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The SUSTAIN-DSS model for Sustainable Transport Assessment

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Abstract

Sustainable Development and Decision Support are two conceptual 'procedures' which are not yet aligned. Sustainability has been a buzzword used by politicians, planners and stakeholders for enabling a trend towards the sustainable society. It is generally expected that the three dimensions of the economy, society and the environment must be included in any measurable sustainability path. However these do not provide much guidance as to how to prioritize impacts within and between the dimensions. A conceptualized approach to sustainability based on the nested model is therefore presented seeking to provide an alternative approach to sustainable transportation assessment, namely the SUSTAIN DSS model. This model is based on a review of basic principles of sustainability presented by the Brundtland Commission report, and operationalized by the use of Multi-Criteria Decision Analysis (MCDA) and the Analytic Hierarchy Process (AHP). The planning and decision-making process related to the new connection across the Roskilde fjord in Frederikssund is used as a case study. It is found that the SUSTAIN DSS model provides a foundation for connecting better to the essence of sustainable development as well as to integrate sustainability into the practice.

Introduction

The transport area in Denmark is subject to massive investments in these years and from an official hold there is a great focus on sustainability, green technology and modal shift towards active and public transportation as a means to reduce the level of CO2 emissions. Accordingly, planning for sustainability has become a global trend and is becoming an integrated focus when assessing new initiatives *(1)*. However, this focus is often lost along the process between visioning and implementing. Many policies attempt to reduce the externalities of transport, however initiatives taken tend to be isolated rather than holistically oriented and sometimes fail in meeting the visions presented *(2)*. Planning for sustainable transportation has faced tremendous barriers in the form of path dependencies established by a large institutional, corporate, cultural and discursive incumbent *(3)*. Banister calls these planning attempts *schizophrenic paths*, since it is *clear that action is needed but no effective action is taken to remedy the situation (4).*

Despite these difficulties, the three dimensions of social, economic and environmental sustainability have become a de facto starting point to conceptualize and operationalize sustainable development (SD) in transport and elsewhere *(5–7)*. However, there is no common guidelines for which criteria to assess and how to balance them. The Cost-Benefit Analysis (CBA) approach has provided a way to translate impacts into comparable monetary units, however it has been found to hold certain limitations when incorporating and assessing attributes such as environmental or social issues *(4, 8, 9)*. The methodology of Multi-Criteria Decision Analysis (MCDA) provides a possibility for incorporating such factors that are not easily quantifiable *(9)*.

This paper presents the SUSTAIN Decision Support System (DSS) model, which is based on a MCDA approach combined with the concept of the nested model of sustainability. This concept is among others proposed in the Ecological Economics literature, which places the three well-known dimensions in a certain order of priority and thereby expresses a stronger understanding of sustainable development *(8)*.

The following section will introduce elements of sustainability and the framework of the nested model. Then the SUSTAIN DSS model is presented and tested on the case study of the new fixed link connection crossing Roskilde Fjord. Finally the results will be related to the overall description of sustainable development and it will be discussed to which extent the needs have been met.

Sustainability and sustainable development

The three dimensions model – also sometimes called the three pillars of sustainability, or the triple-bottom line of sustainability *(10)* – often consists of representing the economy, society and the environment as three equal and overlapping circles. Although interpretations for each of the three dimensions vary, at its most simple level it is understood that addressing all three dimensions will support a process towards sustainability.

In practice however, the three dimensions do not provide much guidance to planners and policy-makers as to how to prioritize between the conflicting and interacting factors that can often emerge. The model has been criticised both for encouraging trade-offs and overlooking the interdependence of these factors *(11)*. In practice, the issue of trade-offs can lead to the default prioritization of effects that can be quantified and monetized, often to the detriment of more complex and long term impacts that often characterize the social and environmental dimensions (Ibid.).

In order to address these limitations, the nested model is proposed as an alternative approach to conceptualising the three dimensions. In the following section, we demonstrate how the nested model can be seen as an improvement by revisiting the Brundtland report entitled 'Our Common Future'. The report was adopted by the United Nations General Assembly in 1987 and it is remembered for formulating the oft-quoted one-line definition of sustainable development: "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" *(12)*. However beyond this definition, the report also provides an exhaustive attempt at clarifying

the concept of sustainable development as well as dealing with issues of trade-offs. The defining elements of the Brundtland report are reviewed here in order to analyse the nested model from a theoretical perspective.

