RESILIENT SUSTAINABLE AUTOMOTIVE STRATEGY
DECISION SUPPORT
Thirty-Six Month Report

Executive Summary

This report covers the period from 1st April to 30th September 2013. There were two major outcomes during this period were the resubmission of the first journal paper, and the beginning of the case study samples with some interim results. The approach which is being developed in this research to support strategic decision-studies within Ford has been named SuReSDS for Sustainable Resilient Strategic Decision Support. The process flow for SuReSDS has also been further developed and four phases of activity identified in a series of decision-support activities, that can form a continuous loop and which correspond roughly to Deming’s Plan-Do-Check-Act. The first of these, “assess system” has been further broken down into simple steps which were used in the case sample studies.

The first case sample study was a small pilot designed to test the proposed Parameter Diagram and system design analysis approach which is core to the SuReSDS approach and the “assess system” phase. It used a recent historical strategy study conducted at Product-Service System level within Ford which produced numerical data. The pilot study verified that a Parameter Diagram approach can be used to define and model the “system” affected by the strategy being studied; in this case reproducing the original study results. The Ford specialist with whom the results were reviewed also stated that the approach appeared feasible and practical for use in typical Ford studies of the type they engage in.

The second case sample used a simplified system model from the first pilot study, the same general study brief and dummy data from public sources (numerical data again) to explore the “assess system” phase further. This study is still being completed but interim results indicate that this approach can be used to integrate wider aspects of sustainability and resilience into the system model, and therefore into strategic studies. Some simple indicators (“metrics” in Ford terminology) for social sustainability and system function resilience were explored. Although these were specific to the type of study it is planned that general rules describing how these can be developed for any system will be developed. The next steps are to add further parts of the SuReSDS process to the system model and study analysis, in particular to create design alternatives and future scenarios involving risks and opportunities these alternatives must withstand or exploit. This supports the next major
phase within SuReSDS of testing the design options against the scenarios in a structured way to identify which one has the best combination of sustainability and resilience.

Alongside this task a general framework will be developed in the near future to describe the two major characteristics of SuReSDS studies, and used to plan the content of the remaining case samples, and find any suitable opportunities. 3 other case study samples are planned, during the remaining research. There may also be an opportunity to do some short pieces of work outside Ford to test SuReSDS in ways which are different to those available inside the company, for example in different sectors or in “live” decision-studies, which will supplement the data available. Two reviews of the case studies are planned, one in early November and one in February to check on progress against the plans devised and to modify the research design if required.

The case study work is planned to be complete by about Easter next year to allow sufficient time for interpretation of results and the final thesis. A timing plan is included at the end of the report covering the rest of the EngD up to thesis submission.

Student URN: 6158815

Student name: Julie Winnard
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**Glossary**

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<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>SuReSDS</td>
<td>Sustainable Resilient Strategy Decision-Support; the working title of the approach developed by this research</td>
</tr>
<tr>
<td>Backcasting</td>
<td>working backwards from a desired future state or target to establish what steps are required to get there</td>
</tr>
<tr>
<td>Capitals</td>
<td>Difference types of resource supporting human and other life; classically the environment, society and economy in sustainability thinking</td>
</tr>
<tr>
<td>FMA</td>
<td>Failure Mode Avoidance; a Ford variant of general design engineering practices also linked to Taguchi’s work used to design system function correctly, reduce risks and avoid mistakes</td>
</tr>
<tr>
<td>Option</td>
<td>different system design alternatives studied within SuReSDS are called design “options” in this approach. Options must create a difference in the choice or setting of Control Factors and/or system function design</td>
</tr>
<tr>
<td>Product-Service System (PSS)</td>
<td>The combination of hardware and software together with an activity in providing a service, that forms a full description of how a product really works (i.e. automobility rather than a car)</td>
</tr>
<tr>
<td>Powertrain</td>
<td>the set of vehicle systems associated with the engine/other propulsion and moving the vehicle, from the air intake system through to the driveshafts</td>
</tr>
<tr>
<td>RED</td>
<td>Robustness Engineering Design; a Ford method based on Taguchi’s work used to make system designs resilient</td>
</tr>
<tr>
<td>Resilience</td>
<td>the ability of a system to continue functioning when disrupted, to recover from disruptions and to learn and adapt to new environments</td>
</tr>
<tr>
<td>Scenario</td>
<td>in SuReSDS a possible future (external) context for a system, usually one of several mutually exclusive possibilities</td>
</tr>
<tr>
<td>Shared Value</td>
<td>the different kinds of value experienced by different stakeholders from a system’s activities; based on Porter and Kramer’s paper and consultancy work</td>
</tr>
<tr>
<td>Significance</td>
<td>(of functions, stakeholders, outputs etc.) importance determined by the degree to which the stakeholders are affected</td>
</tr>
<tr>
<td>Stakeholders</td>
<td>people, organisations or other entities which have an interest in the system’s activities because they receive a benefit or damage from them</td>
</tr>
<tr>
<td>Sustainability</td>
<td>the degree to which a system’s activities impact on different “capitals” within the human ecosystem, or “stakeholders” from these areas.</td>
</tr>
<tr>
<td>System</td>
<td>General definition - a set of things working together in a complex whole</td>
</tr>
<tr>
<td>System level</td>
<td>in the SuReSDS context a system can describe a high level activity such as a business model, a mid-level Product Service System or functional activity such as a vehicle or production at a specific plant, or a lower-level activity or PSS element such as a particular technology</td>
</tr>
<tr>
<td>TE</td>
<td>Transition Engineering; a system design technique for delivering sustainability and resilience</td>
</tr>
<tr>
<td>Variant</td>
<td>specifically within Ford a vehicle variant or model, and for Powertrain purposes one with a unique combination of body shape (“top hat”), chassis size (platform), and propulsion (engine motor or other power source plus transmission)</td>
</tr>
</tbody>
</table>
System Parameter-diagram, for reference with the definitions below

| Parameter diagram (P-diagram) | Shown above. A simple system diagram developed by Taguchi and the automotive industry, widely used in design and robustness engineering, showing how a system’s outputs are related to its inputs via its functions |
| Inputs | physical and energy-related resources plus informational flows from the external environment into the system (includes money and labour). Each input may be a signal or noise |
| Signals | inputs which the system is intended to respond to in some way |
| Noises | inputs which the system is not intended to respond to but can be affected by |
| Function(s) | what the system does, to turn the inputs into outputs, in normal conditions |
| Control factors | function parameters which can be fixed, or even actively adjusted when the system is functioning, to change how the system function(s) work |
| Ideal function(s) | the wanted outputs from the system; what it is intended to do. Usually this is a perfect version of the system’s purpose expressed as a function |
| Error states | the unwanted outputs from the system (including waste) |
| Feedback | How system outputs flow back to its inputs. External feedback route effects (outside the system boundary) are not considered when analysing the system’s performance but are incorporated within signals and noises. |
1 Introduction

This report covers the period from 1st April to 30th September 2013, although the active research period covers a little under 6 months due to illness and a shorter working week at one point.

During this period a name was created for the new approach: SuReSDS. This comes from the project title and stands for Sustainable Resilient Strategic Decision Support.

This name reflects that it is intended to help users structure information and questions they already have, to decide how to address their sustainability and/or resilience issues. The approach is intended to be primarily used to support strategy decisions but also to be flexible to enable its use at different organisational levels. SuReSDS is not necessarily intended to produce the decisions themselves as these will be subject to many other influences and requirements within organisations; it is instead a structured and rigorous way of considering problems and opportunities, and producing an improved quality of recommendations for decision-makers.

2 Outcomes

During this period there were 3 significant outcomes.

2.1 First Journal Paper Revisions/Acceptance

The first journal paper (Surviving or Flourishing? Integrating Business Resilience and Sustainability) was given major modifications and resubmitted to the Journal of Strategy and Management (JSMA) in May (Winnard, 2012c), where it was further reviewed. The paper was fully accepted in July for publication – in theory later this year - provided minor revisions were made. A final resubmission date of mid-October 2013 was agreed with JSMA's editor. At the time of writing these final revisions are in progress.

2.2 Pilot Case Study Sample (1A)

A simple pilot case study was performed to test the concept of using a Parameter diagram (P-diagram) approach, as this is the proposed method of assessing systems within SuReSDS and the lynchpin of the approach. The pilot utilised numerical data from a Ford strategic study to model and investigate a system, and this was compared to the original study to show whether the P-diagram could reproduce a valid system model. The test was successful and an overview of the findings are given in section 5.1.
2.3 First Case Study Sample (1B)

The results of the pilot study (particularly the system model derived) were used as the basis for a full case study sample. Surrogate data from public sources was used to populate the system model and explore the rest of the SuReSDS approach. The sample also provided a way to explore suitable metrics (or classes of generic metrics), to highlight missing elements of the approach that need to be developed, and to write the description of the approach which will supply a “users’ manual”. This case study is half-complete at the time of writing; the study so far along with a review of its interim findings can be found in section 5.2.

3 Ongoing Tasks Overview

3.1 Research Design

The higher-level research design was carried out in the last period (see previous six-monthly report, Winnard, 2013b). In this present period the research design has been applied to the case study samples to structure the work, ensure robust data collection and to identify which research propositions each case sample can potentially address. Details of this work are included in section 5 and the appendices under each case study.

3.2 Baseline Interviews - Analysis of Current Practice

This continued as a background task but was not completed within this period as originally planned due to lack of Research Engineer time and resources. A couple of external benchmarking interviews were carried out but the final analysis of all the data together (especially to compare internal and external interviews) remains to be done. It was felt that sufficient information had already been gleaned to allow the rest of the research to proceed, and this task will be revisited and completed later – it is intended to finish late 2013/early in 2014 (see the plan at the end of this report). This is to confirm the initial analysis and support the beginnings of the thesis write-up next year.

3.3 Developing the SuReSDS Approach

Developing missing parts of the SuReSDS approach was originally a separate background task but this has now been included within the early case study sample work. The other task identified was to develop an instruction manual. A simple manual for users was attempted ahead of the case study samples but this was found to be an extremely difficult and large task owing to the wide-ranging nature of the approach, and initial attempts foundered. It was decided that a simple manual could be developed either during or after pilot case study samples which would likely be conducted offline, that is, either away from
the teams supplying data or at least not within their day-to-day work. The pilot and early case samples also would not involve teams using the approach in “real time” so offer a less pressured setting in which to establish the details of SuReSDS.

It was also realised that the early samples would likely focus only on certain areas of the approach at a time and so allow a better opportunity to work out details of SuReSDS in a modular way. Finally, the original manual was intended to make references to other common tools at Ford where their techniques are borrowed, and not to include their full details, assuming in effect that users would already be familiar with them. However the training and experience of Ford staff varies so although the manual should be as concise as possible, it will have to be sufficiently stand-alone to serve a number of different user types and experience levels. The new plan is for the instruction manual to be developed alongside the case samples, with iterative reviews of it as each sample is completed to apply lessons learnt before the next one is undertaken.

This fits with the general research design in which the generic method is developed, used on each case study and from each use lessons are then deduced not only about the theory behind the methodology, but also about the act of applying it. An overview of the core section of the SuReSDS approach as it currently stands is given in section 4.

