Modeling Strategic Decisions Using Activity Diagrams to Consider the Contribution of Dynamic Planning in the Profitability of Projects Under Uncertainty

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***Abstract*—In this paper, a framework to consider the contribution of decision making and dynamic planning in the profitability of a project under uncertainty is proposed. Unified modeling language (UML) activity diagrams are constructed for different strategies of an ongoing engineering project whose final profitability is highly influenced by a set of uncertain variables, such as demand, costs and prices, or unexpected events. Some of these strategies can be, for instance, expanding, contracting, switching, abandoning, waiting, transferring, etc. A method to derive a simple mathematical model for carrying out a project from any UML activity diagram describing the strategy is also presented. This mathematical model can be easily implemented in a simulation environment, where the random nature of the different uncertain variables of the project, the relationships between them, and its final profitability can be considered. An example of the application of the proposed model is shown. This example also illustrates how to model the uncertainty in demand by means of a stochastic Bass process. We suggest that the proposed methodology be used by itself or as a complementary tool to the existing methods of capital budgeting by solving some of the deficiencies found in them. For instance: 1) net present value or return on investment is static in nature and cannot cope with uncertainty; 2) real options valuation may be an obscure technique and in many cases does not allow an operational strategy to be derived for guiding the project in real life; and 3) decision analysis occurs within the problem of the "flaw of averages," by using expected values of different uncertain variables to calculate the profitability of a project instead of their complete probability distribution.**

***Index Terms*—Business case analysis, decision analysis under risk and uncertainty, development of technology management strategies, flexibility and time-based management, forecasting/statistics/probability, Unified modeling language (UML) activity diagrams.**

I. Introduction

EXISTING capital budgeting tools do not satisfactorily consider strategic decisions and dynamic planning in calculating engineering project profitability in uncertain environments. A new method that can be easily applied and allows an operational strategy to solve this problem is needed.

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To fulfill these requirements, we propose the use of unified modeling language (UML) activity diagrams to model the different possible strategies, which are applied during the implementation of a project. These diagrams can be used to implement the strategies in a simulation environment that allows for the consideration of the random uncertain variables of the project and their relationships, and the final profitability of the project. In this paper, the framework and tools to carry out these tasks are described. The rest of the paper is structured as follows.

1) In the Section II, a critical review of the present methods that are used in the financial analysis of projects under uncertainty is made. In this review, we present the main advantages and drawbacks of the following methods: traditional capital budgeting tools [net present value (NPV) and return on investment (ROI)], real options analysis, decision analysis (decision trees and influence diagrams), and the Monte Carlo simulation. We conclude that none of the existing methods consider the effect of dynamic planning in the final profitability of the project satisfactorily. Finally, we conclude this section with a list of the requirements that a new method should comply with for managers and engineers to solve real problems.
2) In the Section III, we propose a method to model strategic decisions, using UML activity diagrams. We also include some examples of the application of the described method in this section. Specifically, we show how to model some of the most common strategies considered in real options theory, such as the option to abandon, the option to switch between strategies or technologies, and compound options.
3) In the Section IV, we show that any UML activity diagram can be expressed by means of a mathematical formulation and this can be implemented in any simulation environment. The goal of this mathematical formulation is to calculate the profitability of a project that is subjected to uncertain variables by taking into account the effect of dynamic planning in response to that uncertainty using simulation.
4) In the Section V, we describe a simplified real example of the application of the methodology. The example considers a telecommunications operator who has to initiate a broadband Internet access service in a rural or isolated area, and the options involved are: 1) using a less expensive technology with a low startup time, but that cannot

fulfill the requirements of all the users; or 2) using a more expensive and slower to roll out technology, but one that can meet the requirements of all the clients. We show how a good strategy to reduce uncertainty is dynamic and would consist of starting with the less expensive technology and, if demand turns out to be sufficiently large within a few years, then to change to the other technology that can meet the needs of more clients and offer more services. We demonstrate how this dynamic strategy can be implemented in a simulation environment, which is then used to calculate the final profitability of the project.

5) Finally, the Section VI of the paper summarizes the conclusions obtained from our study and the Section VII provides the references.

II. Critical Review of Present Methods of Financial Analysis in the Face of Uncertainty

Traditional capital budgeting tools, such as NPV or ROI, have proven to be suitable enough to value the profitability of projects in which there is no uncertainty. The strategy for implementing such projects is completely defined before the start up. However, these methods fail when they are used to evaluate projects that are subject to significant uncertainties, such as demand, costs and prices, or unexpected events, which can change the course of the project [1]. Such projects require a dynamic planning to respond flexibly to the different events and situations that can occur during implementation.

Real options and decision analysis (decision trees and influence diagrams) are used to value the profitability of a project under uncertainty by taking into account how strategic decisions and dynamic planning made throughout the project can influence its profitability. All these theories have advantages and disadvantages, and none of them can be considered as the definitive solution in addressing the stated problem.

The real options theory takes uncertainty into account and allows pricing flexibility as a way to respond to that uncertainty during a project. The most important contribution of this theory is that it promotes a new way of thinking, in which strategic behavior and the dynamic planning process (expanding, contracting, switching, abandoning, etc.) are considered in the investment analysis. The theory also encourages flexible system design and products from an engineering point of view [2].

The drawbacks of this theory are: first, the existing tools and models in this theory require profound mathematical and financial knowledge, and are not clear enough to be understood by the managers and engineers who make the decisions [3]. Assumptions made in the different models are difficult for a nonspecialist to understand and verify. Many of the proposed models do not even clearly define what the assumptions are and how they should be verified during their application [4]. The information required to solve these models is also usually hard to obtain or cannot be estimated with precision; thus the results are not accurate enough for managers to have confidence in them. Another significant drawback is that the closed-form models or calculation tools developed in this theory usually consider whether an option should be kept open or exercised according to the value of the underlying asset [5]. Most real options methods consider whether an option should be exercised or not according to the price or value of the underlying asset with time. Obtaining from this value the corresponding values of the suitable variables of the project, which can be used by the managers for deriving an operational strategy for the project, is a complex and even impossible task in many situations [3].

Decision analysis applied to financial analysis commonly makes use of influence diagrams and decision trees to set forth decision rules, which investors may apply to optimize the strategy of a project. These techniques allow multiple sources of uncertainty to be taken into account and identify a suitable strategy for any given combination of the possible states of each uncertainty variable. The resulting operational strategy is straightforward with these methods, in contrast to what happens with real options.

The main drawback of the decision tree theory is that it relies on laying out absolutely all of the possible scenarios for the different combinations of uncertain variable states, therefore a decision tree can easily become very complex and cumbersome to solve as its size increases. As the complexity and size of the tree increases, its graphical representation also becomes more of a disadvantage than an advantage. The mere size of the tree increases the probability of overseeing errors [3].

Influence diagrams were originally developed as “front-ends” for decision trees, to study the different sources of uncertainty and the interdependencies existing in the problem being studied. Although influence diagrams and decision trees are mathematically equivalent, influence diagrams do not graphically display all the possible scenarios, as decision trees do [6]. Influence diagrams represent “relationships between the problem component decision variables and random vectors, rather than the relationships between each possible combination of decision and outcome that might occur” [7]. Thus, the size of an influence diagram grows linearly in the number of variables, making it easier to see and debug than the equivalent decision tree. Influence diagrams have a more efficient solution procedure than do decision trees, as they take advantage of conditional independence.