The Nested Model of Sustainability

The nested model, as opposed to the intersected model (cf. Figure 1), depicts the three dimensions of sustainability as three nested spheres, where the economic circle is nested within the social circle, and the resulting socio-economic circles are in turn nested within the environmental circle. Rather than viewing the three circles as three distinct but complementary dimensions of sustainable development, the nested model assumes that a sustainable environment is a necessary condition for a sustainable society, and that a fair and equitable society is also a necessary condition for sustaining economic activity. In other words, the model presupposes first that society and its economy can only exist within the limits and carrying capacity of natural systems, and both depend on the integrity and proper functioning of these systems. Furthermore, this understanding also offers a consideration of the three dimensions as operating on different temporal and geographical scales and thereby making a distinction between the reach of their impacts. Accordingly, the nested model assigns a default hierarchy between the dimensions. The nested model has been proposed for use in both practice and academic literature, see e.g. *(8, 13, 14)*.

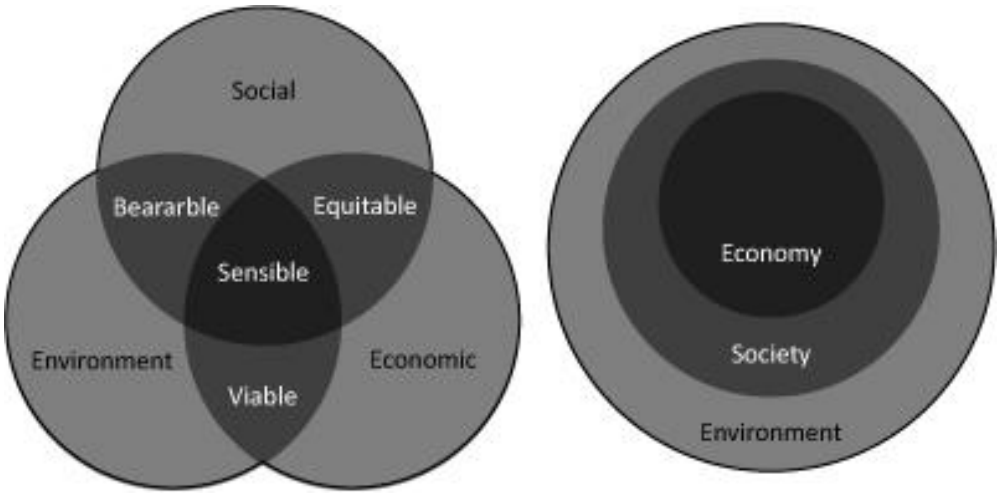

Figure 1: Intersected and nested sustainability models

The nested model is a simple visual representation of the tenets presented by ecological economists such as Daly and Costanza *(15, 16)*, who distinguishes between weak and strong sustainability. Weak sustainability assumes that three types of capital – natural, human and economic – can be substituted. The weak position matches the commonly used model of the three equally important dimensions of sustainability, where performance in one dimension can offset reduced performance in another. The strong position on the other hand suggests that some types of natural capital - such as the ozone layer or biodiversity - cannot be substituted by man-made capital. Because such ecological systems are vital to human existence, they in fact cannot be called natural 'capital', but rather should be accounted for separately and in their own right *(15, 17, 18)*. This approach brings forth the concept of irreversibility, where a small impact may in fact become very penalizing in the long term if it is irreversible (such as a species loss or an ecosystem collapse).

Revisiting the Brundtland Report

At a general level, the nested model can be seen as a fair representation of the concept of sustainable development elaborated by Brundtland.