### 3.4 Developing Metrics

“Metrics” is a Ford term in the context of this project and refers to the type of measurements or indicators used in the SuReSDS approach, rather than individual values in specific studies -analogous to the type (length) and unit (km) of a measurement rather than a specific value of say 10km. A potential need for novel metrics to allow the integration of new information and measurement of qualities related to both wider sustainability and resilience was recognised right at the start of the project and in its objectives. Ford collects many types of information and some of that required by SuReSDS will already exist, such as any describing the issue to be addressed by a decision; however some types of information required will be new to the company and need to be developed based on both sound theoretical principles and utility to the company users. These metrics may sometimes be specific to the company or specific types of study but it is expected that there may be generic metrics also, or generic classes of metric which can prompt users to develop their own suitable ones.

The development of these metrics was originally planned to happen slightly ahead of developing any missing approach elements and before any case study samples. However during discussions it became apparent that it would make more sense to try out the
approach on some analyses in early samples first to find out what sort of metrics it needs, rather than trying to work the other way round. Therefore this task is now happening as part of the case study samples and particularly when reviewing them, to find which metrics (or classes of metric) are used and whether any supplemental ones needed; this has become a sub-task within the case study work.

Once 2 or 3 case samples have been conducted, a higher-level review is now planned, to see if there are generic metric types common to the samples, which can be included in the SuReSDS approach; either specifically, or as prompts and examples to users if they need to develop their own metrics. The review will also include the results of a background search of the literature. This should happen early in 2014 (again please see the plan at the end of the report).

3.5 Outputs from Data

The remaining major tasks of the analysis, interpretation and reporting of results at high-level (across more than one sample at a time to build up the final thesis arguments) follow on from the case study work and were not begun during this period. The first lower level stages of analysis have been started within each case study sample and are summarised in section 5 and detailed within the appendices.

3.6 Literature

During this period a number of journal papers and industrial reports (grey literature) were found which added in some small way to the research. Several were used to assist with the rewrite of the first journal paper in April/May for the first resubmission as they touched on organisational and system resilience. The founders of Creating Shared Value also issued a guide to “Measuring Shared Value” through their consultancy FSG (Porter et al., 2012). Although disappointingly short on specific or generic metrics, this does lay out some suggestions for how social and business value might be established for different firms, by using existing metrics or creating new ones according to the focus of each business. The approach will be reviewed in the light of this report in the coming weeks.

A number of other minor papers and grey reports were identified as being potentially useful especially on the topic of metrics (indicators to be used within the approach) but have not yet been reviewed systematically.
4 The SuReSDS approach

This section provides details of the approach as it currently stands. Not all of the proposed elements of the approach have been fully developed. The approach as a whole is modified from Transition Engineering (TE) as proposed and practiced by Susan Krumdieck and her research team (Krumdieck, 2011a, Krumdieck, 2011b). This uses a seven-step high level approach based on The Natural Step methods to drive step changes in system sustainability and resilience, as shown in figure 1. The published work on TE does not explore fully the relationship between the two qualities, and does not contain a generic method for modelling the system under review. The TE approach is also engineering-focussed and has been developed within the arena of urban transport system design. So although it might be used to support other types of decision such as local planning policy, it needs translating, simplification and clarification for use in supporting business strategy decisions (Winnard, 2012c).

![Figure 1 - the seven steps of Transition Engineering](image)

Like Transition Engineering, SuReSDS aims to deliver change towards more sustainable and resilient systems but in this case business-related ones. As in TE it is intended to do this by ultimately producing a grid of available options ranked against future scenarios by sustainability, resilience and other more standard attributes such as project feasibility, risk and cost (called an Opportunity-Space grid in TE) which can then be used to

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support decision processes. The other major requirement to achieve this is a system model (Winnard, 2012c) which is where the use of adapted Robustness Engineering tools comes in.

Disruption & change sources

Human ecosystem issues

Business critical resources

Market changes (demand)

Form Scenarios
E.g. most likely, Worst, Best

Assess system:
Vulnerability
Adaptive capacity to hazards

Create Options:
To address issues

Test options against
Scenarios: Filter using:
Sustainability, Vulnerability,
Resilience (check for adaptive capacity gains)

Select final options on:
Ranked: Project Feasibility, Project Risks, Benefits

Develop option(s)
Check results (test/model)

Performance monitoring

Final implementation of options

Enter SuReSDS

RED & TE; CSV

Exit SuReSDS

Figure 2- SuReSDS proposed process flow

2 TE indicates process elements based on Transition Engineering and FMA indicates those based on simplified versions of Ford Failure Mode Avoidance methods, mainly from Design Engineering and robustness Engineering. Other elements intend to rely on the user’s own existing processes.
TE looks linear in Figure 1, although periodic reviews of progress might be expected. Strategy formation within companies—and certainly within Ford according to interviews (Winnard, 2012a)—is an ongoing and iterative process, partly reflecting the issue that business conditions are constantly changing. This means that SuReSDS is also likely to be used in an iterative fashion, and that users may come to it at any stage of a strategy or product lifecycle. The diagram of the SuReSDS process contained in the last report proved on further reflection to be more of an information flow chart, so the updated view of SuReSDS is shown in Figure 2.

Although this means that users might arrive in the process initially at any point, they will all have to start at the box marked “assess system” where they will assemble and analyse all the information they have, before being able to move forward by creating or assessing solutions. This activity reflects the need within real strategic studies at Ford to both understand how a system works, and therefore how a strategy might affect it; and the frequent need to discover how the system may be made to work better (Winnard, 2012a). The implementation and performance monitoring stage shown is, strictly speaking, not part of SuReSDS but is shown here for completeness. The overall process of strategy formation and execution resembles a Deming Cycle (Arveson, 1998), with this implementation phase corresponding roughly to the Do/Check and the SuReSDS sections corresponding to Act/Plan stages.

4.1 Assessing the system

This phase of SuReSDS is based upon simplified versions of two complementary Failure Mode Avoidance (FMA) tools used within Ford. These supply the generic method for building a system model which is missing from TE. They are Failure Mode Effects Analysis (FMEA), used to avoid mistakes and Robustness Engineering Design and Product Enhancement Process (REDPEPR), used to address system robustness to “noise” issues or in the terms of this project, improve system resilience. Together with some common analysis processes these make up Failure Mode Avoidance (FMA), the core of the company’s approach to design and development tasks (FMC, 2011, p2-8). They are part of a large and complex system of interacting processes which use a great deal of detailed and precise engineering and marketing data as products are developed. They are also complex techniques in themselves, so a simplified version is being created for use within SuReSDS with its relatively isolated and less well-defined setting of strategy decision-making.

In SuReSDS these simplified tools are applied to the analysis within studies supporting strategic decisions. The traditional FMA methods require a detailed and full
technical assessment of a system in terms of its boundaries and interfaces (FMC, 2000) but this is not always possible for the more complex and less mathematically defined issues within strategy studies. It is therefore proposed to simplify the FMA methods by basing the SuReSDS analysis (initially at least) around a new generic system P-diagram developed from external (Karna and Sahai, 2012) and internal sources (FMC, 2007) which is shown in Figure 3. This is used to build a system model used to assess the strategy's effects.

Figure 3- generic system Parameter-diagram with definitions

4.1.1 The Parameter-diagram

The proposed generic P-diagram uses the same terms for the system elements as are present in the original P-diagram from Taguchi’s system engineering methods (Karna and Sahai, 2012). This is to render the parts of the diagram as familiar as possible to its potential users within Ford, although it is being used in a new setting, as these users are often engineers. A version with definitions is shown in Figure 3; a simpler version is included in the Glossary. The naming is also consistent with SuReSDS being derived from the application of systems thinking to strategy studies (Winnard, 2012c). The intention is that users of SuReSDS will bring their own data and system expertise to the process (potentially including models), and use SuReSDS to structure this information, their questions and recommendations regarding any issues or opportunities. Moreover the approach will allow...
them to incorporate new information (or at least identify a need for gathering such information) pertaining to sustainability and system resilience. Therefore identifying which pieces of information correspond to which parts of the system diagram is a critical first step within SuReSDS.

4.1.2 The topic and level of change within strategic studies

It is also important to understand what kinds of information are already available within the strategic study, and which decisions have already been made. This indicates where on the SuReSDS Deming-style cycle in Figure 2 the strategy sits, and how much of the system design can be altered to answer the strategic questions under study. Previous interviews (Winnard, 2012a) have indicated that Ford strategy studies seem to fall into 4 loose types of change-driven question corresponding to this, which arise from:

- Existing systems with performance issues which need their function improving, with no change in their context
- Existing systems which need to perform well against a new context/situation, generally an opportunity or risk
- New options are available now or in the future for a system and a decision between them (including making no change) is required
- A new or significantly changed system is required to address a major new opportunity or risk

These are given in order of increasing levels of system change and context change. Unsustainability and irresilience can drive performance issues and risks which in turn drive the need for change, and conversely seeking improved sustainability and resilience can manage these risks and improve access to opportunities. This is where SuReSDS is intended to assist decision-makers by structuring unfamiliar information and issues.

If there is no perceived opportunity or risk there will generally be no need for a study, so studies are almost always solving a problem phrased as a question. Almost all study questions are some variation on the theme of “How can I improve my system to do activity X better?”. Evidently strategy studies may be initially looking at one of the types shown above and move through the other types as the implications of different strategic decisions and their lifecycles are considered, or the strategy itself moves into different phases of its lifecycle. The way that SuReSDS is conducted is not expected to change with these different types of study, but the kind and amount of information which is available may change.
depending on the study type, and the approach must be able to cope with all of them to be useful to the company.

### 4.1.3 The system

The strategy which is being studied when SuReSDS is used, is not necessarily the system whose “function" is being considered in the P-diagram. The strategy itself usually concerns a decision affecting the **design** of an activity or product (or combination of these); that is, how it performs well or how it fails. This usually relates to the **2purpose** of the system, what it is intended to do in an ideal world. Strategic study topics or questions drive the path of the study, whilst indicating its initial scope. These driving questions can change during the course of a long study with many reviews, and some studies start with several related questions. Different questions may even refer to different systems affected by the same strategy; for example “If I change my product line-up to meet a particular performance target how does this affect my costs? And how happy will my customers be?". The first question drives a search for a solution to meet the performance target and looks for the effect on costs, perhaps for some subset of all the company’s products. It concerns the performance in terms of both some technical attribute and costs of a group of products to be manufactured, perhaps that year’s production. The second asks about how customer satisfaction will change because of this, so may involve thinking about market acceptance of the change and how individual customers or different customer types might react. It may not be possible to show both in one diagram, but it can be possible to show the effects of one system on the other. So, it is important to know at any point in time which question is being answered to avoid confusion amongst the team using SuReSDS; and to avoid mixing information about different issues or systems leading to poor quality study results.

The decisions which have been made about the system being studied previously also indicate how much of the system diagram –its “design"- is available for adjustment when finding ways to improve it. Only the system functions themselves and the “control factors" which form this design and moderate how the system functions are carried out, are under the control of the company and open to change directly by its actions\(^3\). These choices in the design then affect the relationship between the inputs and outputs- the actual functional and error outputs produced. In some cases the system already exists and so the “functions” cannot be easily changed and many of the control factors may also be fixed; the strategy study will then usually be about only limited parts of the system. A completely new system

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\(^3\) See Figure 3. This choice of design does also mean that different inputs can be selected for the system to respond to but if the system purpose remains the same the ability to do this, and also to change the choice of ideal outputs, is rather limited.
could on the other hand be relatively free of constraints with many possible choices to make; although this is rare – an existing company will always have its own particular resources, strategic aims and interactions between the system and the rest of the company which will constrain any new enterprises.

