Scenario Selection Method for System Scenario Analysis

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Abstract. Scenario analysis is a frequently-used method to explore what a proposed system is required to do in the early phases of system development leading towards finding system requirements. A system which is intended to perform a variety of roles under a range of conditions is likely to result in the need for a quantity of scenarios that becomes intractably pluriform. The consequence of too many scenarios is that either the number of scenarios to be analysed must be reduced to a manageable number or the analysis is likely to be perfunctory, diminishing the value of the analysis. We present a method for reducing the number of scenarios to be analysed through study of the organization of the factors which distinguish scenarios from each other, and for selecting which scenarios need analysis through identifying their points of commonality and identifying where differences may impact system capability. Our method organises the types and potential values of factors related to a particular system development in order to reduce the number of scenarios to be investigated.

Introduction

Scenario analysis is a frequently-used method in the exploration of what a proposed system or systemic intervention is required to do, applied in the early phases of the systems work. Such analysis involves the description and exploration of a range of situations in which the system under consideration is likely to be employed, describing the task outcomes required and the conditions under which those outcomes are required. During scenario analysis the timeline of events and actions necessary for the performance of each scenario will be story-boarded with description of what must happen along with a statement of measures of performance for each salient feature of the scenario.

The level of development of scenarios may vary with both the lifecycle phase of the system development project and with the judgement of the impact of possible findings. Thus, scenario development is likely to be rudimentary at earlier stages of the systems project as broad-brush scenario development is done, to map out the major issues. Later, the work is likely to be developed in greater detail so that it becomes clear what the actions and necessary performance to enable the identified tasks to be performed are. Similarly, for a product or system for which

the impact of failure or poor performance are minor, the scenario work can be truncated with low risk. However, if the likelihood of system failure to provide the required service under all the relevant conditions is high, then it is necessary to investigate each scenario thoroughly and to use a systematic process to identify all the scenarios. In practice most systemic interventions are between the extremes, and therefore require significant scenario development to ensure that the intended effect of the system is well understood, but also that sufficient, but not excessive, scenarios are developed sufficiently to provide insight about the proposed system without demanding excessive work.

The purpose of scenario planning and analysis is to identify the range of issues which the system may confront during its future or service life and to reduce uncertainty (Shoemaker, 1995) and develop each scenario sufficiently that it is clear what the intended performance needs to be in order to provide 'adequate' results. When considering the purpose of scenario work, Bradfield et al (2005) identify four main areas of purpose, which are: making sense of a particular puzzling situation, developing strategy, anticipation, and adaptive organisational learning. In this, it might be seen that two characteristics are important:
1. System and environmental state; and
2. The action to be done by and to the system.

The combination of these characteristics describes what must be achieved by the system under what conditions. These elements of what the system must be and do are the essential characteristics in order to define what constitutes a suitable system for its purpose.

The fundamental challenge is that whilst it is obvious that an efficient path through the exploration of scenarios is desirable, it is also necessary to ensure that the path chosen is effective, that is that it does not leave the engineer vulnerable to flaws in the system concept or design to be introduced as a result of insufficient knowledge and appreciation of what is required of the system (Chermack, 2004). Therefore, the need exists for a method to choose an efficient set of scenarios that results in identification of all of the scenario elements to enable planning of the system without risk of omissions arising from investigation of too few scenarios.

Foundational Elements of Scenarios

We are aiming to achieve an approach to the simplification of the scenario analysis activity which provides a general framework. Such a framework must formulate the problem in an abstracted general form rather than as a set of specific factors, methods and relationships which are presented as a template to fit all cases. A general framework will need to be tailored to fit what is relevant to the specific system under consideration, which with the broad range of systems possible could be any of a wide variety of possible sets of characteristics, some of which will be relevant only in particular cases, and some relevant over a broad range of classes, but few, if any, would be relevant in all cases. The scenario analysis for a system must account for the two sets of factors:
1. The system and environment state conditions.
2. The system function and performance levels.

