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Scenario Driven Flexible Decision Support Systems Generator

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Abstract

Scenario planning is a widely accepted management tool for decision support activities. Scenario planning, development, organisation, analysis, and evaluation are generally quite complex processes. Systems that purport to support these processes are complex and difficult to use and do not fully support all phases of scenario management. Though traditional Decision Support Systems (DSS) provide strong database, modelling and visualisation capabilities for the decision maker they do not explicitly support the scenario management well.

This paper presents an integrated life cycle approach for scenario driven flexible decision support by synthesising ideas from scenario-based decision-making and DSS. The proposed processes help the decision maker with idea generation, scenario planning, development, organisation, analysis, execution, and evaluation for decision support. We also propose a generalised scenario evaluation process that allows homogeneous and heterogeneous scenario comparisons among multiple instances of similar and dissimilar scenarios respectively.

This research develops a domain independent, component-based, modular framework and architecture that support the proposed scenario management process. Scenarios have been introduced as a DSS component that is comprised of a complex combination of other decision-support components. The framework and architecture have been validated through a concrete prototype.

Keywords: SDSSG, DSS, Decision Systems, Scenario Planning

1. Introduction

This research concentrates on two main areas of decision science, namely scenario-based decision-making process and decision support systems (DSS). In the decision sciences, scenarios have been defined in many ways e.g. a management tool for identifying a plausible future [Porter, 1985; Schwartz, 1991; Ringland, 1998; Tucker, 1999; Alter, 1983] and a process for forward-looking analysis. A scenario is a kind of story that is a focused description of a fundamentally different future [Schoemaker, 1993]; that is plausibly based on analysis of the interaction of a number of environmental variables [Kloss, 1999]; that improves cognition by organising many different bits of information [De Gues 1997, Wack 1985, van der Heijden 1996]; that is analogous to a "what if" story [Tucker, 1999]. It can be a series of events that could lead the current situation to a possible or desirable future state. Scenarios are not forecasts [Schwartz, 1991], future plans [Epstein, 1998], trend analyses or

analyses of the past. It is for strategy identification rather than strategy development [Schoemaker, 1993] and to anticipate and understand risk [Fordham and Malafant, 1997] and to discover new options for action. Ritson [1997] agrees with Schoemaker [1995] and explains that scenario planning scenarios are situations planned against known facts and trends but deliberately structured to enable a wide range of options and to track the key triggers which would precede a given situation or event within the scenario. These definitions are not appropriate for scenario modelling, as they do not entail the exact scenario structure. Therefore, we define a proper implementation level definition that addresses the structure of the problem situation and its dynamic behaviour.

Decision makers have been using the concepts of scenarios for a long time, but due to its complexity, its use is still limited to strategic decision making tasks. Scenario planning varies widely from decision maker to decision maker mainly because of lack of a generally accepted principle for scenario management. Albert [1983] proposes three approaches for scenario planning, namely, Expert scenario approach, Morphological approach and Cross-Impact approach. Ringland [1998] describes three-step scenario planning – namely brainstorming, building scenarios, and decisions and action planning. Schoemaker [1995] outlines a ten-step scenario analysis process. Huss and Honton [1987] identify three categories of scenario planning: Intuitive Logics, Trend-Impact analysis, and Cross-Impact analysis. Intuitive logics is related to creating a coherent and credible set of stories [Wack, 1985] and Trend-Impact analysis is concerned with effects of trends. The literature still lacks a suitable approach for planning, developing, analysing, organising and evaluating the scenario using model-driven decision support systems. Currently available scenario management processes are cumbersome and not properly supported by the available tools and technologies. Therefore, we introduce a life cycle approach based scenario management guideline for idea generation, scenario planning, development, execution, analysis, evaluation and usage for decision support.

Generation of multiple scenarios and sensitivity analysis exacerbate the decision makers problem. Scenarios also need to be evaluated properly to assess their quality, uniqueness, appropriateness and plausibility. Hence the decision maker needs an easy to use scenario generation and evaluation system that can compare multiple instances of a single scenario or multiple instances of multiple scenarios. The available scenario planning tools are not suitable for assessing the quality of the scenarios and do not support well, the evaluation of scenarios through a comparison process. We introduce an evaluation process for comparison of instances of homogeneous and heterogeneous scenarios that will enable the user to identify the most suitable and plausible scenario for the organization.