Figure 4- Strategic levels within Ford Product Development

There are typically 3 types of “system” which appear in Ford strategic studies within a product development setting\(^4\) and which correspond to different levels of the development process and strategies which drive it (Winnard, 2012a), shown in Figure 4. There are corporate-level systems (such as the overall business model, or regional level processes for organisational functions), product-level ones (actually product-service systems and therefore shown as such, concentrating on the offering to customers) and at the bottom technology-level (these usually support several products regionally or globally). Figure 4 also shows how although the topic and change level types might be similar (as described earlier), the detail of the system and therefore task-related information within each level can be different. So although the terminology and techniques of SuReSDS are intended to be common across all of these, translating them for users requires an awareness of what level of system they may be considering as well as what type of study question and how fixed the system design is. This may mean specific examples are needed within the manual for SuReSDS to illustrate its use at the different levels.

\(^4\) It is likely that production-based or support-function based parts of the company also have a similar hierarchy of strategy levels within them, but these have not been available to this research.
4.1.4 System models

System models created in this “assess system” phase are intended to support all the other phases of a study and can be based on verbal descriptions (such as general descriptions of business models) rather than more precise mathematics; or a mixture. The context of strategy, especially the economics surrounding corporate-level business strategy, is too complex to model fully not least because too many people (inside and outside the firm) and their decisions are involved (Taleb, 2008). This means that unlike in the original engineering methods the development of a complete model is not expected, or even feasible. Instead SuReSDS relies on capturing those aspects which the users consider to be the most significant, in a structured way. This could often mean the most significant effects of a planned change on stakeholders.

Sometimes this may mean forming as complete a model of the system as possible, in order to decide which parts of it are going to be significant to the study. Like the Delphi technique this means it relies on the team membership being of an appropriate level and knowledgeable enough to provide a good quality analysis and resist uninformed opinions (Rowe et al., 2005, Rowe and Wright, 1999). SuReSDS prompts users to consider whether they have sufficient information and expertise to do the analysis before they start, to try to ensure a good quality process.

4.1.5 Creating Shared Value- a sustainable business framework

It has been envisaged from early on that a sustainable business philosophy such as Creating Shared Value (Porter and Kramer, 2011) could be used to provide a framework during SuReSDS studies to help translate TE’s decision-support analysis into more business-oriented methods. (A short definition of Shared Value is given in section 4.2). It was not clear at the start of this research period exactly where such a framework would fit within SuReSDS, although it was expected it might inform both the choice of any new metrics and prompt users to consider wider areas of sustainability than in classical economics. It was decided that the best way forward was to see what emerged from the case studies and whether the framework was needed consistently at specific parts of the process, or whether it would be a more general tool used to support the approach wherever necessary.

4.1.6 Integrating sustainability and resilience thinking

Finally as SuReSDS aims to integrate sustainability and resilience thinking into strategic studies, it is also critical to identify whether these elements are present within any particular study, and whether they should be if they are not. Within Ford the scope of a study
is not always within the control of those carrying it out, so it will not always be possible to add sustainability and resilience to the analysis and reporting if it is not already there. When this is the case SuReSDS will likely not offer much advantage over existing methods and should not be employed.

4.1.7 Adding Value

This concept relates to a major host company requirement for processes: that they should “add value” when used. This means that the effort of using an extra depth of analysis or tool must pay off by efficiently generating sufficient extra information, which adds in some significant way to the ability to perform the task at hand. There is a threshold implied for the balance between effort expended and outputs gained, and a relationship to the stakes involved, as tools which are useful but very labour-intensive for example will not be adopted unless they deliver some critical information. If the ratio is too high and the stakes not too critical the company will make do without them. As an example, if the decision being studied is more tactical than strategic (concerning the details of strategy execution) the approach is less likely to be “value added” because there are existing techniques which are available for later stages of more detailed work, such as full FMA methods for product development. However in this particular case Ford culture does not distinguish strongly between tactical and strategic matters (Winnard, 2012a). This may not be an issue as the both strategy and tactics tend to be part of the same studies and decision forums within the company, and it will need to be the user who decides whether SuReSDS is appropriate.

All of this informs the approach and when distilled down leads to the initial steps of the method. An overview of the current design of the “assess system” phase is given below in sections, with an introduction to the purpose of each. As the case studies progress this method will be reviewed and updated.

4.2 Assessing the system: initial methodology steps

4.2.1 Definitions

The instruction manual will need to contain a front section explaining briefly the definitions of sustainability resilience and other key terms including system terms borrowed from FMA and RED techniques, providing a background to the instructions below. This has not yet been developed, although an incomplete version is contained within this report’s Glossary.

Complexity: one important general rule which is also adopted from Ford FMA and RED practice is that if a system contains more than about 8 major elements with individual
Some other major definitions worth covering in more detail here are:

**Sustainability**: the degree to which a system’s activities impact on different “capitals” within the human ecosystem, or “stakeholders” from these areas. Usually this is split into society, the environment and the economy (although other ways of splitting this up exist) and looks for positive and negative impacts. An ideal system would have all positive or at least net neutral impacts across the whole set, but this is very difficult to ascertain as the different areas are not comparable on a common basis. Due to the laws of physics (particularly that of entropy increasing with work, or “system activity” in our context) a net positive outcome is also not possible. So for a real system sustainability is improved by reducing the amount of negative impacts - Krumdieck’s “unsustainability”- arising for positive impacts -generally economic and social benefits to specific stakeholders (Winnard, 2012c); and if possible.

**Resilience**: the ability of a system to continue functioning when disrupted, to recover from disruptions and to learn and adapt to new environments (ibid.). SuReSDS rests on the assumption that both resilience and sustainability are required within systems. In the first journal paper it was established that in order to be more sustainable, resilience is also required for systems to make sure that they continue to perform well regardless of circumstances; i.e. that a company does not quickly become less sustainable when business conditions change. Conversely sustainable systems such as companies which are proactive, more efficient and produce less negative impacts to feed back into their surroundings may both reduce the demands on their resilience and have more resources available to develop further resilience, avoid risks and exploit opportunities (ibid.).

**Stakeholders**: people, organisations or other entities which have an interest in the system’s activities because they receive a benefit or damage from them. These stakeholders generally sit in one of the “capitals” areas and may stand as a proxy for it when considering the system’s impacts. For example, the EC Parliament passes laws about CO₂ emissions designed to protect the environment. The environment itself does not have a voice and so the EC law “stands in” as a proxy for the environment. Similarly human society as a whole does not have a voice but “the public” and/or “our customers” can be considered as a
conceptual proxy for human society when a firm is making decisions. Stakeholders are required to focus the SuReSDS analysis when considering “who” receives the Shared Value (and damages) from a system, but also to ensure that important impacts (good and bad) are not left out by ignoring or forgetting certain stakeholders.

Shared Value: the different kinds of value experienced by different stakeholders from a system’s activities. Porter and Kramer propose this as being what companies actually create (as opposed to “just” profits). Also, that the needs of various different stakeholders in society and the environment need to be included when forming successful business strategy as well as more traditional economic stakeholders such as investors and shareholders (Porter and Kramer, 2011); this allows the integration of sustainability into decisions. This type of approach provides a useful way to link the stakeholders from each “capital” and the idea of balanced sustainable impacts into business thinking. It was not initially clear how it would be used within SuReSDS except to prompt lateral thinking and creative solutions; it may appear in most of the different phases being used for different analysis tasks.

Product-Service System (PSS): this is a useful way of considering systems especially those which are traditionally considered as products alone, to ensure that all its aspects and impacts are considered. It also helps prompt more creative solutions -both are important for practicing sustainable engineering and business (UNEP and TUDelft, 2009). For example a toaster is not just a product as it is not directly consumed by being used, but when supplied with power it provides the service of toasting your bread. Similarly cars primarily provide mobility. A complex PSS may have many functions.

4.2.2 Methodology

Although many engineers have some familiarity with FMA and RED methods not all do, and both engineers and non-engineers are involved in preparing information for strategic studies within Ford. Therefore the method is laid out here in sufficient detail such that someone unfamiliar with FMA & RED methods could still use SuReSDS; and to assist the unfamiliar reader. Users who already have experience in systems analysis and design techniques should be able to operate from a much simpler and higher-level set of instructions or guidance; establishing the best level of guidance for each user type is another task within the case studies.

The first part of the method falls into 3 main areas; scoping out the study and the system it concerns, forming a model of the system using words and /or data, and finally assessing both the functions of any existing system set-up and what the effects on it would
be of the strategy being studied. These are shown in Figure 5 and described in more detail below.

**Figure 5- Process flow for Assess System stage**

4.2.3 Identify study scope: subject and system

Ideally the steps should be followed in order to establish the study scope, the topic(s) and the system(s) it concerns. It is important to identify whether all the study questions identified concern one system as if not, multiple system diagrams will be needed with analysis of each. This stage also identifies whether the study contains any sustainability or resilience issues which make it suitable for applying SuReSDS.
• Identify the purpose of the study - which question(s) is it trying to answer?
  
  o If there are several different questions do they all concern the same strategic decision?
  
  o If not are the strategic questions related to each other, for example does one support the next?
  
  o If the questions and/or the decisions are not linked they will need separate analyses in SuReSDS because they require different answers and may concern different systems. Is this the case?
  
  o Do the questions concern future risks, existing issues or opportunities?
  
  o What changes are driving these risks, issues and opportunities?
  
• What level of system does the strategy concern? Check for each type (see figure 4 for reference)
  
  o Corporate or regional-level e.g. business models or goals
  
  o Products-and-services as a system e.g. leased vehicles
  
  o Technology which supports multiple product/services e.g. hardware or software
  
  o If there is more than 1 system level they will need separate system models and analyses. Is this required?
  
• Which people or entities are significantly affected by the system? These are the stakeholders.
  
  o Studies usually consider 2 main stakeholders- the company and customers. Are other stakeholders important to the question? (e.g. the public, investors, competitors, legislators, and always include significant effects on the environment)
  
  o Different stakeholders may matter more or less at different levels- are all the significant stakeholders included for this study?
Significance can be determined by the degree to which the stakeholders are affected by the system. For environmental effects these most significant effects can be obtained by considering the company’s current Materiality Matrix for corporate-level impacts, by consulting the Product Sustainability Index of a current product if available, or by consulting local specialists such as Sustainability Planning. If you are designing a new system you may need expert assistance to identify significant environmental impacts.

- What is the system?
  - Simply describe (preferably in one sentence) what the system is intended to do in normal circumstances
  - If this includes more than 3 verbs (these are the core functions) the system is too complicated and should be broken down further into parts.
  - If it includes more than 7 or 8 nouns (elements which will carry out the function in between the inputs, outputs and controls) again the system may be too complex and require a smaller scope or multiple studies at a lower or higher level to be manageable within this analysis.
  - Do you have enough information and expertise within the team about the system to discuss how it is meant to work normally and how it might fail? (you do not need to know everything but you will need to start somewhere)
  - If not you will need to gather more information or arrange to work with relevant specialists or experts before continuing. You may also find a need to do this later in the process.

- Identify whether the study purpose includes a sustainability question about the system’s function, a resilience question or both and whether they are related. These questions can be hidden or overt.
  - Restate the study purpose question(s) in terms of sustainability or resilience if possible.
  - How can each study question be reframed in terms of…?
- **Sustainability**: improving the positive social, environmental or economic impacts of the system, or reducing negative social environmental or economic impacts (especially beyond the short-term). This corresponds to designing the system’s normal or ideal function and mistake avoidance as in Failure Mode Avoidance.