Each of these types of factors may have a plurality of values. For example, a system which is intended to operate with full performance under some range of environmental conditions may also be expected to operate with defined levels of degradation over a further, extended range

of environmental conditions outside the 'full operation' range. Similarly, the scenarios must include consideration of resilience, and so scenarios should include defining acceptable systems behaviour under various classes of degradation caused by threat events (Jackson, Cook, Ferris, 2015). Table 1 shows a set of factors and conditions of acceptability in a form which instantiates the concept of factors and levels of attainment in an abstract, general form.

Table 1. System factors associated with the definition of scenarios. Note, these factors are presented here as examples; each system needs specific investigation to determine which factors are relevant, and the appropriate level of attainment for each.

Factor	Type	Item (examples of the kind of factors)	Level of attainment
1	Environment state	Ambient temperature during operation	Normal operation: $x \leq T \leq y$ Extended operation: $T < x$ and $y < T$
2	Environment state	Sea state: WMO Sea State Code	WMO State < 4 full operation, no precautions WMO State < 6 full operation, protection precautions active WMO State > 6 can survive, protection precautions active
3	System state	All subsystems function	Full operational performance
4	System state	Communications subsystem nonfunctional	Defined autonomous function plan allows safe, partial function
5	Performance	Load carrying capacity	Load described in mass and dimensions
6	Performance	Speed of movement	Described as linear speed at WMO particular sea state measures

Clearly Table 1Table 1 is a rudimentary description of factors and levels of attainment desired in scenarios, where the gradation in several fields in the 'Level of Attainment' column indicates scenario relevant information, that is, that under certain conditions one level of performance is acceptable and under other conditions a different level of attainment. However, additional information is required to select and construct the scenarios.

Scenarios concern some mission to be performed by the system under defined conditions. That is, the system must be capable of performing a certain task under the conditions. Except in very simple situations the tasks demanded by a scenario will require a storyboard of a sequence of actions to be performed, where each will need to be performed under particular conditions to levels of performance which may be specified in a conditions independent or conditions dependent manner. The levels of attainment described in Table 1 are directly linked to any condition dependence criteria described in the scenarios.

Scenario Construction

The scenarios to be identified will likely have the characteristics of:
1. What must be done, the transformation of or in the world that the system must effect; and
2. The conditions under which the effect must be achieved.

The tasks described as what must be done are Requirements expressed by the stakeholders. As such these tasks refer to whole things that must be achieved, such as shipping some quantity and type of goods from one type of site to another under certain conditions. It may be appropriate to describe the task performance objectives, such as how much, or how fast, etc, in a trade-space associated with the potentially constraining operational conditions. That is, under desirable operating conditions it may be appropriate to demand on level of performance but under more difficult conditions, it may be recognised as acceptable to demand only a reduced level of performance. The decision to permit a trade-space involving performance levels demanded of the system and the conditions may, for many systems, be a very important factor in enabling a solution space that affords more options for solutions and which has at least some available options that are significantly cheaper than if all performance demands are treated as absolute under all conditions.

It is common to find that the scenarios identified may appear to be variations of each other which suggests a strong analogy between the primary scenario and the secondary scenarios. For example, a base vehicle might be used as a goods carrying vehicle with one internal fit and as an ambulance, with a different internal fit. The analogy is that the patient and other medical equipment is, from the viewpoint of stuff to be shifted, analogous to goods to be shipped. However, these scenarios may make different demands on some characteristics of the system, in this example the ride quality where what is acceptable for one use may not be acceptable for another.

Other scenarios relevant to understanding what the system needs to be and do include scenarios of potential extension uses, where a user, in the absence of a purpose built system may choose to build on the analogy of the affordances of the current system and their desired capability to deploy the system for an off-label purpose. And there are further scenarios to address other necessary tasks including, potentially, tasks such as maintenance, installation and commissioning etc.

To determine which scenarios need to be developed we propose the development of a table describing possible scenarios of the form of Table 2. In abstract form, as presented in Table 2 this appears simple with performing a particular system task under a set of conditions. However, the condition set may be multiple for each system task, that is, each task may be needed under each of several sets of conditions. A 'system task' is a complete action performed by or on the system which is most likely to be a compound of a number of smaller activities. Given that there may be a significant set of tasks to be performed and that each of the tasks may be required under a number of conditions the number of scenarios may be large. However, many of the scenarios are likely to have considerable similarity to other scenarios. Therefore, analysis of the full set of scenarios is likely to produce considerable work with substantial overlap. In particular, note that Table 2 anticipates that a system may be expected to perform the same tasks under a range of conditions, each of which is represented by a distinct scenario. These scenarios are distinct because it is plausible that design requirements for the system to perform the task under each of the condition sets may be different.