First off, the sustainable development definition (together with the report's title) sets the normative ambition to satisfy needs and aspirations of both current and future generations, thus clearly putting the concepts of human needs at its core. However the report makes a clear distinction between what could be termed the paradox of poverty versus the paradox of affluence. For countries within the paradox of poverty, the report gives overriding priority to meeting the essential needs of the poor and to provide for minimum consumption standards. This is justified on the basis that poverty generally contributes to a vicious cycle of environmental degradation, health impacts and general vulnerability. However, past a certain point of 'income-per-capita', Brundtland warns about increasing environmental impacts, often of global scale and long-term nature (such as climate change). This can be termed the paradox of affluence. For countries within the paradox of affluence, the primary concern shifts to preserving nature's life support systems. As a result, Brundtland is clear on the need for more affluent populations to bring their lifestyles, values, patterns of behaviour, levels of consumption, energy and resources use in line with the planet's ecological means with regard to long-term sustainability. This prioritisation fits well with the nested model placing the environment as an outer boundary to the socio-economic circles: preserving the basic overall integrity of natural systems that support life is concluded to be a minimum for sustainable development, what Langhelle calls Brundtland's proviso of sustainability *(19)*.

About the economic dimension, Brundtland is prescriptive on the role of economic growth and technological development to combat poverty and meet human needs. However in the paradox of affluence, quantitative economic growth is replaced by a type of growth and development that takes fuller account of environmental and social factors, what is termed the 'quality' of economic growth Conceptualizing economic growth and technological development as a means to an end within social and environmental constraints also fits well with the nested model that depicts the economic dimension nested within the social and environmental circles. Assuming Denmark is generally beyond the basic concerns of insuring that essential needs and minimum consumption standards are met, it can be said to be operating within the 'paradox of affluence'. The Brundtland understanding of sustainable development is summarised in the picture below.

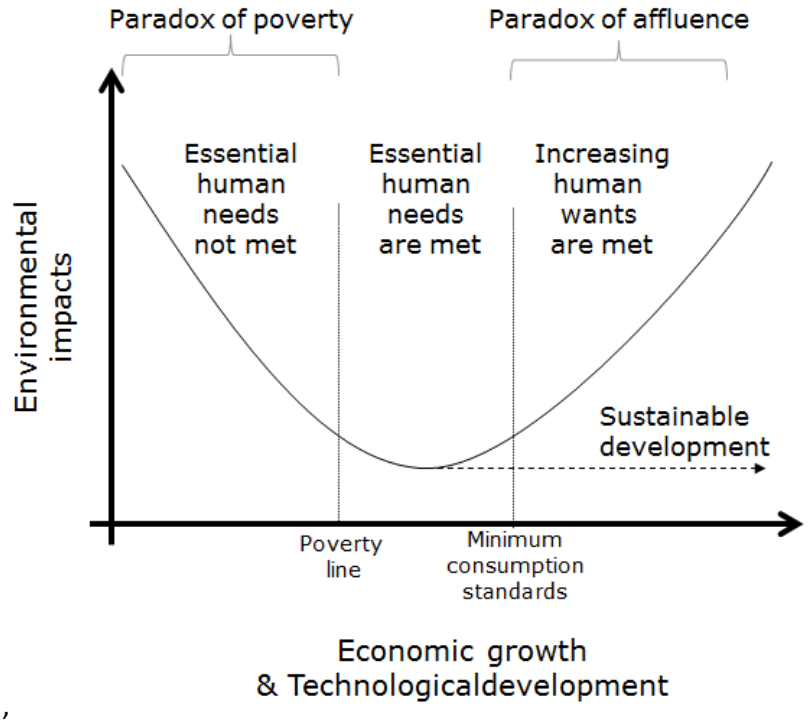

Figure 2: Sustainable development by Brundtland

Limitations of the Nested Model

However, the nested model introduces simplifications that the Brundtland report can help illuminate. This section presents some of these limitations.

Brundtland distinguishes between different types of natural capital, while the nested model does not. Not all environmental capital is critical or irreversible, which implies that not all environmental criteria should receive the same treatment or priority. On this matter, Brundtland shares the views of ecological economists: *regeneration* of renewable capital, *substitution* of non-renewables, *compliance with thresholds* on wastes and emissions, *precautionary principle* for irreversible capital, and consideration for system-wide effects and *integrity*. This lack of precision in the nested model may lead to an overall over- or under-prioritisation of the environmental dimension compared to what a more fine-grained analysis would suggest.