- **Resilience**: making the system more able to keep on functioning when disruptions or shocks happen to it, more able to deploy alternatives when disrupted, and more able to adapt to changes if they are long-term. This corresponds to making sure the system functions well in all situations and long-term as in Robustness Engineering.

  - Does it involve both and are they closely related?
    - E.g. making a system resilient to an issue arising from unsustainability (e.g. climate change), or ensuring a system delivers better sustainability over longer periods by being resilient.

  - Does it have both and they are not related?
    - this is likely to mean separate studies are required for each-check whether they concern different systems or strategic decisions

  - This version(s) of the study question(s) can now be used to focus the system assessment and to drive the creation of any alternative designs required.

  - If the purpose contains neither issue, can the strategy being considered affect either of sustainability or resilience of the system and should they therefore be included?
    - If yes return to the “what is the system” beginning step and add the relevant question about sustainability or resilience, working through the new study scope.
If neither are present, and should not be, do not use SuReSDS if other Ford methods should already provide sufficient support.

4.2.4 **Build a system model**

Here the users are intended to identify what the significant parts of the system are which are relevant to the strategy study. In reality everything should either be an input, part of the system or an output. The system forms a kind of “unit of analysis” to keep all the information consistent during the analysis. However in order to analyse the system performance it is necessary to further split inputs and outputs into wanted and unwanted types, and the system design into things which can be changed and those which cannot.

The P-diagram is necessarily incomplete and conceptual and starts from a simplistic view of the intended functions of the system; but users are encouraged to also look for significant side-effects of the system’s function to enable them to integrate the unsustainable side effects of the system’s intended function into the analysis. Timescales are also important because different amounts of the system design may be changed during them and different kinds of resilience may be desirable or achievable (Winnard, 2012c). A handy and familiar example for most users will be found and used to illustrate each step.

A simple version of the P-diagram is repeated below in Figure 5 for reference.

- Consider the system as though it is an abstract concept. Identify the significant parts of the system using the prompts (see fig. 3 earlier) and draw a conceptual P-diagram of the system. *The P-diagram is drawn from the point of the system’s owner- the stakeholder who makes decisions and can change its “design”*. The system will be complex so can have multiple inputs, outputs and functions happening all at once; concentrate on the most significant for the study. A simpler version of the P-diagram is shown below.
From the earlier short description of the system function write down a list of the things the system is intended to do (ideal functions) “in normal circumstances” (e.g. for a simple business model it might be “make money by making and selling cars to customers”).

Record any significant assumptions as you progress.

Are there different (significant) functions for different timescales (short, medium and long-term)?

Is there a clearly identifiable boundary for the system that shows what is included or not? If not the question or study may be too vague to proceed, or more than one study may be needed to account for different possibilities; it is advisable to define as clearly as possible for each study what is included.

Is there one ideal state for the function(s) all the time or should the system vary its output by responding to something?

What input signals is the system meant to respond to, to do this?

- Signals can be associated with (input) flows of information, physical materials or energy, and this includes money and human labour if appropriate

Do these have different timescales?
- Are there inputs which occur but the system is meant to ignore (often called noises)? This can be fluctuation in the “real” intended signal which does require a response, or something completely different such as a variation in how users interact with the system or ageing of parts.

- Do these noises have different timescales associated with them?

- Also record what effects it has on other significant stakeholders within the functions and errors. It may be helpful to use a Shared Value diagram to do this.

- What can be changed (control factors) to alter how the system responds to both kinds of input? That is, if the system’s design is fixed how would its owner, manager or user control it?

- Is there an existing set-up for these control factors on an existing system or a nominal one for a new system you are designing?

- Can the system produce error states normally as well as ideal functions? This can be too much, not enough, or a poor quality of the ideal output in some way- or some built-in side-effect. Negative unsustainable impacts such as pollution, costs and waste count as errors.

- What unusual things might happen to both the input signals and noises and what effect do these each have on the system outputs, both ideal and error?
  - If it is not clear initially what is a signal and what is a noise it may help to consider everything simply as “inputs” and try to separate them in more detail later when considering the system’s sustainability and resilience
  - Similarly errors and ideal functions can be considered together as outputs at this stage if required

- Can the errors and ideal outputs coexist, and do any of them tend to change together?
o Record why you think these outputs are linked to certain inputs or other outputs, and whether they are related to certain timescales for later use.

o Do the outputs of the system feed back into its input side, and how quickly and directly?

o Now that you have all these elements, can you describe the system function(s) in detail, that link all these elements together?

  ▪ Write a more detailed description (in words) of each function, covering which inputs it responds to and how, what any control factors do, which noises it is susceptible to and why and how ideal functional outputs and errors arise.

  ▪ Describe how the functions relate to each other if there is more than one.

  ▪ Every system element should appear in at least one place: if any does not, check whether the function descriptions are correct; or if the element is redundant or not actually functionally connected inside your system, remove it (if you are unsure, leave it in for now).

• Now the system description is complete consider its performance:

  o Can you establish how you might measure the system function’s resilience: how much the desirable outputs of the system vary with changes in the various wanted and unwanted inputs, and their relationship to the errors? (you do not need to do this right now in detail)

  o Are there significant aspects of the system that you may have missed? (Look for unexplained changes in the outputs, side effects or system elements which are not connected to the rest of the system). If yes and they seem likely to have a big effect on how it performs or fails, it is advisable to stop and seek further information before continuing. If yes but they appear not to have a significant effect record this as an assumption.
- How accurate is the information you have and will it affect your conclusions?
- Record important assumptions made to build the system “model”
- You should now be able to populate the P-diagram – if the system’s significant functions are simple enough, put a short description of how the outputs relate to the inputs inside the function box. Otherwise record these on a separate larger diagram or document.

- If the system information is verbal and not numerical the analysis required by the SuReSDS study can be done from this point on using word-based descriptions. It will not be as possible to form an idea of accuracy or precision but the questions below should still be considered in a more general way.

- If the system information is a mixture of numerical and verbal or estimates from current numerical data, then the system will be described by a mixture of data, equations, assumptions and interpretations. These need to be recorded and some attempt at assessing their effect as below recorded.

- If the system information has numerical content there are some additional steps:
  - Develop mathematical equations to link the signals and noises to the errors and ideal outputs. Data may be inserted into these in different ways depending on the questions posed by the study.
  - How accurate is the data you have and will this affect your conclusions?
  - How precise is the data and will this affect your conclusions?

- Check that data is available- or reasonable estimates- about the effect of the strategy on the system
  - Without this it will be difficult to proceed

- Check that similar data is available for any alternative versions/designs of the system (design options)
  - This is needed if alternatives are to be compared effectively
• Record any assumptions used to generate numerical data and equations, interpretations, forecasts and estimates.

4.2.5 Analyse the initial system design

Usually there will be an existing system or a nominal design which is used to set up the general P-diagram and verbal or numerical system model. This forms a benchmark against which changes and other design options can be tested to support the strategic study. For new systems this is a little more complicated but a proposed system design can be used for this benchmark analysis. The steps shown below may not all be needed if the scope of a strategic study is very narrow. If so a set of rules for eliminating unnecessary steps is needed but this has not yet been developed, and may come out of the case study work.

When the system is complex this kind of single factor analysis (even when numbers are available) will not pick up on non-linear behaviour (Winnard, 2013a); something which is very difficult to account for in a verbal analysis but may be possible to manage within a numerical model. However this would require more data modelling and processes from elsewhere and is not intended to be specifically included within SuReSDS. The approach should instead identify a need for this and trigger the act of further modelling using whatever system or tools the company already employs.

In the full version of SuReSDS it is intended that alternative futures can also be included through the use of simple scenarios, during the systems analysis phase. This would add extra steps and information gathering requirements in the preceding scoping and modelling phases and in the analysis here. However at this point in time this part of the technique has not been fully developed and so the analysis shown is simpler.

Analysing the “benchmark” or nominal system design function

This section assumes the control factors are not adjustable when your system is active: if they are adjusted when active and there is no “normal” or nominal setting for them proceed to the “assessing effects of the strategy” section. It also assumes that either there is an existing system design or there is a nominal design which has been discovered during the previous work to describe the system.

• Performance against signals- current or nominal “benchmark” system
  o Identify key signals if any from the study question (purpose) and their range plus any shocks or gradual shifts which are expected to occur normally, including any which do not eventually disappear
How do these affect the system outputs?

Does the system perform well against its declared purpose for all of the possible input signals?

Is there a nominal signal which represents “normal conditions”?

What is the nominal sustainability of the system: the ratio of wanted outputs to unwanted ones for this signal?

- This is when it becomes important to distinguish between the output types
- Consider all the stakeholders when defining what is wanted or unwanted
- Sustainability is effectively a subset of the performance criteria
- It may be necessary to check that outputs which are sustainable short-term are not unsustainable long-term

What happens to the sustainability of the system outputs when the signals change?

Checking for sustainability issues in the output performance

Can the system always produce the correct desirable outputs and go back to its original sustainability quickly, following the signals?

Are there any signal states or changes which could make the system go out of control and produce large errors and a big increase in unsustainability? (This includes ceasing to function and is one sign of a resilience problem)

Are there any other existing issues with the outputs of the system in this nominal state?

Conversely, are there any signal states that make the system more sustainable?

Resilience to noises – current or benchmark system & nominal control factors
Identify the key noise(s) for the study from its original questions—the one(s) of most interest and its (their) likely range

model or describe what happens to the system across this range

If there is no immediately identifiable key noise do the same for the most significant ones;

or find the noises most strongly linked to the most significant control factors and model the effects of those

Do the noises and signals go together in some way or are they independent?

Find the system’s built-in **passive resilience**, measured (or expressed in words) as the ratio of change in the system’s response to change in a noise; this should encompass both desirable and undesirable parts of the output and may require different metrics for each

If you analyse more than one noise there will be different resilience metrics/descriptions for each

The resilience may be different for different kinds of input (e.g. shocks as opposed to slow changes)

- If it is not clear what is a signal and what is a noise it may help to consider instead what the system will do if a normal input flow of something is stopped, too high, too low, poor quality, or intermittent in different ways, or if it receives a flow of something not normally present

Do you think your system is complex and non-linear?

If so can you account for this in this analysis, or is a separate piece of work required to analyse this?

The resilience may change with the conditions; in a numerical model check whether the resilience is always the same or whether it changes

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5 A useful conceptual technique borrowed from FMA methods
with noise or signal status. (In a verbal description estimations may be possible but generally this level of analysis may not be feasible).

If the system design itself cannot be modified then the preceding steps should identify the innate sustainability and resilience of this design. The strategy study should in this case be proposing this design and so these innate properties of the system performance identify what the effects of the strategy would be. This therefore should answer both the restated study questions in terms of sustainability and resilience, and also the original questions.

### 4.2.5.1 Assessing effects of the strategy- changing the system

However most strategy questions are by their very definition looking to change something significant about the system they concern, its design in other words. When the system design can be modified as part of the strategy study the whole “assess system” process needs to be repeated to assess the modifications proposed against the current system. Or, to assess different alternatives for a new system. There are two main levels of design change to consider; changes in control factor “settings” (more minor) and changes to the system function itself, including which control factors are used (more major).

#### 4.2.5.1.1 Control factor change effects

This section looks at effects of the strategy where the internal functions of the system are not changed but the “settings” that control them can be changed. They may be available for proactive or reactive change “live” when the system is active or they may only be possible to change in between uses of the system. Adding new control factors is covered under “system function design change effects” below.