Though traditional DSS provide strong database, modelling and visualisation capabilities for the decision maker they do not explicitly support the scenario management well. However it supports the decision makers ranging from top executives to line managers for a variety of problems for many phases of the decision-making process. It improves the effectiveness of decision-making in terms of accuracy, timeliness and quality of decisions. Considering the significance of scenarios in the decision-making process, this research includes scenario as a decision-support component of the DSS and defines Scenario-driven DSS (SDSS) *as an interactive computer-based system, which integrates diverse data, models and solvers to explore decision scenarios for supporting the decision makers in solving problems.*

Traditional DSS have been for the most part data-driven, model-driven and/or knowledge-driven but have not given due importance to scenario planning and analysis. Some of the DSS have partial support for sensitivity analysis and goal-seeking analysis but this does not fulfil the

needs of the decision maker. As scenarios are not an integral part of current DSS frameworks and architectures, they do not support scenario based decision-making processes. In most cases, the available scenario analysis tools deal with a single scenario at a time and are not suitable for development of multiple scenarios simultaneously. A scenario impacts on related scenarios but currently available tools are not suitable for developing a scenario based on another scenario. Generation of a scenario and its analysis are not sufficient for decision support. Therefore, there is a lack of synergy between scenario-driven decision-making processes and DSS. The decision maker needs a unique easy-to-use system within a single environment that supports scenario planning, organisation, development, execution, analysis, evaluation, selection, and decision support. The decision making power of the strategic managers as well as mid-level and operation-level managers will be improved by the amalgamation of scenario based decision-making processes with the existing power, functionality, usability, and data access capability of DSS.

To address the problems and issues raised we followed an iterative process of observation/evaluation, theory building, and systems development (Nunamaker et al., 1991). Wherein we proposed and implemented a flexible framework and architecture for a scenario driven decision support systems generator (SDSSG). A prototype was developed, tested and evaluated using the evaluation criteria for quality and appropriateness of scenarios [Schoemaker's, 1995] and principles of DSSG framework and architecture [Geoffrion, 1987; Ramirez et al., 1990; Collier et al., 1999]. The conceptual framework as well as the prototype was modified on the basis of the findings and the process continued until a satisfactory result was achieved. The framework and architecture are domain independent, component-based, modular and supports the proposed scenario management process. Scenarios are introduced as a new DSS component that is comprised of a complex combination of other decision-support components, namely data, model and solver.

In the rest of this paper, we first introduce a life cycle approach for management of scenarios including a detailed discussion of handling homogeneous and heterogeneous scenarios. We then propose a scenario-driven flexible decision support systems generator framework and follow this up with a discussion on how it realises the scenario management process. We then present an n-tiered architecture that details the SDSSG framework. Finally we discuss the implementation platform and domain within which the proposed process, framework, and architecture were validated.

2. Scenarios: A definition, an example, and a mechanism for structuring scenarios

2.1 *Definition of a Scenario*

Scenario is a complex situation containing one or more problem instances. A change in one scenario might have chain effects on the related scenarios. But the basic structure and behaviour of the scenario is similar to the decision support system components *model* and *solver* respectively. Hence we define scenario as a complex situation analogous to a model that is instantiated by data and tied to solver. In its simplest form, scenario is a complex combination of data, model and solver.

2.2 *An Example Scenario*

For example, the mortgage management includes a series of external environment sensitive inter-related scenarios. AMP [2001] describes a mortgage scenario wherein median wage and

home price increases and the interest rate drops. What is the impact of this change or any other changes on individual buyer as well as on the mortgage market? The change in interest rate, average income of the people, demand and supply of the home, etc. highly influence the mortgage markets.

This scenario broadly depends on several other scenarios e.g. affordability scenario, loan scenario, and payment scenario. Affordability scenario helps in understanding the borrower's eligibility to get a loan and capacity to repay the loan. The loan scenario analyses the cost of financing, loan amount, and instalment. Depending on the loan type, this analysis process can differ widely. The payment scenario analyses instalment, interest payment, principal repayment, and loan balance. The payment scenario addresses the entire life cycle of the loan repayment. Affordability scenario is a constraint to the loan analysis scenario. Each of these scenarios can again be disintegrated into several smaller scenarios e.g. affordability scenario depends on the income scenario and expense scenario while income scenario may be subdivided into personal income scenario and family income scenario. All these scenarios are inter-related and the higher level scenarios are dependent on the lower level scenarios. Sensitivity analysis and goal-seek analysis of these scenarios would greatly enhance the decision making process.

2.3 Structuring Scenarios

In view of addressing the complexity and inter-relatedness of scenarios, we propose to divide larger scenarios into multiple simple scenarios having independent meaning and existence. In this context we identify three types of scenarios, namely:

Simple Scenarios – The simple scenario is not dependent on other scenarios but completely meaningful and usable.

Aggregate Scenarios – The results from multiple scenarios are combined/aggregated together to develop a more complex scenario.

Pipelining Scenarios – One scenario is an input to another scenario in a hierarchical scenario structure. In this type of scenario, lower-level scenario can be tightly or loosely integrated with the higher-level scenario.

The decision maker may combine simple as well as complex scenarios together using pipelining and aggregation to develop more complex scenarios.