The same argument applies to time scales. Although the nested model attempts to provide a longer term horizon, not all environmental impacts belong to long-term natural processes of concern to future generations. Noise is a good example of a short-term and local environmental impact which may not be of particular relevance to future generations or to maintaining environmental integrity. A related third concern is the lack of 'veto' power. Although impacts on nature are given a higher priority, the fundamental assumption that the dimensions can be traded remains. If the perceived economic or social benefits of a new infrastructure project are high enough, critical or irreversible capital that contribute to the Earth's life support systems may be sacrificed nevertheless. This implies that the nested model is in fact 'weaker' than what the Brundtland report called for. One way to overcome this would be to set a requirement that all three dimensions must improve for a project to be allowed to go ahead, or to give critical and irreversible capital a category of their own as was done by Joumard and Nicolas *(8)*.

A final critique of the nested model is that it only explicitly covers three dimensions of sustainability while leaving other areas implicit or external. The time dimension and the interrelationship of the dimensions are implicit in the model, while issues of governance and processes of change are considered external. Naturally, the model in itself is not enough, it is meant as a tool that needs to be inscribed within a strategic planning and/or policy-making process. The following table summarises the strengths and weaknesses of the nested model of sustainability.

Table 1: Nested model strengths and weaknesses

Strength	Weakness
Prioritising environmental integrity is in line with Brundtland and is applicable for a rich country.	Different types of environmental capital are not explicitly considered eg. critical, irreversible, non-renewable or renewable.
Long term impacts are implicitly prioritised, giving a voice to future generation concerns.	Not all environmental impacts are long term or relevant to keeping natural systems intact. Not all social or economic impacts are short term.
The existence of global or local environmental thresholds suggests an overriding priority for some environmental impacts.	Limits may still be crossed. There is no explicit 'veto' in the model. Gains between dimensions may still be traded.
All three dimensions economy – society –environment are addressed, providing a more holistic picture.	Issues of governance and change process are considered external.

This section illustrated that the nested model is a useful representation of sustainability, but not without a number of limitations. These limitations will need to be kept in mind alongside the operationalization of the model. The next section shows how the nested model is operationalised for transportation assessment.

The SUSTAIN DSS model

The SUSTAIN-DSS model, illustrated in Figure 2, is designed to expand the foundation for decision-making by allowing for the systematic inclusion of impacts that are not easily quantifiable or monetizable. The model introduces the Multi-Criteria Decision Analysis (MCDA) which is based on value measurement using qualitative input from a ratifying group to overcome this issue.

The MCDA methodology extends information from a multiplicative version of the Analytic Hierarchy Process by Saaty *(20)* (also known as the REMBRANDT technique) which has been proven well suited for group decision making *(21)*. As in the original AHP, the REMBRANDT technique is based on a procedure of pair wise comparisons of alternatives. The comparisons are performed by stating the preference for one alternative over another according to a sematic scale going from indifference to very strong preference. For example, alternative 1 and 2 are evaluated against each other for the first criteria, and then alternative 1 and 3 are compared, and so on. The process is complete when all possible comparisons are made.