- choose combinations of control factors (minor design options) which are significant and appropriate within the strategy and the study question(s) (feasible sets given the study scope) and repeat the previous steps from the “analysing the benchmark system” section to investigate the functional performance, sustainability and resilience of the system in each case:
  - If no obvious benchmark and alternative values of a control factor are evident, choose the extremes and a middle or nominal (best or most likely) setting for it.
  - If the control factors do not have obvious combinations it may be necessary to vary them individually
- If the study question is too undefined and the system design too open this leads to many factors to be varied. This can require a design-of-experiments or Monte Carlo type analysis using another tool outside of SuReSDS

  o Identify how each set of control factors (design option) affects the system performance, its resilience and sustainability

  o Look for combinations of control factors which give the best combination of performance against the signals (including sustainability) and resilience to all the noises studied.

- If control factors are actively “tuned” when the system is active to allow it to respond better to changing signal and noise regimes, this gives an adaptive form of resilience (metrics to be established).

  o Describe how the system’s medium-term adaptive resilience works and could be measured (time-related metric required).

  o If there is no one optimal setting and adjustments need to occur all the time, how can the signals and noises be detected to allow the system to be adjusted in a timely manner?

  o Can the control factors be tuned fast enough to follow the system’s inputs or is there a lag (or alternatively, an over-fast reaction and overshoot)?

  o What are the effects of any lag on the system performance, sustainability and resilience?

- If the control factors are fixed once the system is performing but can be changed before it starts

  o Each of the alternative control factor combinations still represents a new (minor) design option for the system.

  o The system cannot adapt whilst it is operational- how might an issue be detected and the system function stopped so control factors can be changed?
• If there is no one optimal combination for all conditions, what other criteria can be used to choose the control factors?
  o Consider whether the project risk or cost can be used to rank the available options as well as performance, sustainability and resilience

• Consider whether any significant factors have been omitted that would change these conclusions

4.2.5.1.2 System function design change effects

If the system functional design- how the inputs and outputs relate to each other and the choice of which control factors will be used- can be altered, not just the control factors, then this allows for more major design options\textsuperscript{6} to be created. This includes adding or removing control factors as well as system elements. Each system design could have more than one combination of control factors possible within it and evidently this could make for very large studies with a lot of data. If the design options are too open and the study questions do not indicate what the design alternatives are and limit them to a number which is practical to study, some other work will need to be done to find or choose these limitations before returning to SureSDS.

The creation of new design options is another major phase within SureSDS but any option needs to be assessed which is where the flow returns to the steps included in this “assess system” phase.

• Create or identify major system design options appropriate to the study
  o This will usually be driven by a current issue, or future risk or opportunity
  o The options need to be measured against their ability to handle these risks or opportunities as well as to deliver their intended function(s) sustainably and resiliently as before

\textsuperscript{6} Although Ford employees usually tend to call these design options “scenarios” this word is used within SuReSDS to indicate external future scenarios against which any design options will be tested. This is to keep the terminology consistent with other risk-related and business methods, particularly Transition Engineering. Ford do also refer to future business-context scenarios as “scenarios”, confusingly and so care must be taken to establish the SuReSDS definitions with users.
Some studies start with a set of pre-chosen options but some require new ones to be found.

Make sure that the functional changes to the system are clearly identified to allow them to be analysed whether in words or numerically.

- It is sometimes assumed that a system is not actively performing whilst large changes are being made to its design. However managing this change is possible if for example big changes are made slowly. This transition may need its own strategy to maintain functionality whilst changing and this needs to be recognised as an implication at least in any study.

- Each option needs to be analysed in the same way as for the “nominal” system design steps above, to identify whether one is more resilient and sustainable than the others.

  - This means repeating the method steps from very early on, i.e. analysing how the option changes the major elements of the system, its P-diagram, and performance, sustainability and resilience.

### 4.2.6 Intended outputs from this phase

The end aim of the “assess system” process is to have a reasonably rigorous understanding of the current or proposed system (and any design options) in what are envisaged as “normal” conditions, and its significant impacts. This alone could be used as the basis for simple short-term strategy recommendations, but this phase of SuReSDS also intends to look at resilience: what happens when conditions deviate, suddenly or slowly, as a result of unsustainability in the system itself (the product or company for example) and/or from other systems (such as other firms globally). The study’s further generation and comparison of options and their ranking and selection for resilience to more than one future scenario, form the other phases of SuReSDS.

Now that the basic methodology of the “assess system” phase of SuReSDS has been described, in as far as it has been developed, its application within the first 2 case studies can be reviewed.

### 5 Case Studies –Overview

There were two related pilot case study samples undertaken during the six months. The first (called 1A in Table 1 below) was a simple pilot study was used to test the
application of a P-diagram approach to provide a system model. It was based on a previous strategic study by Ford and the results were checked against the confidential results of this. The scope and system from 1A were then used in a simplified form with surrogate data in a second case sample, 1B. The purpose of this is to allow a fuller exploration of how a richer system model can be built using SuReSDS, and how system sustainability and resilience might be established within it and integrated into decisions. This second case sample is still ongoing, so a summary of the work so far and any interim conclusions is given here.

<table>
<thead>
<tr>
<th>Number</th>
<th>Case study sample</th>
<th>Date</th>
<th>Company</th>
<th>Sector</th>
<th>Size at date of study</th>
<th>Case Level</th>
<th>Test type</th>
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<tbody>
<tr>
<td>1A</td>
<td>Fleet (platform) CO2 strategy</td>
<td>Q3 2013</td>
<td>Ford Motor Company</td>
<td>Automotive OEM</td>
<td>Very large 10k+ employees (172k on LinkedIn)</td>
<td>PSS</td>
<td>Offline Pilot</td>
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<tr>
<td>1B</td>
<td>Sustainability &amp; Resilience of Fleet (platform) CO2 strategy</td>
<td>Q3 2013</td>
<td></td>
<td></td>
<td>$134 Bn (2012) rev. $5.6 Bn profits 65-70 sites globally</td>
<td>PSS</td>
<td>Offline</td>
</tr>
<tr>
<td></td>
<td>Dummy data and reusing P-diagram &amp; topic from 1A</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Table 1 - details of first 2 case samples**

An overview of the sample details is given in Table 1 above. Both samples were carried out within Powertrain Engineering at the Ford Dunton R&D site and based on a CO₂ emissions study by the Sustainability Planning function. The case study samples were discussed at various points with internal experts as the team who performed the original work were not available.

Specific research tests for the three sets of propositions (covering the Theory, Process and Content of SuReSDS) had been developed from the original research question and laid out in detail as questions in the last six month report (Winnard, 2013b). These tests derive from the original research brief and central research question developed by Ford and the RE. They reflect both the company’s need for the approach to “add value” and the needs of academic rigour (ibid.). In each case study a subset of these test questions was used to guide the design of the case sample and the collection of evidence.

In terms of academic rigour the sample must provide this evidence to support the creation of a “logical model of proof” through building construct validity, internal validity, external validity and reliability (Yin, 2009, p41). These needs and the general research design are addressed through the use of a case study protocol which is designed to structure the data collection and be common to all the samples, to ensure good quality research. This protocol (as well as the underlying design) is typically developed through the use of pilot case study samples such as this, allowing areas such as criteria for case
selection, methods of investigation and details of the research process to be finalised (ibid., p92-94). As this project is developing a decision-support approach the protocol also enables consistent testing of and any necessary further development of the SuReSDS approach details. The learning in each of these areas is to be reviewed at the end of every case sample so that the protocol, the research design and the approach itself can be improved accordingly for each subsequent sample.

The next two sections give a summary of each case sample and some reflections on what was discovered during each. Fuller details of how the SuReSDS “assess system” method phase was applied in each of them, and the detailed results of this process, are given in Appendix A for 1A and B for 1B. The data used in 1A is confidential to Ford Motor Company so only descriptive information can be given in this report and its appendices.

5.1 Case Study Sample 1A (Pilot)- Platform X CO₂ Strategy Study

5.1.1 Aims

The first case sample was selected to allow a simple test of the most core part of SuReSDS- the use of a Taguchi Parameter Diagram (P-Diagram) to collect and analyse information about the system involved in a decision. The aim was to develop and record the detailed application of SureSDS and to show whether using this type of robustness engineering, specifically the P-diagram-based “assess system” phase, could reproduce the same results as a previous Ford study. If it could do so this general method of forming a system model which underlies SuReSDS would be considered proven.

5.1.2 Specific Research Questions

This sample therefore was not designed to address any of the more complex and focussed research tests already developed. Although the system model approach is based on a simplified form of a long-standing and commonly used engineering design technique (RED) this still needed to be tested in the new context of SuReSDS and strategic studies. The specific research question can be summarised as:

“Can the P-diagram approach replicate the results of a previously completed strategic study within Ford?”
5.1.3 Background – Description of the Original Study

The original study was conducted by a number of Ford employees around the globe to inform senior managerial decisions about future “platform”\(^7\) CO\(_2\) strategy. That is, a strategy which aims to meet an internal corporate target for average vehicle use-phase CO\(_2\) emissions\(^8\) of a family of similar-sized, closely-related vehicles (variants within the product “platform”) which are sold within Europe. This target is derived ultimately in a strategic decision-making process from limits set by the European legislation, covering mass-adjusted average vehicle fleet emissions for each company selling light duty vehicles (including passenger cars) within the region (EC, 2010). The original study was concerned with how the planned design and volume mixture of vehicle propulsion technologies\(^9\) used on a particular-sized platform (called X here) could be altered to meet a specific target derived from a likely future legislative emissions limit under the same law.

The initial criteria on which the sample was chosen were that the study was strategic in nature and was already complete so offered the chance to compare the results of offline testing of SuReSDS with the recent study (Winnard, 2012b). The team responsible for the study also matched the intervention point in the decision-process identified previously: lower-management level and specialist or expert employees typically used to prepare strategy study support information (Winnard, 2013b). Finally, the study contained a sustainability-related issue (CO\(_2\) emissions) which made it suitable for exploring part of the SuReSDS process, bearing in mind the original research premise of using resilience as a way of framing sustainability issues. It was not known before the sample was begun what the related resilience issues might be, but identifying them and using them to help analyse the study’s system is considered to be part of the extra value the approach might offer users.

5.1.4 Method of Case Study Pilot

The case study sample was carried out in two main phases; first analysing the original study data and secondly applying the core SuReSDS P-diagram then comparing the results of this to the original study outcomes. These scoping and system model phases are part of the “Assess System” section of the SuReSDS method, outlined in bold on Fig. 1. The third element of this method section- analysing the system’s performance sustainability and

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\(^7\) A “platform” is a group of similar-sized vehicles sharing many systems and components to optimise economies of scale, particularly in manufacturing costs

\(^8\) measured at the exhaust during New European Drive Cycle- (NEDC as set out in UNECE Regulation 101) - statutory product testing, and referred to often as “tailpipe emissions”

\(^9\) Often referred to as “powertrains” and including the engine, battery or other power source, and all other closely-related systems from the air induction system to driveshafts.
resilience (and looking at different options) was not included in the pilot for reasons of simplicity. The original study was also felt to lack sufficient data to allow this level of analysis. It was also decided that a different case sample using surrogate data which could be shared would be a better place to explore and discuss this further part of the method.