3. Scenario Management: A Life Cycle Approach

We introduce a scenario management process that synthesises and extends ideas from Ringland [1998], Schoemaker [1995], Albert [1983], and Huss and Honton [1987]. The scenario management process uses a life cycle approach that is able to address a variety of problem scenarios. The proposed life cycle approach for scenario management process is illustrated in Figure 1.

The process starts with scenario idea generation and finishes with the usage of scenario for decision support. The following sections present the above-mentioned phases of the life cycle approach for scenario management.

3.1 Idea Generation

The decision maker anticipates the problems and analyses the problems for finding out the influential driving forces of the scenarios. The governing factors, which could be either internal and/or external, exert pressure on the system for various changes. The decision maker as a domain expert may project the possible changes of the indicators that would lead to the development of ideas for scenario planning.

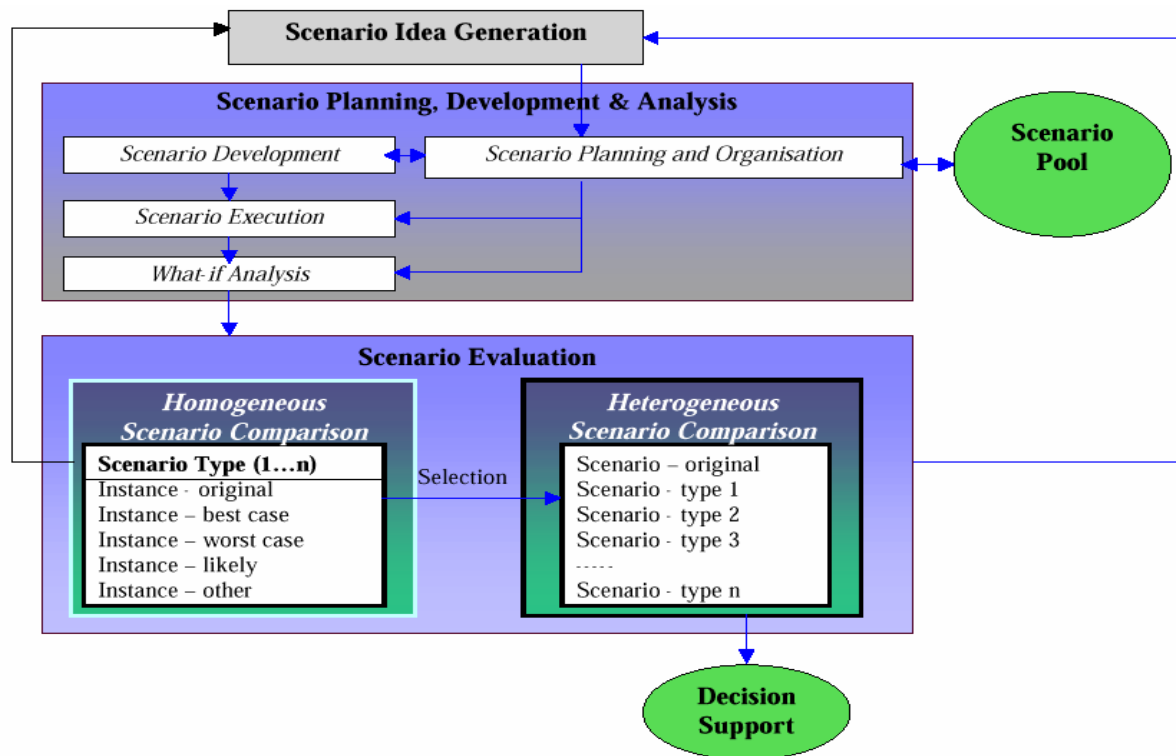


Figure 1: Scenario Management: A Life Cycle Approach

3.2 Scenario Planning, Development and Analysis

In this phase, the decision maker will carry out the tasks of scenario planning and organisation, scenario development, scenario execution, and what-if analysis. Existing scenarios could also act as inputs to this phase apart from the ideas generated from the previous phase.

3.2.1 Scenario Planning and Organisation

Scenario planning includes the activities of identification of the structure and components of scenarios, sequence of scenario development and execution as well as selection of scenarios for analysis. The scenario organisation activities include making available of already developed scenarios at runtime, and storing of scenarios for future use and retrieving of scenarios.

The components of the scenario can be either pre-customised or loosely coupled. For a pre-customised scenario, the scenario planner defines the relationships as shown in Figure 2 between data-model, model-solver, and data-solver as well as with other dependent scenarios during scenario planning.