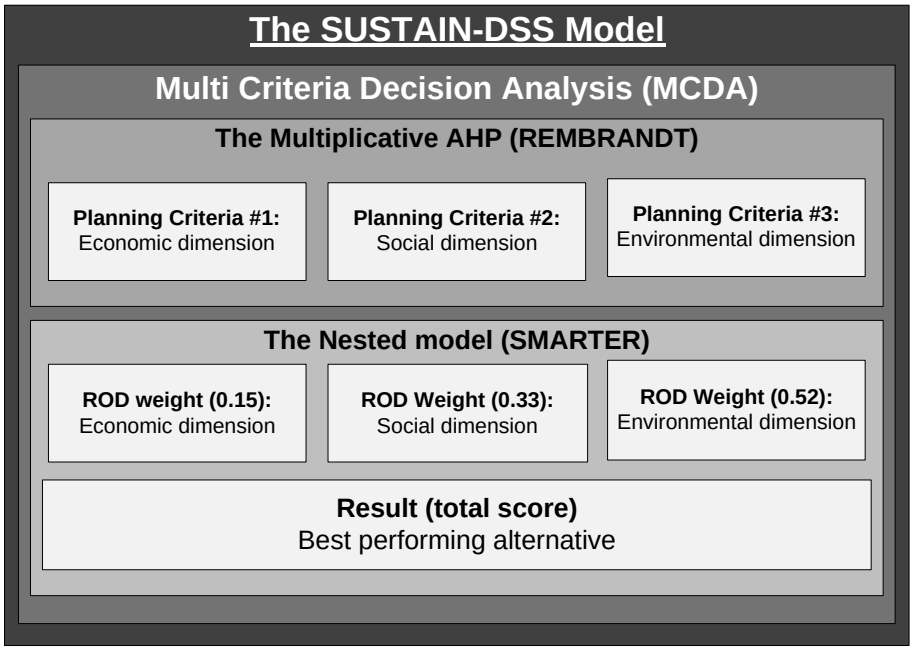

Figure 3: A Schematic overview of the SUSTAIN DSS model

The above however does not provide any ranking of the criteria. The REMBRANDT technique could be used for evaluating the relative importance of each criterion against each other. However, this approach would rely extensively on the preferences of the persons performing the assessment and does not provide the opportunity to align with the priorities sustainability theory would suggest. To overcome this limitation, the DSS model applies the Simple Multi Attribute Rating Technique Exploiting Ranks (SMARTER), which provides a means of assigning direct weights to criteria based on an importance ranking. Predetermined surrogate weights can then be assigned directly to this ranking thereby simplifying the process for the decision makers. In this paper the Rank Order Distribution (ROD) weights are used *(22)*. One caveat in using ROD weights is that as the number of criteria grows, the weight given to the lowest ranked criteria becomes marginal. For this reason, the criteria within each of the three dimensions of sustainability are given equal weights in this paper, while ROD weights are applied as a whole to each of the three dimensions of sustainability. The ranking of the dimensions reflects the hierarchy suggested by the nested model presented earlier. The corresponding ROD weights are given in figure 3 above.

The methodology presented here requires first that project alternatives have been determined, and second that a list of contextually relevant yet comprehensive assessment criteria exist. The section below elaborates on the case study concerning a new fixed link across Roskilde Fjord in Frederikssund. It presents

the four alternatives that are considered as well as the set of planning criteria that were extracted from the original project documentation.

Case study: Frederikssund

In order to test the applicability and effect of the model, it is tested on a case study concerning the decision process of constructing a new bridge crossing Roskilde Fjord at the city of Frederikssund. The planning of the connection has been an on-going project since the 1960's, but has concluded after the government in March 2013 provided the legislative framework for a high bridge crossing south of Frederikssund, which is to be funded mainly through user charges *(2)*.

Figure 4: Map of Frederikssund and the Roskilde fjord

The bridge has faced increasing congestion for several decades, but due to a location within a Natura2000 protected area, the construction of a new bridge has not been so straightforward. The bridge forms a local and regional link, but is not of national importance, and raising the money for a new connection has therefore been difficult *(2)*. Furthermore, the growth of the city of Frederikssund over time has located the bridge in the very city centre, putting restraints on the possibilities for expanding the current connection. The type of solutions listed in the EIA report are found to be similar to those proposed when the problem was first acknowledged in the 1960's *(23)*. The case study shows that no alternatives to building a new link have been seriously considered e.g. solutions that are not car-oriented or other traffic-reducing measures. This calls for a wider set of alternatives to be considered.

Alternatives

In this paper, the following alternatives are evaluated. The first two alternatives are based on the EIA and follow the conventional 'predict-and-provide' approach *(24)*. The final two alternatives are proposed by the authors in order to evaluate options that would support a shift to other modes than the car. They are:

- **Alternative 1** is identical with the officially decided solution and consists of a high level bridge located south of the city centre and funded through user charge;
- **Alternative 2** is an expansion of the current bridge, also funded through user charge;
- **Alternative 3** is a light rail link constructed through a new bridge connecting the western peninsula with the train station in Frederikssund;
- **Alternative 4** is a service of free shuttle busses on the existing connection funded through user

charge applied to other modes using the bridge.