However, both influence diagrams and decision trees share the same significant drawback. Both of them occur in the problem of the “flaw of averages,” as they use expected values for the different uncertainty variables to calculate the profitability of the project. Both of them also require assumptions to be made about the discount rate and the different uncertainty variables of the project [3].

To conclude, with the revision of the existing methods to carry out financial analysis in the face of uncertainty, it is important to mention the simulation methods. The most common technique used in this category is the Monte Carlo method to simulate the uncertainty variables of a project, used in conjunction with traditional capital budgeting valuation tools, such as NPV and ROI, and sensitivity analysis tools [8]. Although this technique does not consider the incorporation of the dynamic planning process in the calculation of the profitability of a project, it allows different scenarios to be considered, as well as the valuation of their profitability from a statistical perspective. Showing the profitability as a probability distribution is an important step in recognizing the uncertainty in a project. Thus, for example, instead of giving a discrete result as in the traditional methods, simulation methods provide a probability distribution from which the probability of a positive result for the project can be obtained.

Simulation methods correct the problem of the "flaw of averages" that exist in traditional methods and decision analysis, by randomly taking into account different probable values of the relevant uncertainty variables of the project (for example, demand growth, prices, etc.) in multiple stages of the project execution. This is accomplished by modeling these variables, using stochastic processes or probability distributions. If it is possible to specify the stochastic processes for the underlying uncertainties, and describe the function between the input uncertainty variables and the output payoff, computers can do the "brute force" work [2]. However, defining the suitable stochastic processes and probability distributions is not an obvious task and using incorrect models could lead to completely erroneous results.

In conclusion, none of the existing methods consider strategic decisions and the dynamic planning process in the calculus of the profitability of a project facing uncertainty to be solved in a completely satisfactory manner. A new method that can fulfill the following characteristics so that managers and engineers can solve real problems is needed.

1) The new method should provide a general framework that can be applied to any problem. This will avoid the proliferation of many theories and tools, with different assumptions and only applicable to specific scenarios.
2) Using a general framework for the theory will also allow further advancement of the theory. Instead of developing specific and isolated models, the scientific community could focus on brushing up the general framework and developing different models with it to solve the most common problems existing in real cases.
3) It should use existing and well-accepted tools and methods, and define clearly understandable steps for its application. This will allow the theory to be accepted in the corporate environment by managers and engineers, and its results too will be easily understandable and accepted by a wider audience.
4) It should consider uncertainty correctly and avoid making many assumptions that have to be checked by its users for the suitability of the application.
5) It should also avoid the "flaw of averages" problem by working with probability distributions and stochastic processes instead of using expected values.
6) Finally, the proposed framework should allow the user to follow a series of predefined steps that form a part of a rigorous study of the problem and derive the operational strategy for the project easily.

III. Modeling Strategic Decisions With Activity Diagrams

The UML is a standardized general-purpose modeling language widely used in the field of software engineering. It includes a set of graphical notation techniques to create abstract models of specific systems that can subsequently be implemented with any general software programming language [9], [10]. UML activity diagrams are part of these notation techniques and are used to model the flow of activities that constitutes a process, for instance a business process.

Exercising a particular real option or using a particular strategy within a project implies a series of decisions to be taken and actions associated with them to be performed in a timely manner. Strategies for a given project or business are, finally, implemented by means of business processes. As the UML activity diagrams consider decisions and actions to model business processes, any strategy or real option can be modeled and described by them. The obtained activity diagram can then be implemented and considered in the financial analysis of a project under uncertainty by means of a simulation. This enables the analysis of the profitability obtained, using such a strategy. To do this, a simulation environment is needed. This could simply consist, for instance, of a spreadsheet such as microsoft excel with macros implementing the Monte Carlo method or can be implemented in any general-purpose programming language.

The choice of UML activity diagrams instead of other modeling languages that are used to specify business processes, such as Business Process Modeling Notation (BPMN) and Petri Nets is justified in Section IV.

To use UML activity diagrams for modeling in the proposed framework, it is necessary to relate the concepts involved in defining the strategic decisions that are to be adopted in the dynamic planning process of a project, to the concepts used in UML activity diagrams. The whole business strategy can be modeled as follows.

1) **Strategy:** It can be defined as a concrete plan of action for any situation that may arise and is applied to fulfill some specific goals. This plan of action is made up of a set of decisions taken during different situations that occur throughout the project and which imply carrying out a sequence of activities with the goal of obtaining good profitability. The implementation of a particular strategy is, in fact, made by using a particular business process that can be modeled by means of a UML activity diagram.
2) **Activities:** The set of actions that are accomplished to fulfill a specific goal. An activity can represent a phase or task in a project. Examples of activities in the case of an engineering project are: the carrying out of a specific phase of a project, to roll out technology or infrastructures in a point of presence or area to offer some service in that location, a technology switch or migration, to abandon a project, to wait until some condition is fulfilled, to remove resources from the infrastructure of a project deployed, to extend the resources of the project, to interchange materials or information between projects, etc. Activities can be carried out in sequence or in parallel. UML activity diagrams contemplate specific notation to model concurrent or sequential activities.
3) **Transitions:** The change from one activity to another over time. This change can take place unconditionally or as a consequence of making a decision from the initial activity.

4) **Decisions:** A decision allows a point in the flow of activities to be specified, where it is possible to take different options or paths (make different transitions) according to the conditions that are fulfilled.
5) **Conditions:** Decisions are made up of conditions. A condition is a logical expression that must be fulfilled when making a decision. In UML activity diagrams, conditions are called guards. Conditions apply to one or more of the indicators of the project and/or events that occur during the project. We can define an indicator as a numerical value that allows some aspect of the project to be described and is useful when making any decision. An indicator is calculated through different variables of the project, by means of a formula or expression that relates them. A variable is a nonderivable parameter of the project that influences it, for instance, demand, prices, the cost of a given project resource, etc. We are interested in the uncertainty variables of the project that evolve over time.
6) **Time:** Time must be considered when implementing the activity diagram of a particular strategy in a simulation environment. A unit of time must be defined (e.g., month or year) within the model. Variables are defined to evolve with time. Considering that t_i is the present moment in time, transitions can take place when time evolves from t_i to t_{i+1}. Decisions, which bring about transitions, are taken at t_i, in accordance with the conditions that are fulfilled exactly at that moment. These conditions, in turn, are calculated from indicators that must be calculated from known values of the project variables (values for $t < t_i, t_i$ being the present moment in time) or by estimated future values of the variables (which should be derived from the already known values of these variables). If these rules are fulfilled when defining the activity diagram, we can assure that the result describes an operational strategy that can be implemented in the real world to control the project.

Any strategy, real option, or dynamic planning process applied during the project in the face of uncertainty can be defined by using the previously defined concepts and can then be represented by means of a UML activity diagram. Fig. 1 summarizes the graphical representation of each of the defined concepts in a UML activity diagram.