Most of the information about the original study was available as raw (mostly numerical) data in spreadsheets, and presentation slides associated with the study which had to be interpreted to apply SuReSDS. There was also limited legacy knowledge about the study passed on from an original team member to their successor in the UK, a Sustainability Planning expert. This extra information was obtained during meetings by interviewing this same expert as the key informant; this was done to ensure that the pilot study only utilised the original data and interpreted it as correctly as possible.

The full account of the steps used in the study is laid out in Appendix A in detail along with the information about each step. This process can be summarised by reference to the method in section 4.2 as execution of the study-scoping and system-modelling parts of the “assess system” method. The case sample and its results were discussed with the key informant intermittently as it progressed, and also if questions arose about the original study. The major conclusions were identified from this feedback and from reflecting on the experience of carrying out this pilot study.

5.1.5 Results of Case Study Pilot

The results are summarised here but given in more detail in Appendix A. Two purposes were identified for the pilot sample, operating at different levels within the research. In addition to the specific research aim referred to as a question in section 5.1.2 there was the strategic purpose of the original study which the pilot was seeking to reproduce. This was needed to scope and structure the SuReSDS exercise within the sample and identified at the start of the process as:

“How can platform X electrified powertrains be chosen to meet the 2025 platform average CO₂ emissions target?”

The original study only concerned CO₂ emissions so was missing a lot of information such as costs which appear usually in Ford strategic studies; this and the pilot purpose limited the complexity of the system analysis performed. The system itself was quite hard to identify initially as the study concerns a plan for the future together with how possible strategy decisions might affect its ability to deliver against the legislative target. Eventually
by working through the scoping steps the system was identified as the “planned platform X fleet” and its general function identified.

The system’s ideal function needed some realistic thinking to identify and was first described as “Produce average CO$_2$ emissions less than or equal to the platform target”. As this average is made up from the contributions of lots of different vehicle variants within the platform, this was expanded slightly to become “Produce a combination of emissions from different variants such that the average emissions do not exceed the platform target”. The method steps were then followed in sequence to create a more detailed system model using the P-diagram, identifying which information corresponded to which parts of the diagram.

The results of this exercise are shown above, indicating which elements were not present in the original study. Two different sets of equations were then developed for the same system so that it could be used to backcast (work from the target output to find some key missing control factors) or forecast (work from selected input and control factors forwards to see if the target was met). After several false starts the forecasting function model was populated with data from the original study and used to recreate the results of one of the strategy options$^{10}$ (control factor combinations). This was discussed with the key informant, who verified that the model now reproduced the original data. Therefore the SuReSDS method had been successfully used to reproduce one of the answers to the original study question.

$^{10}$ These detailed equations and data cannot be shared but a simpler version with surrogate data used in case study 1B is available within Appendices B and C.
Due to the simplicity of the pilot study and the lack of different kinds of data (such as costs and social effects) within the original study it was decided not to develop further system models to reproduce more of the original study strategy options, as this would take too long and have very limited scope for exploring the SuReSDS method further.

5.1.6 Review of Case Study Sample Results

5.1.6.1 Answer to research question

The pilot demonstrated that it is possible to reproduce a typical numerical Ford strategy study. So the answer to the research question posed by the pilot; “Can the P-diagram approach replicate the results of a previously completed strategic study within Ford?” is “Yes.”

5.1.6.2 Other useful outcomes

The key informant indicated during discussions that if they were to do a similar study the use of these parts of the SuReSDS approach would be a suitable way to structure their information.

For strategy questions it is already apparent from this pilot that it may be important to differentiate in the system model between what the plan is and what actually happens later. This relationship was noted for further exploration in the next case study sample.

5.1.6.3 Reflections on the case study method and protocol

Some difficulty was experienced during the pilot, due to inconsistencies in the original data compounded by the absence of any original team members. As with many company studies there was no particular reason for the original team to make a separate record of the methods used or process followed, including how and why assumptions were made. The key informant was needed to help interrogate the data, then check and confirm the mathematics of both models afterwards.

The main learning for the protocol of future case study samples therefore was that for those based on studies carried out by the company, at least one original team member needs to be accessible to the RE for interaction whether by interviews or discussions. This is necessary even on recent “offline” samples or complete studies, to enable good quality and timely data-gathering. This is because studies are already know often to be iterative, occasionally leading to inconsistent data files where only some parts have been updated; their processes are generally not recorded, leaving a great deal unknown. Access to the original team would also help distinguish misleading information more quickly which can be
discounted. This observation also highlighted that recording sufficient information about the process of an original study in the first place, to compare it to the new approach and with any interviews of informants about their experiences afterwards, will be important in some cases. It may be this should be done by observation where possible and where access to “live” studies can be obtained. However with long iterative studies this may be too labour-intensive so perhaps interviews about their process with the team members could be used instead.

It is planned to review and revise the current research test questions used as guidance, the data collected and the whole research design, once the first 2 case samples have been completed.

5.1.7 Conclusions

The proposed SuReSDS systems analysis approach for building system models has been proven on one numerical PSS-level pilot sample. Moreover it provides a way to structure such analysis which appears to be compatible with the requirements of potential users, in this limited context.

Bearing the reflections on the method in mind and the need to be able to discuss details of the case study data outside the company, for the next study it was decided to reuse the scope and system model from this pilot study but to substitute publicly available data. As this data would be selected by the RE and used to create new results there would therefore be no requirement or ability to compare it with an original study, and thus no need for information about an original study’s process. This approach was considered appropriate because the next sample study was designed to further explore the SuReSDS method and its capabilities rather than to produce results for use within real-world decisions.

5.2 Case Study Sample 1B (Pilot)- Sustainability and resilience effects of Platform X CO₂ Strategy

5.2.1 Aims

This sample started with the system model verified from sample 1A but then added surrogate information which was available publicly, to allow more free discussion of the results. As the main purpose was to further explore the detailed techniques of using the P-diagram within SuReSDS, and not to produce accurate models for real-world decision-making, it was decided to use current data about the system in most cases rather than produce labour-intensive accurate future estimates normally required. The focus was still the “assess system” step of the method, but with more of its proposed steps this time. The
intention was to carry out some simple analysis within the steps and identify what kinds of sustainability and resilience might be measureable within a system model using simple numerical data, and whether it was possible to investigate how they relate to each other.

In particular the addition and integration of extra metrics (types of indicator) for any “missing” areas of sustainability was expected to be key. As a role for Shared Value concepts had not yet been identified the potential for use of Shared Value thinking was also of interest. As before the study was to be discussed and reviewed with key informants to obtain the views of potential users. Any important findings about the process of the analysis were to be used to refine the instructions for the approach. It was again expected that the case study protocol, the research questions and the approach itself might all be adjusted from the findings.

5.2.2 Specific Research Questions

Again this pilot was limited in scope to allow a limited number of focussed research questions. Summarising the aims above gives the following questions:

- Can the system model from 1A be populated with public data successfully?
- Can the full P-diagram approach be used to expand the system model to integrate system sustainability and resilience into the analysis?
- Does the approach establish meaningful measurements for these properties?
- How do they influence the strategy study results?
- How does Shared Value as a concept fit into this approach?

Plus two aimed specifically at the key informants.

- Would this full “assess system” approach be suitable for use within Ford strategic studies?
- What benefits might it offer to users compared to existing techniques?

5.2.3 Background

In this case there was no original study conducted by the company. The system model was inherited from study 1A however and the analysis “purpose” from 1A was also reused (how the X platform fleet variants can be chosen to meet a future emissions target). This was used to drive the SuReSDS process. The model used in this study was simplified 5
variants to make the test simpler; with one each of the different types of powertrain: gasoline engine, diesel engine, hybrid electric vehicle (HEV) gasoline, Plug-in HEV gasoline (PHEV) and battery electric vehicle (BEV). These were considered the most mainstream variants available currently and to give sufficient variation for exploring the system model and approach method.

5.2.4 Method of Case Study Sample

This sample study fell into three main phases; populating the original system model equations with substitute data, performing a simple set of analyses with just the minimally-modified original model and surrogate data populating the variables, and then expanding both the P-diagram system model and data to allow a wider analysis of sustainability and resilience. This last phase also aimed to discover where the practical limits to a numerical SureSDS study might lie. As before it was possible to discuss the end results in informal interviews with the same Sustainability Planning Specialist, the key informant from 1A, to check the mathematical validity of the results, and gain feedback on various areas important for answering the research questions. It was quickly realised that it would also be useful to discuss the method itself in more detail and so a second key informant was found, the Design Process Specialist who develops local FMA and RED tools and their associated training. The intention was to review the SuReSDS method with this informant in more detail.

Throughout this study the SuReSDS method steps were again used to structure the analysis. This sample is still in progress and what has been done is not yet fully analysed or written up, so a summary of the progress so far is given here. These interim results have in part been discussed with the key informants and their feedback is included. Further details including the step-by-step use of the SuReSDS method steps with their corresponding results are shown in Appendix B.

5.2.5 Results of Case Study Sample

At the start of this sample the initial scoping steps of SuReSDS were carried out to check that the carried-over study purpose and system scope were still the same, so that the model would be appropriate. The internal study question within SuReSDS was reconfirmed as “How can platform X electrified powertrains be chosen to meet the 2025 platform average CO₂ emissions target?”

The carried-over model of the “planned platform X fleet” was also considered a suitable starting point. However it was recognised that the model lacked any error states or noises (because these were absent in the original company study used as the basis of Pilot
1A) and thus would need modifying at later stages of analysis. This modification would be required to enable further testing of the SuReSDS method. The first activity was established as the population of the model with new data to provide a starting point for all the following analysis.

5.2.5.1 Populating the original model

To create a full set of dummy data to test the approach, CO₂ emissions of the best existing models of gasoline diesel and BEV Focus vehicles within Ford were used, and the most popular competitor model for the PHEV (which happens to be Toyota’s Prius), plus a very near HEV (the Toyota Auris). This mid-size platform was chosen as it is very popular, its mass is very close to the European average so requires little or no adjustment of the EU CO₂ emissions legislative target, and there are several novel powertrains meaning there is sufficient data available. A future value for the emissions legislation was chosen from current predictions and a slightly lower internal target chosen.

The backcast model of the planned system with 5 variants was populated, using the dummy data chosen and an internal target slightly lower than the legislative one. This allowed the solution of its equations as before in case sample 1A to find a volume of HEVs and PHEVs. It gave a successful set of control factors for the system. This constituted Design Option 1 for the system and run 0 (zero) of the model which was to be used as the reference point for the rest of the study.

However this system design could not be analysed further with system elements still missing from the P-diagram. The remaining method steps for forming the system model under SuReSDS were therefore carried out to revise the model. It was realised during this process that the “planned X platform fleet” system in this analysis actually has two functions; allowing the planned system to be designed to meet its future emissions target, and driving the delivery of the actual emissions when that future date arrives. (This might be argued as a second linked system but for simplicity’s sake it was decided to keep this as one system for this study). These two functions are partly reflected in the two sets of equations; the backcasting set is used to find the planned variables to meet the future target and the forecasting set has to then be used to find out what the actual emissions will be. The actual average emissions are defined by actual CO₂ emissions for each variant, which was identified as a set of control factors because they are mainly under the company’s control, and the actual sales volume for each variant, which was identified as a set of noises as this is mostly not under the company’s control.
An additional error state was also found. The legislation imposes a fine if the manufacturer’s average emissions exceed the limit. The output of the system therefore produces two mutually exclusive results; either average emissions within (or equal to) the limit and no fine, or emissions above the limit and a variable fine calculated from the actual emissions average excess and actual sales volumes. The model was updated to reflect these extra factors and is shown in Figure 8. The system performance could now be assessed fully using the proposed SuReSDS steps.