Since Alternative 1 has already been selected for implementation (the construction works commences in 2014), the case thereby serves to exemplify the assessment procedure of the SUSTAIN-DSS model.

Criteria

The set of criteria to be used in the model intends to reflect the context as well as mirror the reflections done in the planning process that took place preceding the actual decision for the new bridge. The criteria have been formulated directly from the background literature of the case study, as well as through a coding of current trends in planning as described by Owens *(24)* and Banister *(4)*. The planning criteria are extracted from various stages of the planning process and are presented below in order of their perceived importance from the documentation.

First, it seems without doubt that both 'increased mobility' and 'economic viability' of the project received high priority in the final phases of the planning and constituted main elements in the basis for decision. They are therefore included in the set of planning criteria, where the economic viability is assessed based on a socio-economic analysis.

Based on the Environmental Impact Assessments (EIA) and public hearings *(23, 25)*, the main environmental impacts raised by nearby residents are noise and pollution. Since they are of major concerns to both residents and politicians, they are therefore included in the set of planning criteria. Due to the very unique and characteristic nature of the fjord and its surroundings, any harm done will not only be of general environmental concern, but also of (local) political concern. Impacts on the fjord such as water flow, bird life, and marine environment are thus included. Impacts on the climate are conspicuous by their absence in the assessment. The increases in CO_2 levels are stated, but no actions to reduce the levels are suggested. For this reason, climate change is not included in the assessment.

The characteristics of the fjord are a hallmark to the area and are important for attracting new residents, businesses and tourists. Therefore scenic adaption of a potential project should meet and if possible enhance these characteristics. This was an important argument presented by contractors *(26)* which has been adopted by local politicians.

The technical characteristics of the project (such as capacity and speed) are also used as a criterion. This supports the notion of speed being a desired feature, but also reveals the paradox and conflicts between some of the planning objectives: increasing speeds and relieving congestion can be considered desirable and will benefit time savings, but will also increase the risk and severity of accidents *(27)*.

Finally accessibility to neighbouring municipalities has been a strong and stated argument for increasing road capacity, and should be seen in the context of achieving a coherent region. On the other hand, this type of accessibility is limited to those able or willing to drive and own a car, while other socio-economic groups may not benefit directly.

The final set of planning criteria used for the assessment of the four alternatives consists of 2 economic criteria, 3 social criteria and 3 environmental criteria. They are:

Table 2: Final criteria set and weights

#	Criteria	Case-based weights	Sustainability dimension	Nested model weights
C1	Transport network and accessibility	0,23	Social	0,11
C2	Socio-economic assessment	0,20	Economic	0,08
C3	Noise	0,17	Environmental	0,17

C4	Local pollution	0,14	Environmental	0,17
C5	Impacts on the fjord	0,11	Environmental	0,17
C6	Scenic adaption	0,08	Social	0,11
C7	Technical characteristics	0,05	Economic	0,08
C8	Coherence between regions	0,03	Social	0,11

These eight criteria reflect the foundation for the decision making done in the case study. The assessment of each alternative used here is done based on values that are centered on the car as a primary mode choice. This approach is selected to best reflect the process that took place. A detailed description of the criteria assessment for each of the four alternatives can be found in Pryn *(2)*.

Results: Case-based prioritization

The four alternatives are assessed together in an MCDA using the 8 criteria as shown above. The criteria are ranked and assigned ROD weights in order to reflect their relative importance *(22)* (see table 3). This analysis forms a benchmark for using the model and thereby serves as a consistency check with the actual outcome of the planning process.

As expected this analysis confirms Alternative 1 as the preferred solution. What is somewhat surprising though is that Alternative 2 and 4 are performing equally well. When looking at the criteria assessed, it becomes clear that the improved mobility of alternative 2 is counterbalanced by the environmental and even the economic performance of alternative 4. The results are shown in the figure below.