UML offers the possibility to extend and adapt its metamodel to a specific area of application through the creation of profiles. A profile adds elements that extend the existing metaclasses and consist of stereotypes, constraints, and tagged values. A stereotype is a model element defined by its name and the class or classes to which it is assigned, which are usually metaclasses from the UML metamodel (for example, the activity or control flow metaclasses in the UML activity metamodel). A stereotype can be represented by its own notation, e.g., a special icon. Constraints are applied to stereotypes to indicate restrictions. Finally, tagged values are additional metaatributes assigned to a stereotype. The UML metamodel for activity diagrams is extended to incorporate in [11]: 1) business goals; 2) performance measures to quantify the degree of achievement of these goals; 3) alerts that are emitted in case the goals are not fulfilled; and 4) organizational structure. All these elements are incorporated

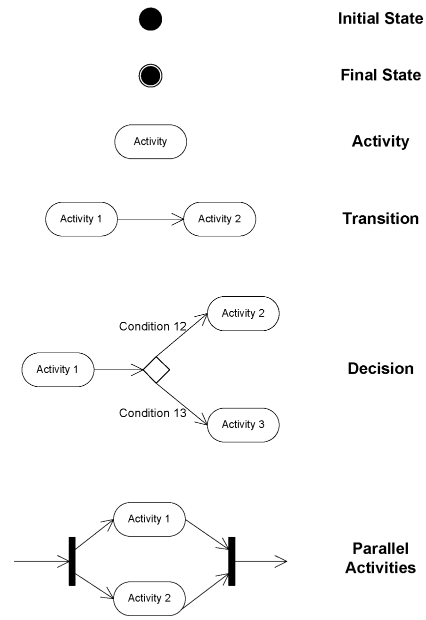


Fig. 1. Basic UML activity diagram graphical symbols.

as stereotypes to improve the capability of the UML activity diagrams to model business processes, by making their goals and performance measures visible in the model itself.

UML extension capabilities can be considered as a significant advantage in favor of choosing this modeling language among others in our framework. By using UML, we have the guarantee that future needs for modeling strategies in our proposed framework are going to be satisfied by extending the UML activity diagram metamodel. However, in our research we have been able to model successfully all the relevant strategies taken into account in the real options theory with the existing metamodel for UML activity diagrams, and therefore, we do not consider it necessary at this moment to extend it and add additional graphical notation. In fact, using stereotypes would increase the complexity of use and make the methodology less general. By keeping it as simple as possible, it will allow any activity diagram to be transformed into a finite-state machine diagram, and then, translate this finite-state machine into a mathematical model for simulation. This process will be explained in detail in Section V. As the final goal is to implement the activity diagram of a given business strategy in a simulator, some considerations on the role of time must be taken into account.

1) Time evolves in a discrete way and transitions between activities occur over time.
2) Transitions occur if their associated conditions are fulfilled and these conditions are checked over time. Time is considered a variable that affects the project execution and can be considered to build up a condition.

Stereotypes are used to define time-performance measures, which are used as restrictions associated with the activities in [11]. For instance, it is possible to associate a maximum time for carrying out a given activity. Although a similar idea

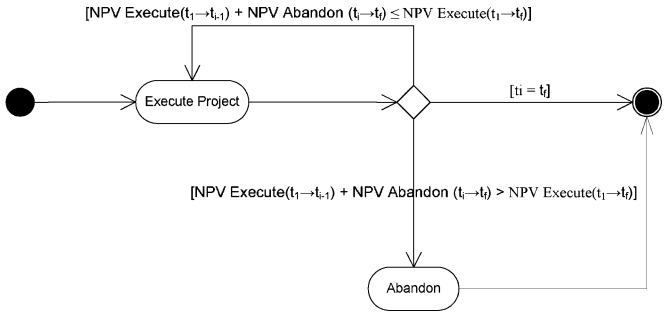


Fig. 2. UML activity diagram for the option to abandon.

could be applied in our case, we have considered that it is better not to define specific variables, as we want to keep the proposed methodology as flexible and general as possible. Thus, any variable can be considered to build the conditions associated with transitions between activities in an activity diagram. The only restriction is that these variables must be considered subsequently in the simulation environment used to implement the activity diagram.

By examining the aforementioned concepts, it is possible to model any strategy for a project by means of activity diagrams. In the following examples, the most common strategies that are considered in the real options theory are modeled by means of UML activity diagrams.

A. Option to Abandon

There is the option to abandon a project at any given moment if it is estimated that the results for the project will be better by abandoning it at that time than by continuing it until completion. This strategy can be modeled using a two-state activity diagram (execute project and abandon), such as the one shown in Fig. 2.

In this diagram, we have:

1) t_1 is the moment in time when the project starts, t_i is the present moment in time, t_{i-1} is the previous moment in time, and t_f is the moment in time that the project ends.
2) ***NPV Execute (**$t_1 \to t_{i-1}$**)*** is the NPV value obtained with the project from its beginning to the present moment in time (this not included). This indicator is a perfectly known value at that time of the project, as all the variables needed to calculate it are known past values (demand, costs, prices, etc).
3) ***NPV Abandon (**$t_i \to t_f$**)*** is the NPV that can be obtained in time that remains to finish the project at t_f if it is abandoned at the present moment in time, t_i. Abandoning a project can imply: 1) obtaining some incomes, as some intermediate results are sold; 2) some cost reduction, as the intermediate results of the project can be transferred to other projects; and 3) some increase in costs that are needed to pay for the removal of resources, etc. All these aspects can be considered in the *NPV abandon (*$t_i \to t_f$*)* indicator.
4) ***NPV Execute (**$t_1 \to t_f$**)*** is the NPV of the project on completion at finalization time. This indicator can be broken down into two terms, one already known and one that has to be estimated: *NPV Execute* $(t_1 \to t_f) =$ *NPV Execute* $(t_1 \to t_{i-1})$ + *NPV Execute* $(t_i \to t_f)$. To estimate the term, *NPV Execute* $(t_i \to t_f)$, there are different options, for instance, to use the values of demand, incomes, and expenses obtained at t_{i-1} for the period between t_i and t_f. The only condition is that any estimation must use the known values to estimate the future ones, to obtain a strategy that is implementable in real work.

B. Option to Switch

Managers have the option of switching when a change of strategy is possible during the project, based on the observed and expected results. Activity diagram shown in Fig. 3 models a dynamic planning process where at any given time, t_i, it is possible to change the strategy of the project if the expected results of the new strategy will be better than those estimated for the present strategy. The conditions considered in the diagram can be explained similarly to the conditions explained for the option to abandon.

Many decisions made during the project can be modeled by means of this diagram. For instance:

1) **Option to decrease production:** It is the option to reduce expenditures and investments during the project by removing unused resources or downsizing production capacity if the demand declines. To implement this strategy using the UML activity diagram in Fig. 3, we have to associate strategy 1 with the action of decreasing the production and strategy 2 with the action of not decreasing the production.
2) **Option to increase production:** It is the option to increase the resources available for the project if demand increases and obtain higher profits.
3) **Option to choose between technologies:** It is the option to change between two different technologies during the project so that the best technology at any given time and up to the end of the project is chosen. In this case, strategy 1 in the diagram in Fig. 3 can be associated with using technology 1 for the project and strategy 2 can be associated with using technology 2.

C. Composition

Composition exists when a project can be broken down into different phases and tasks, and the success of the whole project depends on the success of any of these individual phases. Most engineering projects follow this schema, for instance, the development of a telecommunications service or an R&D project, the constitution of a new telecommunications operator, etc. The following UML activity diagram (see Fig. 4) shows an example of how to model this kind of project.