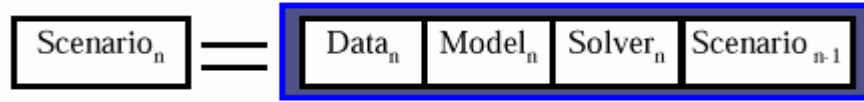


Figure 2: Pre-customised Scenario Structure

For a loosely coupled scenario the relationships among the data, model, solver, and dependent scenarios remain independent until they are defined and mapped during scenario development and execution at runtime as shown in Figure 3.

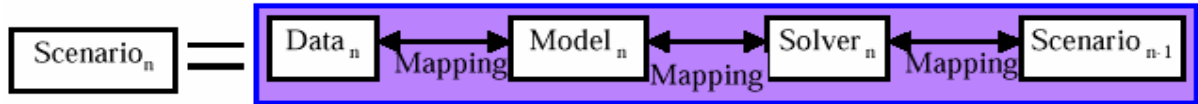


Figure 3: Loosely Coupled Scenario Structure

The scenarios are cached in a runtime pool that can easily supply the existing scenarios for developing pipelining or complex scenarios. The developed scenarios or the executed scenarios are stored in a scenario pool for future use.

3.2.2 Scenario Development

In this stage, the decision maker organises the related data, model, solver and scenarios (if, needed) for constituting a scenario. The decision maker could potentially use pre-customised and/or loosely coupled scenarios in development. The scenarios are developed in mainly two phases: basic scenario development phase and what-if analysis-type scenario development phase.

3.2.3 Scenario Execution

Our proposed scenario development process ensures that the scenario can be executed using data, model, and solver. The data could be both internal and external. The models are instantiated with the data, and then the model instance is executed using the appropriate solver. For a complex scenario, the decision maker may need to apply more than one model and solver to analyse different dimensions of the scenario.

3.2.4 What-if Analysis

The what-if analysis can be divided into two categories, namely sensitivity analysis and goal-seek analysis. Sensitivity analysis assesses the impact of an increase or decrease in any parameter or scenario value over other scenarios. Sensitivity analysis allows changing one or more variables/scenarios at a time and analyses the impact on the related scenarios. The main objective of sensitivity analysis is to identify and analyse the amount of impact on the related scenarios.

Goal-seek analysis accomplishes a particular task rather than analysing the changing future. This analysis is just a reverse or feedback evaluation where the decision maker supplies the target output value and assesses the required input.

3.3 Scenario Evaluation process

The decision maker can develop scenarios using different combination of data, model, solver and other scenarios. The question is – do all these scenarios represent a unique situation? Each scenario might appropriately draw the strategic question; represent fundamentally

different issues; present a plausible future; and challenge conventional wisdom. Schwartz [1991] and Tucker [1999] discourage too many scenarios and advocate for the use of best-case scenario, worst-case scenario and most-likely scenario. However, the selection of an appropriate scenario relies on the judgment of the decision maker. The comparison may take place among homogeneous scenarios or heterogeneous scenarios as shown in Figure 4. The heterogeneous comparison process is dependent on the homogeneous process. This two-phase comparison process is detailed in the following sections.

3.3.1 Homogeneous Comparison

Homogeneous scenarios are a similar type of scenario but the instances are quite distinct from one another. The decision maker selects a scenario instance on completion of each homogeneous scenario comparison. For example, in Figure 4, five outer ellipses represent five different scenarios while small ellipses containing T_1I_1 , T_1I_2 , T_1I_3 represent three instances of scenario type 1 and the ellipse containing **Original** represent existing scenario of the organisation. During homogeneous scenario comparison process, the decision maker compare multiple instances of scenario 1 i.e. T_1I_1 , T_1I_2 , T_1I_3 with the instance of the Original **scenario** and selects the best plausible scenario, which is T_1I_3 as shown in the Figure 4. The decision maker then repeats the whole process until the homogeneous comparison process is completed for each type of scenario and selects one instance from each scenario. If the decision maker does not find any suitable instance of a scenario in a homogeneous comparison, the process as described above is repeated to develop a different scenario instance for the same scenario. If none of the scenarios is plausible, or do not have an optimal result, the decision maker can repeat the whole process as shown in Figure 4. From this homogeneous scenario comparison, the decision maker can select at least one plausible scenario instance for each type of scenario. The selected scenario instances are T_2I_3 , T_3I_1 , T_4I_2 , and T_nI_1 for scenario 2, 3, 4 and 5 respectively as shown in the Figure 4.