![Diagram](Figure 8- updated system model with errors, actual and planned variables)

### 5.2.6 Assessing the minimally-modified system model

The input signals to the system (the legislation target and internal target) do not change so these will not cause the system outputs to change. The only source of change without altering the system design therefore, is noise; the way that actual sales volumes vary from the planned ones. Initially resilience of the system output to noise was of interest and a simple measure for this system property needed to be identified.

The simple in-built resilience of the system design was identified as the change in the system performance relative to a change in a noise factor. To test this the actual volume of the most numerous vehicle variant in the design (the PHEV, variant B) was varied to give a noise effect and the system resilience calculated. The total volume of vehicles was held constant to enable a better comparison with the reference data. As might be expected the platform fleet’s emissions varied with the proportion of PHEVs in the fleet; because this variant is relatively clean more of them means a lower average emissions figure.

Two different ratios were calculated for the resilience and the results are shown graphically in Figure 8. They both appear linear- that is, the ratios remain constant and the system output does not become more or less sensitive to the actual volume of PHEVs as
this actual volume changes. Due to the way the equations were set up variant B and variant C (HEV) make up a constant volume also so if B’s becomes too large C’s sinks to below zero. This is impossible so was identified as a limit within the simulated system and shows in Figure 9 as the point where the volume of C crosses the x-axis.

![Figure 9](image)

**Figure 9- variation in actual emissions against target (y axis) with PHEV volume (x axis)**

Various measures of this simple type of resilience were explored using different noises to try and discover whether it is always linear for this system. For some simulation runs some control factors were also varied –effectively producing different design options of the system which vary from Design Option 1 in minor ways. The aim is to explore the resilience (and later, sustainability) of these options within SuReSDS. This work is still ongoing and has not been fully analysed so the details are not included here.

It was decided early on to attempt to add some wider sustainability concerns to the system performance to see if this is where Shared Value concepts (Porter and Kramer, 2011) might be helpful.

### 5.2.7 Expanding the P-diagram: Adding extra sustainability elements

Once the modified CO₂ model had been set up further parts of the system were added to attempt to reflect the wider meaning of sustainability; this is a new and experimental part of the method. For this study it was decided to use the classical “3 capitals” of Triple bottom line thinking: sustainability; environmental, economic and social. This was because it covers a full definition of sustainability and is relatively widely accepted by business. It was also decided to tackle the addition of these elements one at a time to see what effect they had on the system.
At this point an expanded system function was proposed: Produce average CO2 emissions less than or equal to the platform target and identify the effect on economic viability, society and other environmental impacts.

This reflects the fact that the initial system model has not been designed with sustainability particularly in mind. Eventually the system function might be modified once the system’s impacts were known, to add extra criteria to reduce impacts or improve beneficial outputs of the system. For the moment this proposed function can be used to guide the expansion of the system model.

5.2.7.1 Adding economics

The system model already contains a fine in the description of its ideal and error states. In theory metrics for different kinds of economic impacts particularly costs are relatively easy to find, without resorting to new approach elements as within business and industry parts and development cost are always being balanced against performance. The main issue was finding feasible metrics and accessible public data to represent economic impacts at platform level within this study.

A number of unsatisfactory indicators created from public data were tried out and attached to the model. They were designed to simply reflect (or be driven by) the system’s emissions performance rather than to add extra functions to the system. At the time of writing no satisfactory metrics had been found; for two reasons.

Firstly the P-diagram is drawn from the point of view of the entity which can make decisions about its system design- in this case the company. Yet many impacts of the system occur to other companies within the economy or other people within human society. Some of these impacts are already reflected in attributes which companies measure internally for their products, such as Cost Of Ownership, but not all. This raises the question of whether the model needs to capture all of the impacts of the system’s function in any one of the three areas, or whether it should only cover the most significant. If the most significant general impacts are not affected by the strategy under study, perhaps the model should ignore these and instead focus on those areas which are significantly affected.

Secondly companies do not share most of this economic data, believing that it could be used as competitor intelligence by their rivals, or adversely influence investors for example. A case in point is the R&D cost of developing a new vehicle: this varies a great deal and it is impossible to form a view on the size of typical costs to develop say a hybrid powertrain as the information is simply not visible outside of companies. More work is
required therefore to identify any indicators at the right scale for the model, how to integrate them and to find dummy data. It was decided to leave the fine within the model as the sole economic indicator of performance for this initial simple study.

5.2.7.2 Adding social impacts

The main innovation and progress came when social impacts were explored. Some reflection indicated that normally the social impact to the company of the decisions (unless they radically alter the company’s products and services offerings or the company is exceeding requirements to change its reputation) is rather neutral. The conclusion that the social impacts or value of the platform CO2 strategy lie with other stakeholders led to a key new step; the use of Shared Value (Porter and Kramer, 2011) concepts to create a new view of the system’s function(s).

With any commercial PSS there must be some benefit to the system’s users which is what they are prepared to pay for. It was realised that by drawing a diagram of the values exchanged between different “stakeholders” representing the various sustainability capitals, this relationship could be studied and the effects of the strategy considered. The case sample had already identified three main stakeholders earlier in its process; the company, the environment as represented by proxy by the EC CO2 emissions law and customers. These last are the subset of society buying the new vehicle and using it (see Appendix B). These are the representatives of each “capital” most strongly and directly affected by the system’s functions, that is by the platform fleet’s emissions.

First a generic view was drawn for the value exchanges inherent in the first purchase or use of a new car (to keep the diagram relatively simple); the functions which are the fundamental purpose of the system. Some lateral thought is required to make sure that a PSS view is taken to capture all the things that the system does not just the hardware. The most significant stakeholders involved in interacting with the platform of vehicles were added for each of the three areas (the EC legislation as a proxy for the environment, customers as a group representing society and the company itself representing the economy). The most significant flow of “value” in each direction between each pair was then added. There are evidently several flows between stakeholders and this diagram could be refined with some further work but for a simple analysis this was considered sufficiently clear.
The likely effects of the platform emissions strategy on these flows were then considered and described qualitatively. These were overlaid on top of the diagram as boxed arrows to show whether they improved or degraded these flows, as shown above. The blue boxes indicate what seem at first thought to be neutral effects, green boxes show improved flows, yellow boxes could be variable depending on which subset of the stakeholder groups is being considered and stripy boxes could have a positive or negative effect; more research or specialist input would be needed to identify exactly which. This image was then used to derive new metrics for the social impacts of the strategy.

The intention of this diagram initially was not to become overlaid on, or part of the system P-diagram but to inform its contents. It should prompt users of SuReSDS to work out what other functions or damages arise from the system for other stakeholders, so that they can be included in a the system function and particularly error states as a description of what the system really does.

Figure 10- Shared Value diagram for vehicle platform, 1B
As customers are really paying to access mobility for themselves and those people (and items) important to them, two platform-level indicators for this mobility as a system function were created and investigated; the average vehicle range for the platform and the number of customers with “range anxiety” (associated with battery electric vehicles - BEVs). The range of the vehicle is a way of comparing how far each can travel without having to restock with fuel or electrical energy. The NEDC tests (UNECE, 2013) define statutory fuel economy figures in MPG for conventional cars, an equivalent for hybrids (MPGe) and an “autonomy” range in miles and km for electric vehicles. The fuel economy of the mixed-driving cycle for the current vehicles we are using for dummy data can be converted into a range by combining it with the size of their fuel tank. The results of doing this are shown in the table below.

<table>
<thead>
<tr>
<th>Class</th>
<th>Maker</th>
<th>Model</th>
<th>energy store/tank</th>
<th>MPG/ MPGe</th>
<th>conventional range</th>
<th>electric only range</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2013 Ford</td>
<td>BEV</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>100 miles</td>
</tr>
<tr>
<td>B</td>
<td>2013 Toyota</td>
<td>best PHEV</td>
<td>45 litres</td>
<td>134.5</td>
<td>1330 miles</td>
<td>15.5 miles</td>
</tr>
<tr>
<td>C</td>
<td>2013 Toyota</td>
<td>best HEV</td>
<td>45 litres</td>
<td>72.4</td>
<td>716 miles</td>
<td>1.25 miles</td>
</tr>
<tr>
<td>D</td>
<td>2013 Ford</td>
<td>best diesel</td>
<td>53 litres</td>
<td>67.3</td>
<td>784 miles</td>
<td>-</td>
</tr>
<tr>
<td>E</td>
<td>2013 Ford</td>
<td>best petrol</td>
<td>55 litres</td>
<td>57.7</td>
<td>697 miles</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2- calculated or given ranges of the five platform variants

However it is a common piece of knowledge within the sector that customers-private individuals that is- mostly do not buy their cars on the basis of range; and for most people vehicle selection is not even strongly based on fuel economy which is related to running costs. For the most part range doesn’t seem to matter, therefore, provided it is not perceived as being limited. As we move from the least efficient powertrain (conventional petrol) to the most efficient one which still uses fuel (PHEV) fuel economy and therefore range gets better-so if range is not an issue for petrol vehicles it will not be for the others. The glaring exception is the BEV with its limited range of 100 miles; this is reflected in the public and media’s usage of the term “range anxiety”. The BEV is the only one where range is perceived as an issue and mobility is therefore seen as limited.

So the average range of the actual fleet can be calculated to give an indication of fleet-level mobility, using the figures from Table 2; this will vary like the CO₂ emissions do as the make-up of the actual fleet varies. Or the level of customers within the fleet who perceive that they have limited mobility could be recorded. These could also be considered as two different aspects of the system’s outputs which (unlike the emissions compliance and associated fines) can happen simultaneously. This reflects the fact that although BEV buyers might feel they are limited, they do still have access to mobility. Adding the variables for both these metrics to the system model gives us the P-diagram shown in Figure 11.
This model allows extra equations to be added to the model to calculate the fines and the average range. As should already be clear the metric for those customers with potential “range anxiety” about their limited mobility also happens to be the volume of BEV cars sold—the volume of variant A which is already recorded and used in the system model. So this range anxiety metric does not add any extra information to the model except interpretation.

<table>
<thead>
<tr>
<th>Functions arising from fleet CO2 contribution</th>
<th>Signals</th>
<th>Desirable functions</th>
<th>Undesirable outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{variant(x)} \times \text{CO2(x)} \times \text{volume%}(x))</td>
<td>external: Legislation limit</td>
<td>(\text{planned platform fleet CO2} = \ &lt; \text{internal target})</td>
<td>(\text{fleet CO2 fines})</td>
</tr>
<tr>
<td>(\text{for} \ x = 1 \ to \ n)</td>
<td>actual: fleet CO2 fines</td>
<td>(\text{actual platform fleet CO2} = \ &lt; \text{external target})</td>
<td>actual: range anxiety</td>
</tr>
<tr>
<td>(\text{new: actual variant(x)} \times \text{CO2 contribution} =)</td>
<td>actual: range anxiety</td>
<td>(\text{weighted fleet average max range})</td>
<td></td>
</tr>
<tr>
<td>(\text{actual CO2(x)} \times \text{actual volume%}(x))</td>
<td></td>
<td>(= \ \text{sum(max range(x))} \times \text{actual Vol}(x))</td>
<td></td>
</tr>
<tr>
<td></td>
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</tr>
</tbody>
</table>

**Noises**
- actual volume of each variant as % of actual total

**Desirable functions**
- planned platform fleet CO2 = internal target
- and therefore FINE = zero
- actual platform fleet CO2 <= external target

**Signals**
- actual total volume = sum of actual variant volumes
- \(\text{CO2 and fuel economy are related}\)
- \(\text{new variant(x) max range = electric "autonomy" OR}\)
- \(\text{fuel tank capacity divided by MPG}\)

**Undesirable outcomes**
- fine per vehicle sold = fleet actual sales volume*CO2 target overshoot
- % fleet customers with impaired range

**Control factors**
- technology variants and models chosen:
- planned CO2(x) for each variant
- planned volume(x) for each variant as % total volume
- actual CO2 of each variant
- internal target: platform limit
- actual fuel economy of each variant
- actual fuel tank size of each variant
- actual electric range of each variant

**Figure 11- new Triple Bottom line simple system model**

To keep things simple therefore the range anxiety was left out of the next phase of calculations. As the model had already been used to assess its resilience to a particular noise (the volume of PHEVs actually sold, as shown in Figure 8) it was decided for a simple comparison to look at how all three system outputs (emissions, fines and range) varied in the same situation. The data were calculated and normalised so that they can be shown on the same graph, shown in Figure 12.