The diagram considers the different project stages and the different tasks to be accomplished at each of the stages. We can see in the diagram how the different tasks can be carried out both in parallel and in sequence. At the end of each task, if applicable, a decision is made to determine whether to carry on with the project or to abandon it. This choice can depend on the success or failure of the corresponding task, which can

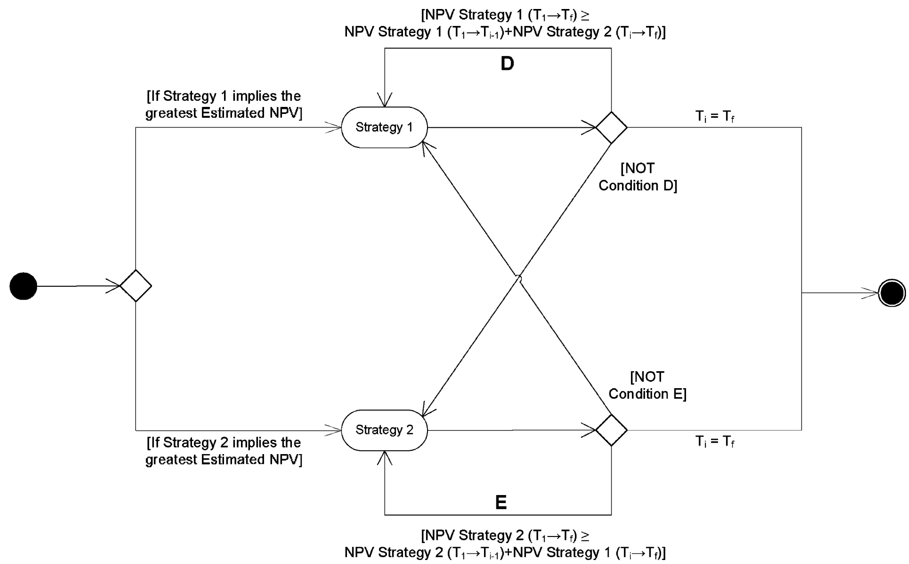


Fig. 3. UML activity diagram for the option to switch.

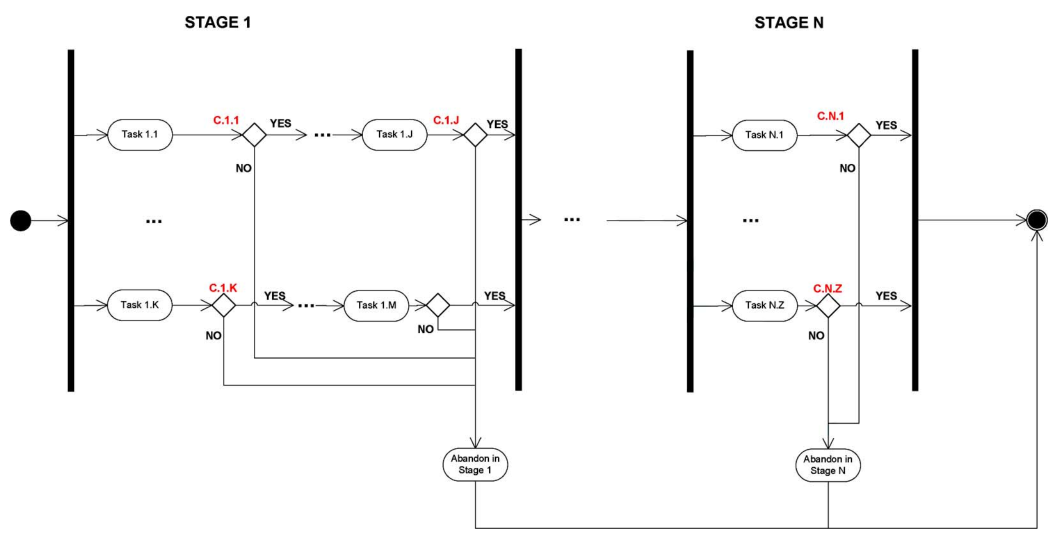


Fig. 4. General UML activity diagram for composition.

be determined by a condition on different indicators associated with the results obtained in the task.

D. Transference Between Projects

There are many cases in which, despite the abandonment of a project, it is possible to make use of its intermediate results in other projects. UML activity diagrams are also useful to model the transference of products, knowledge, and materials that can occur between projects. This can be done by representing the flow of materials between the tasks of different projects. Each flow implies that the destination task could reduce their costs by reusing some of the intermediate products obtained in the original task. Reutilization can always occur, for instance, if the element to be reused is knowledge, or only occur if the original task fails, and thus, the associated project and intermediate products or used materials are not needed anymore in that project.

IV. Why UML Activity Diagrams? A Justification

UML activity diagrams are used as a high-level modeling tool that allow the strategies and processes in a given project or business to be defined without needing to know the low-level details involved in the next steps of the proposed framework (mathematical formulation of the problem, simulation, and financial analysis). Thus, managers, nontechnical staff, or engineers without financial background can abstract the details of the underlying financial theories and focus on the specification of the problem by using a general-purpose tool. This is an advantage compared with other theories, such as real options and decision trees in which the steps in defining strategic decisions and problem-solving are intrinsically related.

Another advantage of UML is that it is also a widely accepted language and the activity diagram notation is easy enough to be learnt and used by nontechnical staff.

Finally, UML extension capabilities are another important advantage in favor of choosing this modeling language from among others in our framework, as this guarantees that it will be possible to satisfy future needs by extending the UML activity diagram metamodel.

Among other languages and notations that are used for business process specification, the most known are BPMN [12] and Petri Nets [13]. All these notations offer similar functionalities, and could be used for modeling strategic decisions and processes in a project or business under uncertainty. However, we have opted for UML activity diagrams in our framework for the following reasons.

A. UML Activity Diagrams Versus BPMN

There are minor lexical differences and differences in nomenclature between UML activity diagrams and BPMN. UML activity diagrams are an execution-oriented language that has the possibility of building an execution engine. BPMN has been designed with the aim of being a notation for high-level modeling. As a result, several constructs in BPMN (e.g., OR-join and complex gateways) do not have fully defined semantics for execution. The rationale for this is that BPMN will be used by domain analysts whose goal is not to produce a system implementation, but rather a set of requirements to be handed over to information technology analysts and software developers.

Thus, UML seems to be a better choice for our framework, as our goal is to produce a model to define the strategy of a project and implement it by means of a simulation environment. UML is an execution-oriented language, which offers a less ambiguous semantic than BPMN. However, both languages offer very similar functionalities, as can be seen in [14], where the author identifies the 21 most common patterns that describe the behavior of business processes in BPMN and the equivalent pattern for each of them in UML activity diagrams. It should be possible to use BPMN in our framework by simply constraining its use to those patterns that are not semantically ambiguous and can be, subsequently, implemented in a simulation environment. In any case, those ambiguous patterns are not commonly used.

Other advantages of UML in comparison with BPMN are that it is a more extensible and used language.

Both UML activity diagrams and BPMN share the characteristic of being a view[1] (the process view) for the business process definition metamodel being developed through a request for proposal (RFP) process in the object management group (OMG). This metamodel is an extension of the UML 2.0 metamodel, and so UML activity diagrams are a natural successor to it. BPMN maps are also very close in this view. Since both notations are very similar and are views of the same metamodel, it is possible that they will converge in the future [14].