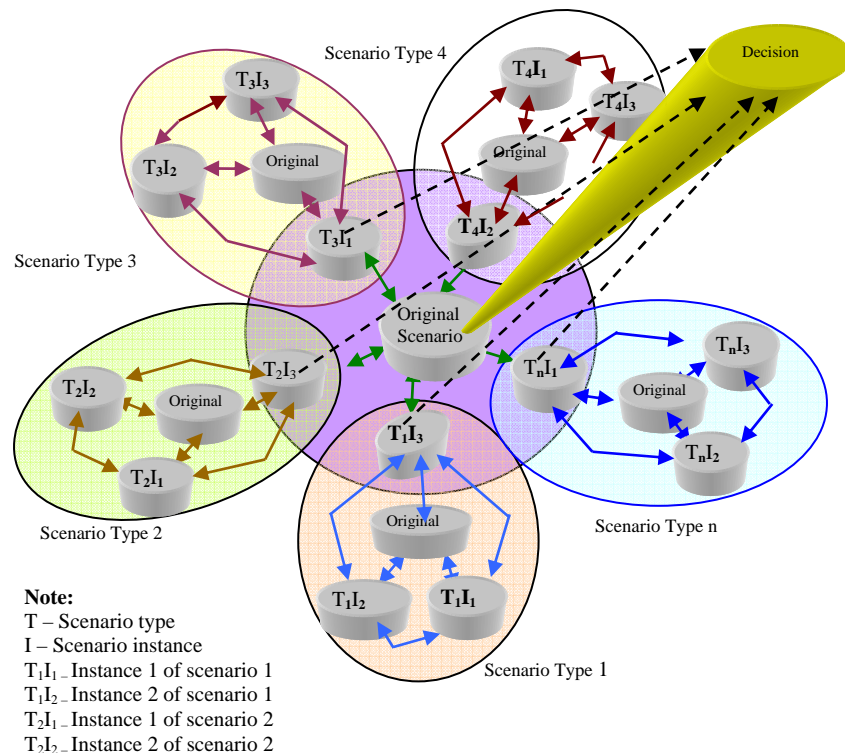


Figure 4: Scenario Comparison Process

3.3.2 Heterogeneous Comparison

On completion of the homogeneous scenario comparison process, the decision maker shall undertake the comparison among the selected scenario instances as shown in the big circle in the middle. Heterogeneous scenarios are different types of scenarios. But the change of a scenario may impact other scenarios as they may have some kind of inter-relationship among themselves. It is almost impractical to compare heterogeneous as the attributes of these scenarios are widely varied from one another. But as the impacts have been presented using some common attributes, the decision maker can compare them easily. If the decision maker finds that a specific instance of the scenario is not suitable for heterogeneous comparison, then the whole process can be repeated to identify a new instance for that scenario. This gives the decision maker an excellent picture of the whole decision problem and the probable solutions. For example as shown in the figure 4, instance of five scenarios i.e. T_1I_3 , T_2I_3 , T_3I_1 , T_4I_2 , and T_nI_1 have been compared with the instance of the Original **scenario** during heterogeneous comparison.

The following section proposes a framework that realises the scenario management process discussed in this section.

4. SDSSG Framework

Few of the DSS frameworks emphasise fully featured scenario planning, development, analysis, execution, evaluation and their usage for decision support. DSS components such as data, model, solver, and visualisation have been extensively used in many DSS framework design but they have failed to consider scenario as a component of DSS. Scenario plays such an important role in the decision-making process that it is almost impractical to develop a good DSS while leaving out this component. Scenario systems need to be modelled. So they are more closely related to model-driven DSS but the scenarios are more complex than models. Therefore, the scenario-driven DSS might add scenario as an independent component in addition to existing decision-support components of data, model, solver and visualisation.

The scenario does not have a separate existence without its base components. It means that every scenario is built up from a unique nature of the problem (model) that can have a number of alternative unique instances (data) and each instance can be interpreted, executed or implemented using one or more alternative methods (solver).

To overcome the problems and address the issues mentioned above we propose a scenario-driven decision support systems generator (SDSSG) framework as illustrated in Figure 5. The SDSSG components are separated into the following two categories:

- Decision-support components (DSC) that include the data, model, solver, scenario and visualisation. These components have a direct relationship with the data pool, model pool, solver pool,

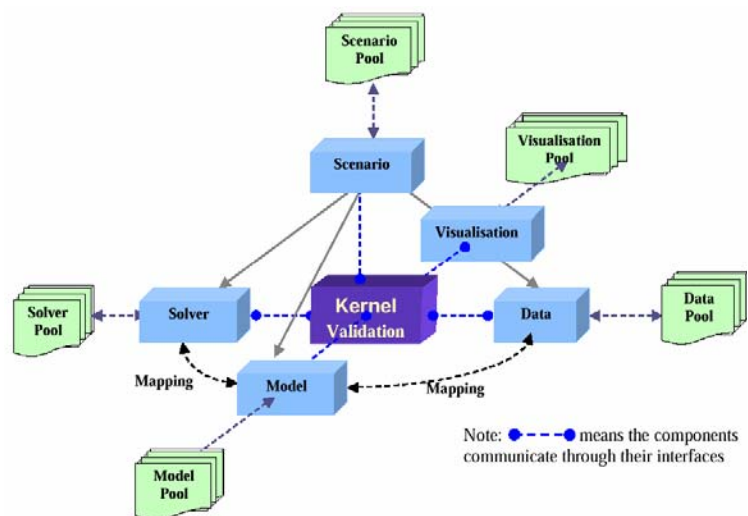


Figure 5: SDSSG Framework

scenario pool, and visualisation pool.