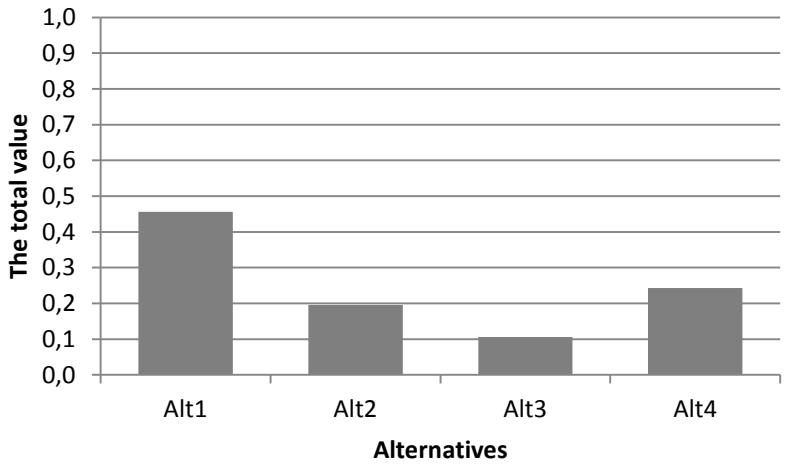

Figure 5: Resulting graph of the case-based assessment

Results: Nested Model prioritization

To test the effect of the nested model, the same set of criteria and assessments of each alternative have been used in the SUSTAIN DSS model. The assessment of each alternative within each criterion remains the same, but the weighting is altered according to the nested model based on the affiliation of the criteria to each dimensions. Within each dimension, the criteria are assigned equal weights summing up to the weight assigned for each dimension (see figure 3 and table 3).

Interestingly, the preference of the alternatives shifts to the favour of Alternative 4 following this change in weighting. This is so since the criteria where alternative four performs well now receive a higher weighting while on the other hand, the criteria where alternative 1 performs well are diminished.

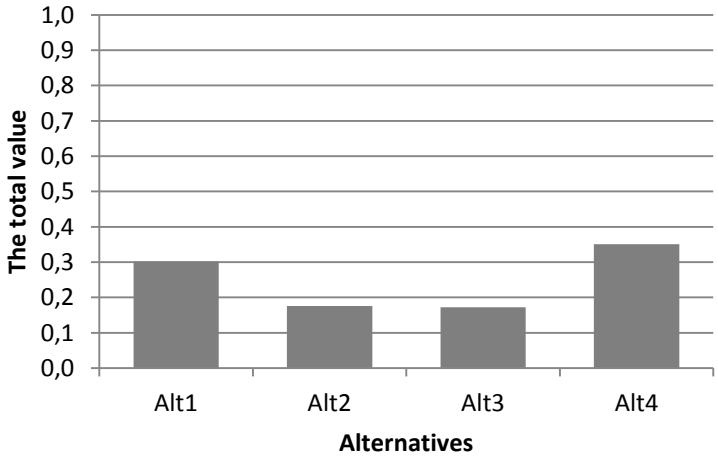

Figure 6: Resulting graph of the SUSTAIN DSS assessment

Discussion

From the results above, it is clear yet unsurprising that a different set of priorities changes the outcome of the planning process, even when the set of criteria and their individual assessment remain unchanged. In this case, applying the nested model of sustainability leads to a higher preference for the free shuttle bus alternative using existing infrastructure as the 'more sustainable' option.

The two assessments provide an insight on how new weighting can affect the preferred alternative. However different results may occur if a new set of criteria is used for assessing the alternatives. The first assessment is indicative of an underlying car-based mindset, while the second illustrates the potential for a new paradigm in assessment. The division and prioritisation of the existing eight criteria into the three dimensions does not provide a guarantee per se of meeting sustainability demands. Furthermore, the eight criteria secure no special attention to a number of wider sustainability issues as they are rather a reflection of the current and contextual planning objectives.

This conceptual difficulty suggests the need for a new and if possible, standard set of criteria for assessing sustainable transportation altogether. This ideal set of criteria would ensure a more holistic approach that could include more multi-modal and long-term considerations. For example, Banister elaborated in some depth what a wider understanding of sustainable mobility could include *(4)*. Such criteria could also address some of the limitations that were raised concerning the nested model approach, namely the lack of consideration for different types of natural capital affected and concepts such as irreversibility.