B. UML Activity Diagrams Versus Petri Nets

Petri Nets are a formal language for specifying concurrent systems and has also been applied for specifying business processes. They are intended for use by computer scientists or especially trained software designers. Classical Petri Nets seem to be more suited to low-level description, while UML activity diagrams are a higher level specification language. Models produced with Petri Nets are usually more complex, and contain more nodes and edges than models produced with UML activity diagrams. Classic Petri Nets do not allow data and time in the models to be considered. To solve all these problems, many extensions of the classic Petri Nets have been proposed. Three well-known extensions are: 1) colored Petri Nets to model data; 2) time Petri Nets to consider time in the models; and 3) hierarchical Petri Nets to structure large models. A Petri Net extended with color, time, and hierarchy is called a high-level Petri net. These enhancements in Petri Nets allow them to be used as a higher level language. However, we believe that in spite of these efforts, high-level Petri Nets are more complex to learn, use, and interpret by nonspecialists than UML activity diagrams. The latter are more familiar to people used to working with workflows and business processes, and thus, can be easily learnt and used by management staff and nonspecialists. The use of UML activity diagrams to model business processes is also more widespread. We can also expect that their use will become more widespread as a result of the efforts of the OMG in developing a business process definition metamodel in which UML 2.0 activity diagrams is considered.

One of the advantages of Petri Nets is that they offer a much reduced notation than UML activity diagrams by avoiding ambiguity in semantics and allowing mathematical models. However, UML activity diagrams can be transformed into an equivalent Petri Net, as described in [15] and [16].

Finally, in [17], a comparison between Petri Nets and UML activity diagrams is made. The authors formalize the intended semantics of activity diagrams, and then, compare them with various Petri Net semantics (for low-level and high-level Nets). They state that Petri Nets model closed systems, as all the changes in the Nets are caused by the firing of some transitions that represent an activity in some part of the system itself rather than outside the system. They also indicate that standard Petri Nets model active systems, as a transition is enabled if its input places are filled and it does not have to fire immediately. However, an activity diagram has a reactive semantic and it models open systems. This is because an edge is enabled if its source state nodes are active at a moment and its associated trigger event occurs in the environment.

Thus, the authors conclude in [17] that since workflow systems are open, reactive systems, Petri Nets cannot model workflows accurately, unless they are extended with a syntax and semantics for reactivity.

In our case, we want to model strategies for engineering projects that are applied reactively in an open system, to face the uncertainty of internal, and mainly external variables (environment can affect the business profitability dramatically). Thus, UML activity diagrams seem to be more suitable than Petri Nets.

[1]A view is an abstraction focused on describing one or several specific aspects of a business, while omitting details that are irrelevant.

V. Using Activity Diagrams With Strategic Decisions in Financial Analysis

Once the different strategies that are to be applied during the project are modeled by means of UML activity diagrams, they can be used in a simulation exercise, where the uncertain random variables and the relationship between them, and the final profitability of the project can be considered.

1) The random nature of the different uncertain variables can be modeled by using probability distributions and stochastic processes. In Section VI, we will see an example of how to model the uncertain demand trend of a telecommunications service by using a stochastic process based on the Bass diffusion model.
2) The different uncertain variables can be related with the final profitability of the project by means of the traditional capital budgeting formulae, such as NPV and ROI. Thus, the final profitability is also a probability distribution that can be obtained by the simulation of the uncertainty input variables. Finally, from this distribution, we can calculate the value of the probability of obtaining a positive profitability for the project.
3) The strategy in a UML activity diagram will be applied to change different aspects of the project (resources used, areas of deployment, demand that is attended to, etc.), according to the values the uncertain variables take over time. These aspects in turn will influence the final expenditures, investments, and incomes of the project, and thus, its final profitability.

The following steps are proposed in implementing the UML activity diagram in a simulation environment.

1) To transform the UML activity diagram into a finite-state machine diagram.
2) To derive a mathematical model from the finite-state diagram and implement it in a simulation environment.

A. Transforming the UML Activity Diagram Into a Finite-State Machine Diagram

The use of UML activity diagram notation is a good option for modeling the strategy of a project because it is a high-level language that allows nonexperts to abstract the details of the underlying financial theories and focus on the specification problem. This notation provides an easy way to describe systems and processes. However, to obtain a mathematical model, it is necessary to use a more formal semantics, so that problems with the transition from the analysis to implementation can be avoided. To achieve this, we propose transforming the obtained UML activity diagram into a finite-state machine diagram, and then, derive a mathematical model from this, which can be implemented in a simulator environment. Finite-state machine diagrams, as well as Petri Nets, are low-level modeling tools with a formal semantics. Therefore, it is possible to derive a mathematical model for any specification of a defined system by using these low-level modeling tools (see [15] and [16]). The author also shows that finite-state machines or their state diagrams can be represented by a subclass of Petri Nets and analysis methods for Petri Nets, including a matrix equation approach are described in [13].

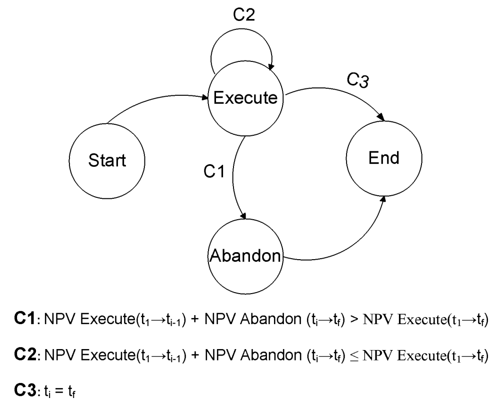


Fig. 5. Finite-state diagram equivalent to the UML activity diagram for the option to abandon.

To transform a UML activity diagram into a finite-state diagram, we have studied the most common patterns that can be used in them (in accordance with [14]) and obtained their equivalent patterns in a finite-state machine diagram. The result is summarized in Table I, which can serve as a useful guide for modeling the strategy of a project.

As an example of the application, consider the UML activity diagram for the option to abandon, as shown in Fig. 2. This diagram uses only the exclusive choice pattern, which is described in Table I. To transform it into a finite-state diagram, we only need to transform the occurrences of the exclusive choice pattern into the equivalent pattern for a state diagram. The result is shown in Fig. 5.

B. Deriving a Mathematical Model From the Finite-State Diagram

Once we have obtained the equivalent finite-state diagram from a UML activity diagram, it is possible to derive from this, the following set of equations to calculate at instant *t*, the states that will be activated at instant $t + 1$:

$$t_{ij}(t) = c_{ij}(t)o_i(t) \tag{1}$$

Equation 1: Expression to calculate whether transition from state *i* to state *j* is activated at instant *t*.

$$o_j(t+1) = \begin{cases} 1, & si\ \exists\, i,\ t_{ij}(t) = 1 \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

Equation 2: Expression to calculate whether state *j* is activated at instant $t + 1$.

where

1) *i* refers to the state *i* of the finite-state diagram.
2) *j* refers to the state *j* of the finite-state diagram.