We need now to find a method to simplify the set of scenarios to be analysed. This task can be performed by identification of the action sequence required to perform the system task which constitutes the action of the scenario. Since the task must be performed under some set of conditions, as identified previously, Table 2, it is necessary to capture the information of the

conditions under which the actions will be performed within each scenario, Table 3. Note that in Table 3, between each pair of labels for Actions, e.g. Action 1 and Action 2, there is an additional action name of the form of "Transition Action *x* to Action *y*". This is included here to explicitly emphasise that the Actions which are most likely to be thought of by scenario describers whose focus is on the capability provided by the system are the large scale actions which are clearly part of the purpose of the system. However, the transition from one state of the system, associated with the previous and later actions, must be considered, and if not considered appropriately could be the cause of accidents. (For example, accidents which occur during processes such as loading or unloading vehicles, or during construction works, when the action is associated with potential instability of the platform on which it is being performed.) Calling out the concept of transition between the larger actions causes attention to be put on making appropriate consideration for the impact of the various transition actions which are required between task achieving actions. Explicit identification of the transitions is also helpful in the next stage of using this approach.

Table 2. Itemisation of possible scenarios.

ID	Scenario Name	System Task	Conditions of Scenario
1	Scenario Name 1	System Task 1	Condition set 1
2	Scenario Name 2		Condition set 2
3	Scenario Name 3	System Task 2	Condition set 3
4	Scenario Name 4		Condition set 4
5	…	…	…

Table 3. Itemisation of action sets demanded by each scenario and the conditions sets under which the actions are required.

ID	System Task	Actions Performed BY or ON the System (in Order)	Condition Sets for the Action
1	System Task 1	Action 1	Condition sets 1, 2, 4
2		Transition Action 1 to Action 2	…
3		Action 2	…
4		Transition Action 2 to Action 3	…
5		Action 3	…
6		…	…
7	…	…	…

At this stage we have identified a large range of scenarios, associated with achievement of some set of system level tasks to be achieved under a group of sets of conditions, Table 2. This list of scenarios is potentially large. Since the system level tasks require performance of the particular activities and transitions under all of the sets of conditions, the application of the simplification of Table 3 has reduced the number of scenarios to be developed to only one for each of the system level tasks. In the expansion we cannot use the idea of "worst case" conditions, because each condition set is a set of conditions which are in different dimensions which could interact with the proposed system in complex ways that do not make any condition set necessarily the worst case.

However, at the stage of Table 3 we may have another opportunity for simplification of the scenario work. Each scenario comprises a sequence of actions and transitions, each identified as the atomistic tasks to be achieved. It is likely that there is duplication of actions and transitions between various system tasks and groups of condition sets. Therefore, the analysis for each action or transition can be done once in order to determine the system or lower level requirements arising from the scenarios.

Conclusions

The scenario analysis approach described here can be used to reduce the work of analysing scenarios through identifying the elements of actions and transitions and conditions under which they must be achieved thereby enabling the achievement of the primary purposes of scenario analysis in informing the specification of the system and enabling planning for system use and support. For future work we are planning to advance this work through a more complete literature review, the development of an information model describing how scenarios fit into systems engineering and working through a simple worked example to show how the process would be used.

References

Bradfield, R., Wright, G., Burt, G., Cairns, G. and Van Der Heijden, K., 2005. The origins and evolution of scenario techniques in long range business planning. *Futures*, *37*(8), pp.795-812.

Chermack, T.J., 2004. Improving decision-making with scenario planning. *Futures*, *36*(3), pp.295-309.

Jackson, S., Cook, S.C., Ferris, T.L.J. (2015) A generic state-machine model of system resilience, *INCOSE Insight*, 18(1), April, pp 14-18.

Schoemaker, P.J., 1995. Scenario planning: a tool for strategic thinking. *Sloan management review*, *36*(2), p.25-40.

Biography

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