- Integration Components (IC) that include Kernel, Component Set, Mapping and Validation Component.

In this framework, the DSCs and ICs are independent of one another. The DSCs do not interact or recognise each other directly, rather the components communicate via the kernel component. Mapping develops the correct path of communication between data and model, and model and solver, while the validation component tests the correct matching of the interface and the proper communication between the components. The framework is fully flexible to update the components at the implementation level.

The data, model, solver, scenario, and visualisation can be stored in different component pools as shown in Figure 6 and the framework allows retrieving these components from the component pool. The related model, data and solver can be combined together to develop a scenario that leads to a specific decision support system. This scenario can be saved to the scenario pool for future use. So, different combinations of the data, model and solver create different scenarios. This also allows using the scenario(s) as an input for developing other scenarios. Every instance of the scenario can be termed as a specific decision support system. Therefore, the framework is a generator of scenarios as well as the decision support systems.

The framework allows generating a number of simple, aggregate, and pipelined scenarios. Scenario information can be saved to the scenario pool. Previously developed scenarios can be retrieved from the scenario pool and the same can be customised using models and solvers. The scenarios can be used as specific DSS or as complex data for input to the next level of model for further analysis. Different scenarios can be computed simultaneously and sensitivity and goal-seeking analysis can be done using different scenarios. The framework is suitable for analysing internally coherent scenarios or scenario bundles, and examining the joint consequences of changes in the environment for supporting the decision maker's strategy.

The components of the framework can be independently developed and could remain independent within the system at runtime until it is called for a specific purpose. Multiple components can be loaded to the system simultaneously from the component pool and formed into a *component set* which in turn can be utilised independent of the component pool.

5. Realisation of the Scenario Management Process using the SDSSG Framework

In this section we discuss and illustrate (Figure 6) the mechanisms through which the Scenario Management Process is realised using the SDSSG framework. Specifically we discuss the means by which the framework supports all the life cycle phases of the proposed scenario management process.

The key features of this framework are as follows:

- **Supporting Idea Generation:** Allows the decision maker to use their own heuristics to develop the ideas by applying permutations and combinations of related data, model and solver for constituting a modelling-based scenario;
- **Scenario Planning:** Supports the planning of modelling-based scenario structure, pre-customised and loosely coupled scenario.

- **Runtime Scenario Organisation:** Incorporates a runtime only temporary storage system named Runtime Scenario Pool (RSP) to store the completed scenarios. The completed scenario(s) can be pulled from the RSP to develop complex scenarios and this completed scenario can again be stored in the RSP.
- **Scenario Storing and Retrieving:** Allows saving, retrieving, updating or deleting the scenarios from the scenario pool using the data access component. The RSP is linked with the component set through the Kernel and data components. So the scenario can be saved to the scenario pool of the component pool.
- **Scenario Development:** The basic scenario is developed using building blocks such as data, model, solver, and previously executed scenarios. The sensitivity scenario and goal-seek scenario analysis processes use the original data source, user input data regarding the changes of scenario parameter, dependent scenario values from the runtime scenario pool with related sensitivity model(s) and solver(s).
- **Development of Aggregate and/or Pipelined Scenarios:** In a pre-customised pipelining system, scenarios are pre-defined as a chain from lower level to upper-level scenarios. The upper-level scenarios directly receive the value from the executed value of the lower-level scenarios. But in loosely coupled scenarios, a top-level scenario uses the values of the lower-level scenario from the runtime scenario pool. So developing an aggregated and/or pipelined scenario is quite easy.