TABLE I
UML ACTIVITY DIAGRAMS' MOST COMMON PATTERNS AND THEIR EQUIVALENTS IN STATE DIAGRAMS

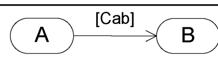
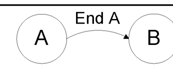
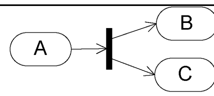
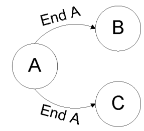
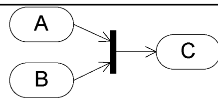
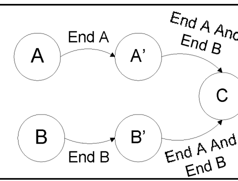
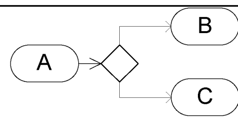
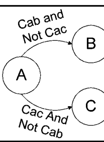
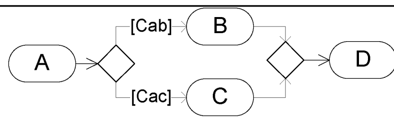
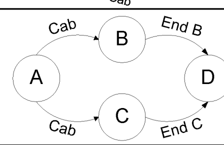
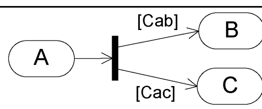
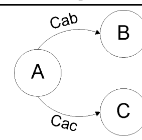
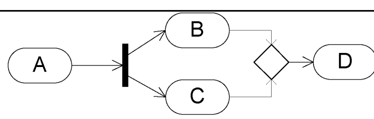
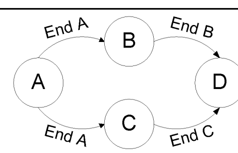
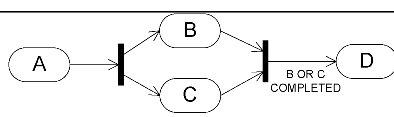
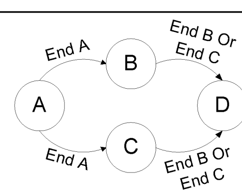
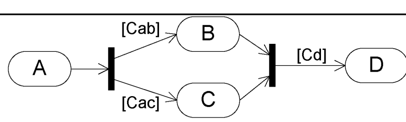
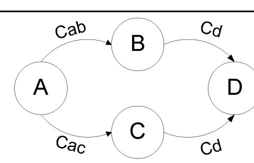
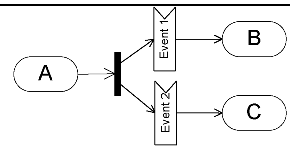
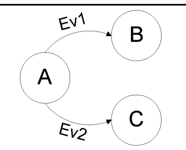
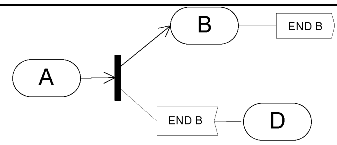
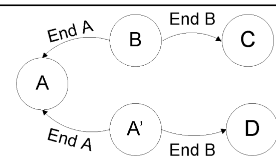
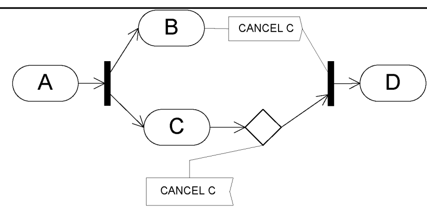
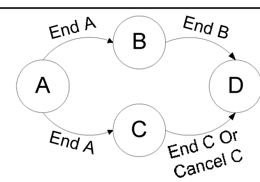
Pattern	UML Activity Diagram	State Machine Diagram	Description
Sequence			Ordered series of activities. Transitions occur according to conditions.
Parallel Split			A single path through the process is split into two or more paths so that two or more activities will start at the same.
Synchronization			A point in which two or more flows of activities must be completed before the process can continue.
Exclusive Choice			A point where a decision must be made and only one of various possible paths can be chosen.
Simple Merge			A location in a process where a set of alternative paths is joined into a single path.
Multiple Choice			Differs from the Exclusive Choice pattern in that the Multiple Choice pattern allows from one to all of the alternative paths to be chosen.
Multiple Merge			A location in a process where there are multiple paths merging and it is possible that the following activity (D in the example) will be instantiated once for each of the merged paths.
Discriminator			A point where a set of parallel flows come back together, but flow will continue immediately after one of the parallel flows is completed, without waiting for the others.
Synchronizing Merge			To synchronize all of the parallel paths that are incoming to an activity, but by defining a specific synchronization condition, Cd. For instance, this allows not having to wait for all the paths to be finished for going on to the next activity.

TABLE I
(Continued)

Deferred Choice			This pattern is similar to the Exclusive Choice pattern, but the decision is based on an event that occurs during the process. Once the event occurs, the other alternative paths are disabled.
Milestone			To model points in a process where it is important to know whether a specific event has occurred or a condition has been met (milestones). The process must be able to identify and react to the milestone. This is modeled by signals.
Cancel Activity			To model two competing activities. When one of the activities finishes, it signals that the other activity should stop processing.

3) $c_{ij}(t)$ is associated with the condition to activate the transition between state *i* and state *j*, and is defined as follows:

$$c_{ij}(t) = \begin{cases} 1, & \text{if condition to activate transition between state } i \text{ and state } j \text{ is true at instant } t \\ 0, & \text{otherwise (including that no transition exists between state } i \text{ and state } j\text{)} \end{cases} \quad (3)$$

Equation 3: Expression associated with condition to activate transition from state *i* to state *j*.

4) $o_i(t)$ is a variable to express whether state *i* is activated or not at instant *t* and is defined as follows:

$$o_i(t) = \begin{cases} 1, & \text{if state } i \text{ is activated at } t \\ 0, & \text{if state } i \text{ is not activated at } t \end{cases} \quad (4)$$

Equation 4: Variable to express whether state *i* is activated or not at instant *t*.

Equation (1) shows whether transition between states *i* and *j* is activated at instant *t*. This equation is 1 or true if state *i* is activated at instant *t* and the condition to pass from state *i* to *j* in the next instant of time is fulfilled.

A state *j* is entered at instant $t + 1$ if, as (2) expresses, there is at least one transition entering that state activated at instant *t*.

VI. Example of Application: The Option to Switch Technology

Once we have defined a methodology to consider the dynamic planning process that is accomplished during an uncertainty project in its profitability calculation, in this section a simplified real example of an application is described. This example allows the concepts explained in the previous sections to be clarified while showing the potentials of the proposed method.

A. Definition of the Scenario

The scenario considered focuses on the possibilities that a telecommunications operator (telco) has, while initiating broadband Internet access services in rural areas. The Spanish government has launched several programs in recent years to promote the extension of the broadband access telecommunications services in rural and isolated areas of the country. In these programs, telcos are offered funds to aid them in setting up network infrastructures to meet the broadband access demand of rural clients, as a way to reduce the existing digital gap between rural and urban areas.

The main problems that a telco encounters in this scenario are the uncertainty of demand and the high startup costs of the network infrastructures that are needed in rural areas. Thus, a proper selection of the strategy and technologies in these areas is mandatory. A good strategy would consist of starting initially with a radio technology, such as very small aperture terminals (VSAT), WiMax, or high-speed downlink packet access (HSDPA)/high-speed uplink packet access (HSUPA), which will allow a cheaper and faster rollout than with cable technologies, to reduce risk resulting from uncertainty in demand. However, at present radio technologies do not offer a bandwidth, quality of service, and security as good as those offered by cable or fiber technologies. This implies that radio technologies do not offer the entire telecommunications operator's services portfolio and that not all the potential clients' demands can be met, in contrast to cable or fiber technologies. Thus, as part of its strategy, the telco could decide after several years of radio technologies in the area to switch progressively to cable or fiber technologies. The condition to switch the technology could be that the demand is high enough to make the use of cable or fiber technologies more profitable in offering more services and attend to more clients in spite of the switching costs. That is if the demand in the area does not grow sufficiently enough, then the operator will continue offering its services by means of radio technologies.