Nevertheless, it was shown that the nested model of the three dimensions of sustainability may be conceptually accurate, yet simple to understand and operationable into a MCDA process. However, it must also face the tough question: is it useful in driving change?

On one hand a stronger conceptualisation of sustainability implies a basic reframing of the ethics behind the planning for sustainable transport. Using the nested model may at the very least *contribute to shape knowledge and/or introduce new ideas (28)*. Compared to the more traditional approach consisting of producing a CBA analysis complemented by an EIA report, the MCDA approach provides the opportunity to integrate both monetized and non-monetized effects into one common tool. This alignment of effects may contribute to an earlier and more holistic assessment of all impacts. In addition to this, the very process of MCDA requires an early engagement with experts and stakeholders in assessing the various alternatives against all possible impacts, which may help build a sense of ownership and gain acceptance for the project. Finally, the process requires explicitness on the criteria used as well as their prioritisation. Such transparency provides clarity to all stakeholders involved in the decision-making process.

On the other hand, although the tool is intended for instrumental use rather than just inspirational, it cannot replace decision-making. In suggesting a 'more sustainable' alternative, it is limited by the set of criteria that are considered. As it was already highlighted in the theory about the nested model, factors falling outside of the three dimensions of economy – society – environment are not explicitly considered. In a context of governance, such factors may include strategic fit with existing goals and visions, agency knowledge and capacity, the presence of effective leadership, or the barriers posed by norms and public expectations (just to name a few). However, based on the assumption that a decision departing from the results provided by the tool would require proper justification, the process may help increase accountability and thereby avoid *symbolic* use – where the assessment process is used as a means to justify a decision that has already been taken *(28)*.

Naturally, validating the process presented here in a real planning context could inform further on its potential and limitations in enabling 'more sustainable' alternatives to come through.

Conclusion

This paper uncovered some of the conceptual and analytical limitations of the planning approach illustrated by the case of a new connection across Roskilde fjord in Frederikssund, and it proposed some pathways to overcome them. At a conceptual level, a stronger and more fine-grained understanding of sustainability is suggested as a starting point, and at the analytical level, the use of weights based on the nested model of sustainability is exemplified as a way to operationalize this.

Although the model is simplistic in that it does not accurately reflect the numerous complexities that compose sustainability theory, it was shown that this simplicity also renders its operationalization possible and provides valuable insights to the challenge of planning for more sustainable transportation. More particularly, it was shown that the reprioritisation of the environmental dimension above the socio-economic dimensions is consistent with the definition of sustainable development endorsed by the Brundtland report of 1987. Whereas the model bundles different types of natural capital into one and does not prevent critical thresholds to be crossed, it allows concerns for long term environmental integrity to supersede more narrow and short term considerations that traditional methods allegedly fail to do. This future generations' perspective embedded in the protection of long term environmental integrity is the basic of the new ethics proposed by Brundtland that is deemed applicable for developed countries such as Denmark.

For the case of a new bridge connection across the Roskilde fjord in Frederikssund, it was shown that applying the model leads to a different conclusion on the preferred alternative. Overall, the alternative of a free shuttle bus service operating over the existing connection is considered 'more sustainable' than the officially decided solution of building a new southern connection for car-based traffic.

This paper thus demonstrates the value of revisiting in more detail sustainability theories in order to beat the *schizophrenic paths* revealed by Banister. The overall challenge raised is to arrive at a more precise understanding of sustainability that can inform prioritisation of often-conflicting issues and integrate that knowledge into existing processes of governance. The Brundtland report was selected for its wide acceptance and universal adoption, and it was found that, when reviewed beyond t its one line definition, it can serve as useful guidance for such prioritisation. Thus the nested model approach proposed here is meant as a method, on one hand, for reaching further and connecting better to the essence of sustainable development, and on the other hand, to integrate this understanding into real practice. Because of its simplicity, the nested model serves as this 'bridge' between conceptualisation and operationalization of sustainable transportation planning. However further research is needed to demonstrate whether the same model can also serve as a bridge to its strategic utilisation in a complex, democratic political process where paths dependencies and myopic interests may form serious barriers to change.

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