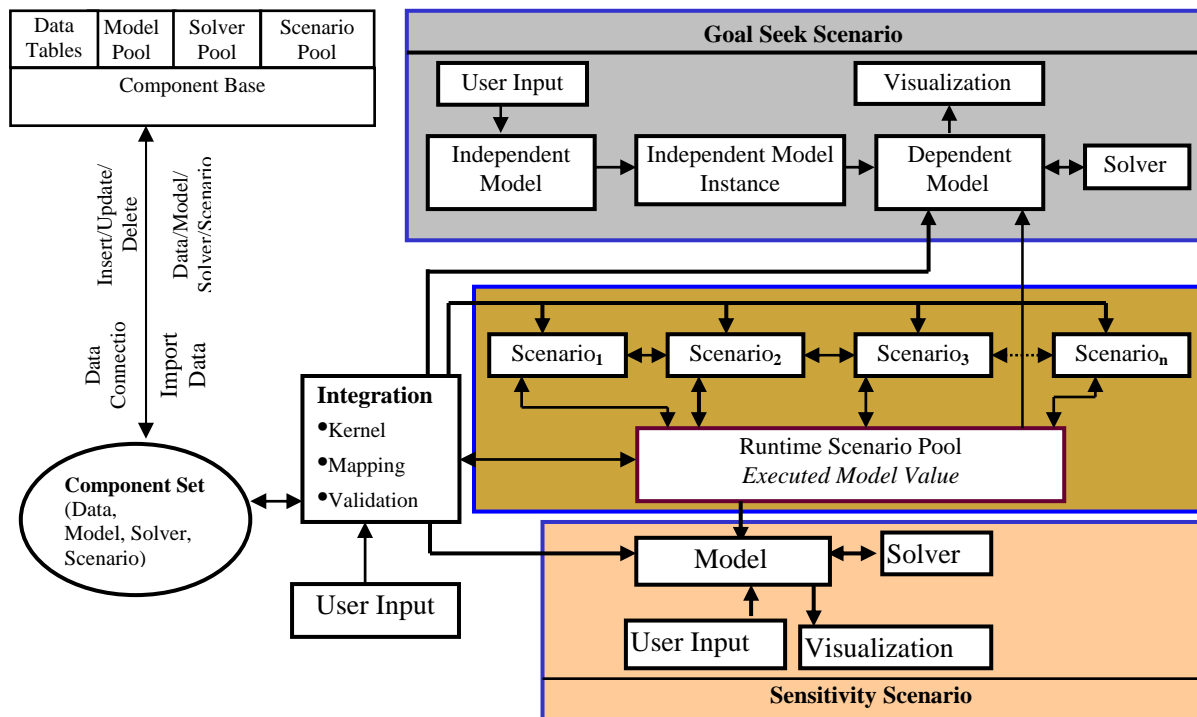


Figure 6: Realisation of the Scenario Management Process using the SDSSG Framework

- **Scenario Selection:** The framework allows the user to select any scenario depending on the suitability, quality and appropriateness of the scenario.
- **Scenario Execution:** The framework facilitates instantiation of model with the data and execution of the instantiated model with appropriate solvers.

7. Implementation Platform and Domain

The framework and architecture can be implemented using any platform that supports component-based development. Since object-oriented and component-based concepts are the central focus of the SDSSG framework and architecture, Microsoft's .NET Framework, was considered as the implementation platform and C# was used for implementing the system architecture. Component technologies (e.g. Dynamic Link Library, Component Object Model), Database Management Systems (e.g. SQL 2000 Server, Microsoft Access), and Extensible Markup Language (XML) were also used in building the system.

The SDSSG framework, architecture, and implementation were tested within the context of the mortgage domain (Figure 8). Specifically we implemented Affordability Scenarios, Lending scenarios (equal instalments, reducing instalments, interest only, etc), and Payment Scenarios. Within each of these scenarios we explored sensitivity and goal-seeking analyses.

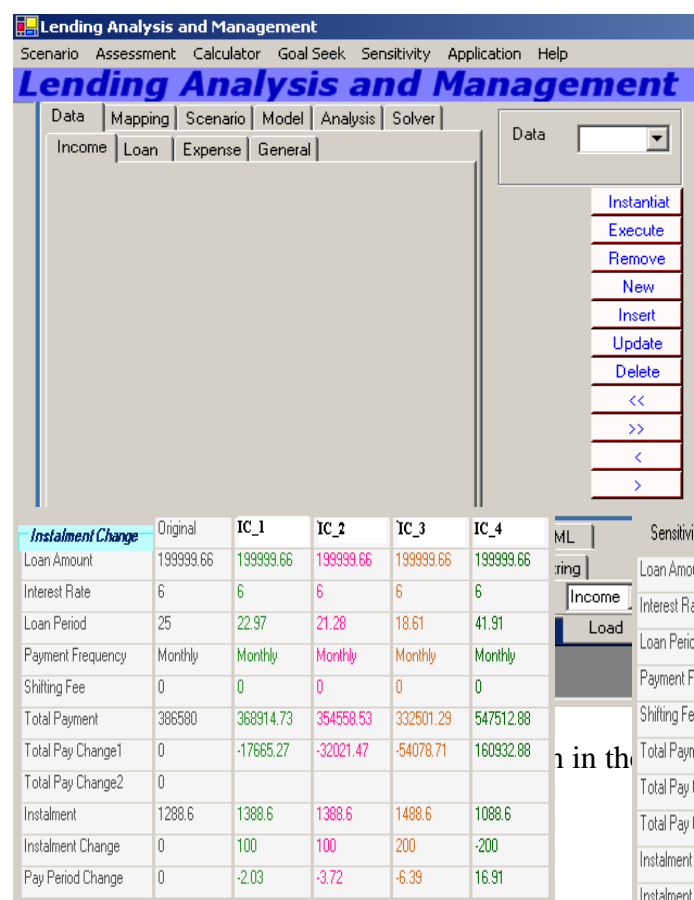


Figure 9: Homogenous scenario comparison

Once a base scenario has been developed, we explore a number of alternative scenarios including the best-case and worst-case scenarios through sensitivity analysis. We used the system to compare multiple scenarios of similar type (homogeneous comparison as shown in figure 9) or different types (heterogeneous comparison as shown in figure 10) or both homogeneous and heterogeneous at a time in a single visualisation.