B. Building the Model

To study the aforementioned scenario, a business model must be built, which can be simulated to obtain its associated profitability distribution function. The following tasks must be accomplished to build such a model: 1) to define a stochastic process to describe the demand trend; 2) to define the areas of service and the points where the technology must be deployed; 3) to define how demand is distributed between these points; 4) to model the resources necessary to meet the demand and the dimensioning rules; 5) to define the cost model associated with these resources; 6) to define the income model associated with the demand; and 7) to model the strategies or the dynamic planning process to be accomplished during the project. In this section, we focus on the two tasks that are more intricate and the object of this paper: tasks 1 and 7.

1) Defining a Stochastic Process to Describe the Demand Trend: To estimate the demand trend for broadband Internet access services in a rural area, we can use the demand trend for similar services in urban areas as the starting point. For instance, Fig. 6 shows the demand trend for the asymmetric digital subscriber line (ADSL) Internet access service in Spain. The real ADSL clients' evolution from Oct. 2002 to Feb. 2006 is shown in pink. A Frank Bass diffusion curve [18] is calculated by applying regression analysis to the observed real data to estimate the ADSL evolution in the future; this curve is shown in blue in the diagram.

To estimate the demand trend for broadband access services in rural areas, we can assume that this will follow a shape similar to the trend observed for ADSL services in urban areas. Thus, we can assume the same parameters, which model the effect of innovation and imitation, p and q, for the Bass curves in urban and rural areas. These parameters are: $p = 0.00073929$ and $q = 0.036192$. Next, we have to estimate the maximum demand that will be reached in the rural area under study (m parameter in the Frank Bass model). This is an uncertain value; therefore, we can model it by means of a probability distribution. By analyzing the potential market in the rural area and observing penetration rates reached in urban areas, we could estimate an expected value for the maximum demand. Then, the margin of error for this expected value is estimated. Both parameters, expected value and margin of error, are used as the mean and variance of a Gaussian probability distribution. Finally, a stochastic process is obtained by simply substituting the parameter m of the Frank Bass model for the defined Gaussian probability distribution. In (5), the mathematical expression for this stochastic process is shown, while Fig. 7 shows several examples of this process obtained by the Monte Carlo simulation. We can see how the different curves are distributed according to the Gaussian probability distribution.

$$F(t)_{\mathrm{ADSL}} = \mathrm{Gaussian}(\mathrm{media} = 3.600; \mathrm{deviation} = 33\%) \cdot \left[\frac{1 - e^{-(0,00073929+0,036192)\cdot t}}{1 + (0,036192/0,00073929)e^{-(0,00073929+0,036192)\cdot t}}\right] \quad (5)$$

Equation 5: Frank Bass stochastic process for rural ADSL demand trend in the area under study.

In the scenario being studied, we are going to assume that the ADSL demand would evolve according to the stochastic process and curves shown in the (5) and Fig. 7, respectively, while if WiMax technology is used, demand would be 75% of the demand met if ADSL was used instead. Thus, the Frank Bass stochastic process, if a radio technology such as WiMax is used can be described by (6).

$$F(t)_{\mathrm{WiMax}} = 0,75\ \mathrm{Gaussian}(\mathrm{media} = 3.600; \mathrm{deviation} = 33\%) \cdot \left[\frac{1 - e^{-(0,00073929+0,036192)\cdot t}}{1 + (0,036192/0,00073929)e^{-(0,00073929+0,036192)\cdot t}}\right] \quad (6)$$

Equation 6: Frank Bass stochastic process for rural WiMax demand trend in the area being studied.

2) Modeling the Option to Switch Technology: Fig. 7 captures the uncertainty of the demand trend in the rural area under study. Deploying a cable technology in a rural area can profitable or not depending on its final demand. This must be large enough to allow a positive balance between the incomes from the clients and the costs of technology startup. Thus, a good strategy is to start using a radio technology such as WiMax, and if demand turns out to be big enough in several years, then change to ADSL technology to attend to more clients and offer more services. We have supposed that WiMax technology can cater only to 75% of the demand of that with ADSL technology. Thus, the option to switch technology in the future will be exercised if the costs of changing from WiMax to ADSL technology are lower than the increase in incomes which are derived from having a higher demand with this last technology. This strategy can be modeled by the UML activity diagram in Fig. 8, which is a particularization of the one shown in Fig. 3.

In the diagram in Fig. 8, T_i refers to the present time in the project, when a decision must be made to carry on with WiMax technology or switch to ADSL. This decision must be made in accordance with the following indicators: NPV WiMax ($T_1 \rightarrow T_f$), NPV WiMax ($T_1 \rightarrow T_{i-1}$), and NPV ADSL ($T_i \rightarrow T_f$). To calculate these indicators for the future time, $T_i \rightarrow T_f$, an estimation of what the demand trend in this period will be, must be made. We have considered for this period that demand

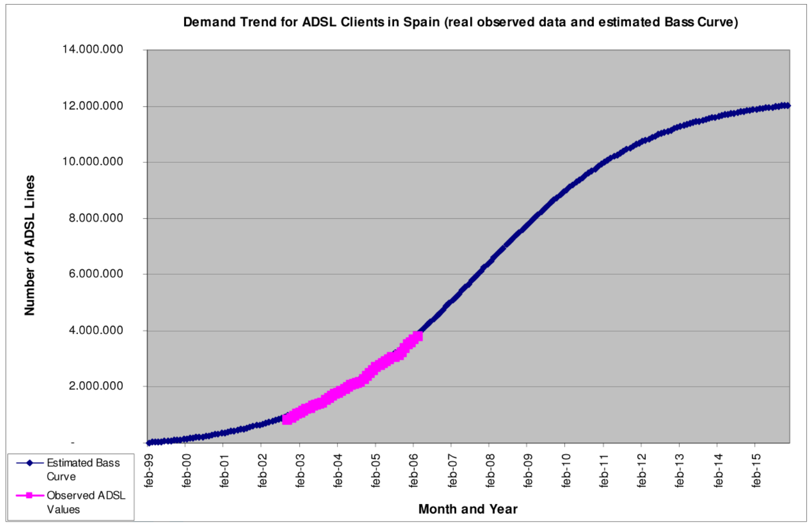


Fig. 6. ADSL demand trend in Spain.