The emissions and range are easy to interpret here because they are both desirable outcomes which improve as the actual volume of PHEVs (actual VolB) rises. The fine was conceptually more difficult- it is a negative outcome which falls as actual VolB rises; so it too improves. The graph therefore shows this in effect as a line following a path showing the “reduction of the fine to zero”.

<table>
<thead>
<tr>
<th>Underlying system</th>
<th>Desirable functions</th>
<th>Undesirable outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{planned platform fleet CO2} = \ &lt; \text{internal target})</td>
<td>(\text{weighted fleet actual average max range})</td>
<td>(\text{fine per vehicle sold} = \text{fleet actual sales volume*CO2 target overshoot})</td>
</tr>
<tr>
<td>(\text{actual platform fleet CO2} = \ &lt; \text{external target})</td>
<td>(\text{sum(max range(x))} \times \text{actual Vol}(x))</td>
<td>(% \text{ fleet customers with impaired range})</td>
</tr>
</tbody>
</table>

**Equation for fines per vehicle sold:**
\[\text{fine per vehicle sold} = \text{fleet actual sales volume*CO2 target overshoot}\]
Figure 12- normalised performances of the triple system model

In this case sample for the metrics and strategy chosen, the three impacts come directly from the CO\textsubscript{2} strategy and the way they change almost always corresponds. This is because better platform CO\textsubscript{2} means lower or no fines for the company under the legislation and better fuel economy therefore better range for the customers (with the exception of BEVs). This indicates that the general sustainability of the system (at least as measured across these indicators) also rises.

The Shared Value diagram began to introduce some qualitative factors which could potentially be incorporated into the system model. The analysis also ignores some major costs due to lack of time to devise data-the technology cost to the company for providing the cleaner variants for example typically runs counter to the performance (in this case the ease of meeting CO\textsubscript{2} targets). The model does not yet measure the lifecycle CO\textsubscript{2} impacts or other environmental impacts associated with the varying proportions of different powertrain technologies in the fleet so misses some possibly significant sustainability impacts. Up to this point the interplay of resilience and this wider view of sustainability has also not been investigated. This is all part of the further work planned to complete this case study.

5.2.8 Review and reflections on Case Study Sample Results

5.2.8.1 Answer to research questions

These are the questions within the study, The first research question: “Can the system model from 1A be populated with public data successfully?” has been answered “yes” by the successful simulation of a new system to create Design Option 1, which has been used throughout this first part of the case study. This indicates that generally...
the use of system models and data based on the P-diagram gives rise to useful tools for analysing strategic choices, at least the limited forms explored so far and within simple numerical studies.

In terms of the other specific questions, some reflections are given below under each:

- How can sustainability of the platform X CO2 emissions be measured?
  - Triple Bottom Line style metrics can be used to record the social and economic as well as environmental effects of the system, and the effects of the strategy on them

- Is this the only correct measurement or could the model and/or question be altered?
  - Other metrics than the specific ones chosen here could be used and these remain to be investigated; it appears that there will be generic rules for how to define these measurements in any system

- How can the resilience of the platform X CO2 emissions be measured?
  - In this simple study this was defined to be the ratio of the change in output of the system against a noise

- Is this the only correct measurement or could the model and/or question be altered?
  - This is just one of many single-factor versions of resilience possible inside even a simple system
  - It is not yet clear how a general measure of resilience to variations in more than one noise might be achieved- more investigation is needed

- How do these new factors influence the strategy study results?
  - There were no original results to compare with. However future work in this case study is intended to create design option alternatives to be assessed and compared.
o The first example and simple expanded model selected happens to have outputs which all vary the same way- they all improve in the same direction.

- How might Shared Value apply to the analysis?
  - On this occasion it was useful for eliciting other impacts from the system and the strategy effects on these
  - This particular diagram was drawn to be at platform scale to be consistent with the model but it can also be drawn at other scales for example for individual customers
  - There may be other places within SuReSDS w=that this approach can be helpful

5.2.8.2 Feedback from key informants

The case study is still in progress and so only interim discussions have occurred with the two key informants. An initial assessment from this feedback already indicates some key findings however:

- The approach seems suitable for identifying sustainability and resilience issues within strategic studies
- It also seems to offer a way to integrate these into the analysis
- The resilience issue seems to flow from the sustainability one as sustainability is a wider definition of system “performance”, and is linked therefore to classical engineering ways of identifying robustness.
- This means the methods for improving system resilience may also closely resemble the RED techniques for improving robustness- removing noises or desensitisation and introducing “soft” failure modes to reduce the severity of impacts for example
- The general practice of analysing a numerical study for resilience this way (analogous to certain elements of robustness in current design engineering practice) could add an improved level of rigour to strategic studies
The Shared Value diagram could be a useful construct for structuring information about and considering the wider effects of strategic decisions. Further case study opportunities were identified as a result of this.

The value exchanges within the Shared Value diagram need more clarification as to type and meaning; it is currently much easier to explain those between society and the economy than the others.

It isn’t clear what happens if the system functions are more complicated in their relationship and in how they link between the 3 “capitals”. More work is needed to identify the reasonable limit of the approach and any guidelines for how complete the model should be.

Numerical examples mean that backcasting or forecasting limits what can be realistically varied by hand (it is a laborious and confusing process, but not necessarily worse than existing studies), and complexity in the system or non-linear effects may be missed as is noted in the training for Robustness experiments (FMC, 2000). This is an existing problem for any numerical analysis, however techniques such as Monte Carlo simulations can already be performed using existing tools within the company; this just happens not to be common practice currently.

Numerical data such as LCA results requiring experts have not yet been tackled. Lack of expert data in this area may limit the scope of some studies. Or as some types of environmental impact data are counterintuitive and require such analysis this may indicate the need for more expert access (and presumably more experts full stop) in such techniques in future.

The social impact began to introduce metrics that were more word-based than numerical in some cases. The ability to mix the two metric types needs to be investigated during this and the remaining case studies.

5.2.9 Interim Conclusions

The Sustainability Planning Specialist is of the opinion that the approach seems suitable for use in Ford strategic studies prepared by or participated in by him and his colleagues. More development of the approach and more testing is needed to answer some questions about the approach in different types of study. Just this part of the approach has produced useful information and useful structure in this pilot study. This is counted as a
significant result by the Specialist despite there being no original study or recommendations to compare the case study results with.

The further stages of this case study should provide further evidence of the applicability of SuReSDS within strategic studies and serve to fully test and develop the last parts of the “assess system” phase, for numerical studies. Further development of generic method steps and guidelines for producing metrics for example will also be reviewed with the Design Process Specialist. The development of the Shared Value diagram has also assisted with generating ideas for further case study samples.

5.3 General conclusions from Pilots 1A and 1B

The way that the sustainability and resilience issues for a system (and therefore for any strategy affecting it) can be clearly identified and integrated within SuReSDS is the most important research finding from the work so far. This should be further investigated in the other case studies planned within the research.

For the development of the approach itself, some difficulties in defining and explaining the elements of the P-diagram in principle has prompted the process of reviewing the results with the Design Process Specialist. The first review was done to enable a check of existing company manuals to confirm how this diagram is used within Robustness Engineering, and to more firmly establish its most important aspects (Winnard, 2013a, FMC, 2007). This feedback will be used along with the study results to modify the user instructions for SuReSDS.

5.4 Other work

Within this period an opportunity was identified to test the Shared Value part of the approach in a completely different company. This arose from personal contacts of the RE and concerns a project to develop an improved NGO aid and development hygiene product. An initial meeting was used to assess the use of the Shared Value diagram against recent information from the project but this has not yet been processed. This contact may also allow “live” testing of some approach elements during future decision-making on this project which would enable the collection of evidence types which are unlikely to be available within Ford. These results and any upcoming opportunities will be reviewed in the light of any requirements driving further case study choice, and added to the research if this is possible without detriment to the existing research plan.
6 Next steps

The research design, the case study protocol and the approach itself will be reviewed in the light of these pilot and case study results and modified as needed. This will happen at the same time as a search for suitable next samples and is planned for early November. The results of each case study will also be used to inform the next.

The choice of further case samples needs to be driven by key aspects of the SureSDS approach which need to be developed or tested. Recent discussion of these aspects has revolved around whether the complexity of the studies it is applied to, the complexity of the systems or the level of uncertainty (or lack of quantitative definition) of either might be the relevant criteria to use. There is not yet a confirmed set of criteria and identifying these from the experience of the case studies so far and the theory which underpins SuReSDS is an urgent task. A set of proposed criteria will be developed in early October for review by audio shortly afterwards (exact date TBD) and will be used to drive part of the larger review of results planned for early November.

Altogether 4 case study samples are planned within Ford, counting 1B as the first. Another very conceptual analysis of mobility based on qualitative data and mainly expressed in words rather than numerical form is envisaged. This would encompass wider system resilience issues, the use of non-numerical data and allow the testing of scenario-formation and the use of these scenarios to sort between options. This might parallel an existing company study and would be especially useful if the work can involve parallel activities with one or more team members. Alternatively there may be 2 stages, one for the RE to develop further elements of the SuReSDS approach and one for the team to try them, allowing comparison of results from the same data.

A further technology-oriented Ford study is currently being completed with numerous sustainability issues to be managed which are proving awkward for the team to handle. Use of this for a case study would allow identification of whether there is a difference between the anticipated “technology” (lowest) and PSS (middle) levels of use for the approach. It would be an offline study using real data and could include one or more team members in using the approach. All case study ideas and opportunities will be reviewed against the criteria to be set in the immediate future.

A second review of the case study work is planned near the end of the planned 4 studies in late January or early February 2014. This will be used to review the evidence within and across the cases and identify whether any further studies are required to complete the evidence and research design. The analysis and interpretation of results is an
ongoing task which will run alongside the case study work throughout. About the date of the second review the planning and first stages of the thesis will also begin. The final timing plan will also be reviewed at this point and adjusted.

6.1 Timing plan

The latest plan is shown at the end of the main body of this report in Figure 13. It shows the next few months of activity including the next steps identified above in more detail up to the end of the Engd. The three task types are taken from previous reports and timing plans for consistency. The shaded bars indicate continuous background tasks, reviews or tasks which may begin early or end late.

Julie Winnard 30th September 2013

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Figure 13- research tasks timing plan for the remainder of the EngD
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Delft University of Technology.


