers to do the above so that what they consider is reduced to only what is relevant to this decision and so that sustainability is included alongside other things that are valued. We hope that the decision-makers will therefore begin to understand and face any trade-offs between all the things that value network actors value, including having a better (or less bad) impact on (the sustaining of) global society.

The method *supports* decision-makers to compare the alternatives and therefore make trade-offs and ultimately decide; the method does not make the decision for the decision-makers. This is in-line with the use of modelling in structured decision-making to provide insights, not answers [2, pg. 23–24]. Modelling encourages explicit definition of relationships between values and consequences and including interdependencies. It enables peer review and another opportunity for insights into consequences. [7]

We designed the method based on literature. Furthermore, we consider that our case study results show promise that the method might prove useful.

6.2. A single, limited case study

We are the only ones who have tested the method, and we have only tested it in one case study. In addition, we did not support the case study decision-makers throughout their decision-making process, as we suggest in the method. Instead we performed the steps, using information solicited from two value network actors, Trafikverket and Atlas Copco. Even though Trafikverket have the most power in this decision, Atlas Copco were most involved in our study. However, although we did not complete all the steps with all the decision-makers and had only a little contact with the most powerful decision-maker, this is a real decision and Atlas Copco wanted us to focus on this decision because they want to understand the decision, from a sustainability perspective and from other perspectives, and to be able to discuss it with Trafikverket.

6.3. A study generally consistent with others

We considered a decision in line with Payne et al.'s three basic components [3, ch. 2]: the alternatives (our step 1), relating actions to outcomes (step 5) and the values associated with the outcomes (steps 3-6). In addition, the way that we identify actors and what they value has parallels to Peppard and Rylander's approach [23] when analysing value networks. Our work is also aligned with Zhang et al.'s work [25] on adding a value-focused perspective to requirements engineering. However, Zhang et al. focus more on analysis and not so much on the decision-making process, and do not explicitly address sustainability. We think that there is a lot of potential for combining our and their approaches, but unfortunately only became aware of their work after we had finished our study.

Hallstedt et al. [26] also consider both value and sustainability within the context of product development. We are consistent with their use of modelling, even in early phase decisions, to encourage decision-makers to explicitly state assumptions. However, our method is not consistent with how they assess value and sustainability consequences. They do not consider sustainability alongside the other values, but separately. Our and their methods probably differ due to different purposes.

Our method makes users break down their complex decision into more manageable steps and encourages them to use particular techniques to help mitigate their bias, and thus is in line with Arvai et al.'s suggestions for sustainability decisions [5]. However, our method differs from their proposal to identify values before identifying alternatives. Identifying values before identifying alternatives is an approach also supported by value-focused thinking [7]. We chose instead to introduce alternatives before values because decision-makers may find it difficult to identify value network actors if there are no concepts. However, we do encourage users to iterate between the steps, including defining the alternatives and identifying values.

6.4. Conclusion: A promising approach

Integrating sustainability considerations into decision-making by focusing on what is valued is the novel aspect of the approach we present in this paper. In order to compare concepts, decision-makers use what is valued, by decision-makers and by those impacted by the decision, to develop indicators. Our approach includes incorporating sustainability considerations alongside other factors by framing sustainability as being what society values. We undertook a case study based on a national road authority's decision of whether or not to pursue active design in road construction, and with significant input from a major industrial partner specialising in road construction technology. Our testing in this case study demonstrates the potential of the proposed approach to support decision-makers aiming to select concepts that are both more sustainable and more competitive. Additional research and application of this approach will be helpful in refining it further.

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