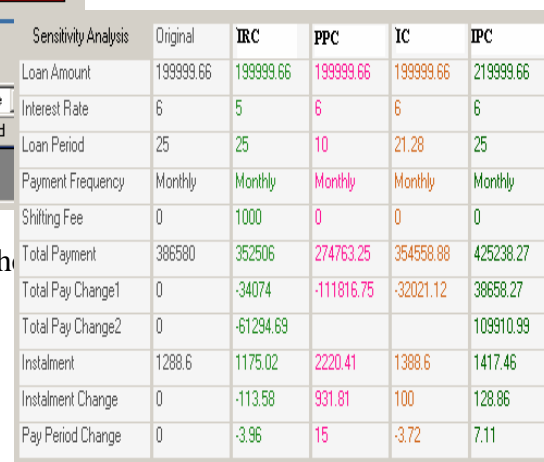


Figure 10: Heterogeneous scenario comparison

The system was tested and evaluated for sensitivity analysis for refinancing from different lending sources, and increase or decrease of the interest rate (IRC), loan amount, initial payment (IPC), instalment (IC), and pay period (PPC). The loan payment scenario sensitivity for different instances of IC is shown in Figure 9 for a \$200,000 loan at the rate of 6% per annum. Figure 10 shows another example of the sensitivity analysis of the same loan for IRC, PPC, IC and IPC. Both the analyses present the impact on the payment period, net savings/loss, and instalment. PPC, IC and IPC do not have any impact on IRC as this is an

external factor. Apart from this we also explored sensitivity analysis on complex interlinked scenarios which in turn were made up of sub-scenarios.

The system supports complex analyses from the very lower-level scenarios to higher-level/aggregate scenarios. Scenarios analysed bottom-up may or may not satisfy the prime objective. In this circumstance, a top-down scenario analysis (goal-seeking analysis) could bring the optimum acceptable scenarios that would satisfy the objective.

The prototype supports different level of users. A DSS builder may configure the SDSSG system and develops and stores different scenarios as well as specific DSS for future use by the naïve users.

8. Conclusion

Current scenario planning and analysis systems are very complex, not user friendly, and do not support modelling and evaluating multiple scenarios simultaneously. Scenario based decision support systems focus mostly on developing corporate strategies rather than supporting tactical or operational level decision making. To overcome these problems we propose a scenario management life cycle and a framework and architecture that support the lifecycle. The lifecycle as well as the framework and architecture are validated through a concrete implementation of a prototype.

We develop a generic life cycle based approach for scenario management that supports a range of activities from idea generation to final use of the scenarios. Key phases of the life cycle are idea generation, scenario planning, organisation, development, execution, analysis, evaluation, and finally decision support. The process hides external factors and complexities of the scenario and allows the seamless combination of decision parameters for appropriate scenario generation. This research also proposes a generalised scenario evaluation process that allows homogeneous and heterogeneous scenario comparisons among the multiple instances of similar and dissimilar scenarios respectively. It enables the decision maker in finding appropriate and plausible scenarios. This research introduces the concepts of scenario structure and their development strategy. It decomposes large complex scenarios into multiple small and executable scenarios and uses the decomposition and re-composition methodology for defining the scenario structure.

The research further realises the scenario-driven decision-making process using model-driven decision support systems. This research develops a generic scenario driven flexible decision support systems generator framework and architecture that supports the above-mentioned scenario management processes. It also supports sensitivity and goal-seeking analysis. It uses decision-support components, integration components, and component pools. Scenario has been introduced as a new DSS component that is developed as a complex combination of other decision-support components, namely data, model and solver. The proposed framework and architecture are domain independent, platform independent, component-based and modular. The architecture is comprised of multiple layers e.g. component pool layer, data access layer, decision support services layer, integration layer, and user services layer. Each layer performs specific functions, which are suitable for implementation of the architecture as a single-, two- or three- or n-tiered system. A prototype was developed using the framework and architecture. The implemented system is suitable both for the naïve user as well as the DSS builder. The naïve user can easily use the semi-automated pre-customised system while the DSS builder can use the versatile loosely-coupled system.

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