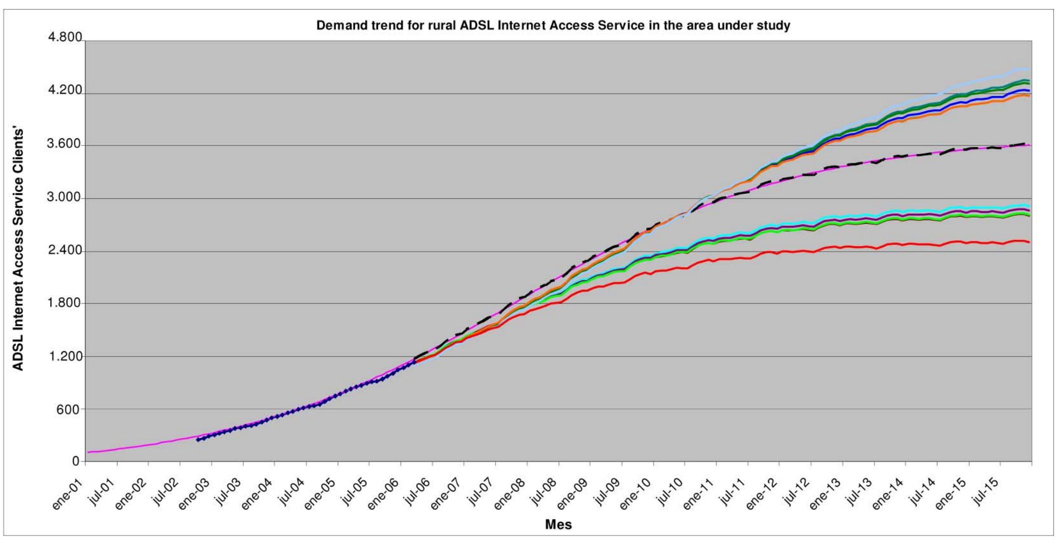


Fig. 7. ADSL demand trend in the rural area being studied.

remains constant and equal to the demand at T_{i-1}, which is a known value at T_i, and thus, an operational strategy (easy to implement in the real world) was defined.

We show that the indicators involved in the decisions can be calculated from the demand trend, and the costs and incomes of the project. All these variables have been modeled in accordance with real data (costs of equipment for the different technologies, other startup and operation costs, the tariffs for similar services on the market, and historical data of ADSL demand).

C. Simulation and Results

Once the business model for the project has been built, the next step is to implement it in a simulation environment and carry out a significant number of trials with different particularizations of the uncertainty variables according to their probability distributions. This can be done by applying the Monte Carlo method to simulate the uncertainty variables of

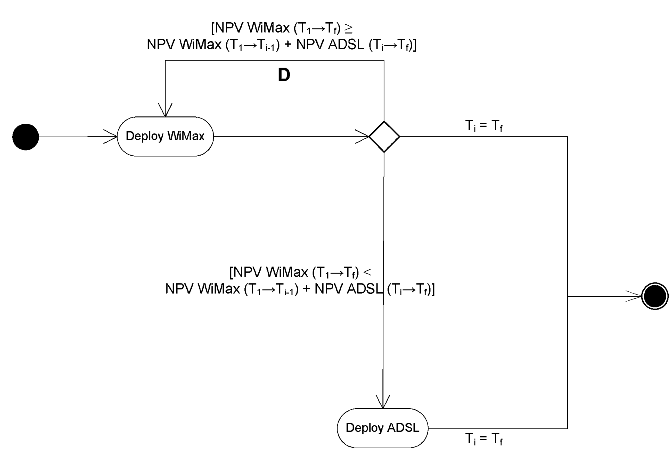


Fig. 8. UML activity diagram for the option to switch technology.

the project. Thus, the resulting NPV of the project will follow a probability distribution, as it is a function of the uncertainty

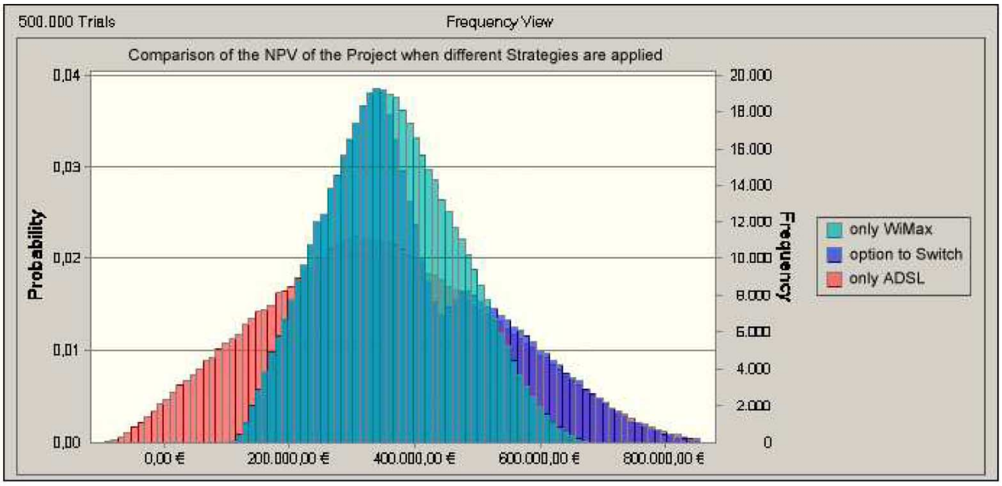


Fig. 9. Resulting NPV distribution functions for the three considered strategies.

variables of the project, which are also described by probability distributions.

Our objective is to illustrate how the NPV of a project can improve if we consider a dynamic strategy to adapt to the different situations that can take place during the project. In our case, the applied strategy allows managers to decide at any moment in time whether to switch technology or not. To compare the benefits of this strategy with other static approaches, we have also calculated the NPV of the project in which two different static strategies were applied: 1) to use WiMax technology during the lifetime of the project; or 2) to use ADSL technology during the lifetime of the project, too. The resulting NPV probability distributions for the three strategies are shown in Fig. 9.

We compare in Fig. 9, the NPV probability distributions if only ADSL technology is used during the lifetime of the project (in red) with the NPV if only WiMax technology is used (in light blue). We can see that by using only ADSL, we can obtain a better NPV than by using only WiMax, but it would also be possible to obtain negative values for the NPV. That is, the risk of the project is higher by only using ADSL than with only using WiMax, but it is also possible to make more profit from the project. In contrast, we can see that the best strategy is the dynamic one (NPV probability distribution in dark blue), in which WiMax is used at the beginning and ADSL can be used later if costs are compensated by the increase in clients and incomes. We can see how this probability distribution carries no risk of that of using only ADSL, but also gives better values. The dynamic strategy considers the best of both technologies, by using them when they are more suitable, according to the dictates of the uncertain variables of the project.

VII. Conclusion

The framework proposed to consider the contribution of decision making and dynamic planning in the profitability of a project under uncertainty offers the following advantages against present capital budgeting methods such as NPV, real options analysis, and decision analysis.

1) It is general enough to be applied to any problem. The steps to be followed in applying the method are independent of the problem to be solved. This avoids the proliferation of multiple methods and models, which are only applicable in solving a specific problem and under some specific hypotheses as seen in other techniques.
2) The proposed general framework supposes a different approach than that considered by a real-option analysis. Our idea is to define the general framework (methodology and tools) first, and later to use it to define the different strategies and apply it to different existing problems. Thus, researchers can focus first on standardizing the general framework, and then, on defining how it is to be applied to solving the existing problems. In a real-option theory, each researcher tries to define a proper mathematical model for the specific problem they are studying.
3) The proposed framework also makes use of tools (NPV and ROI), methodologies (UML activity diagrams), and disciplines (simulation) that are well accepted nowadays. This facilitates the acceptance of the framework for scientists, engineers, and professionals in enterprises and the hypothesis, calculation, and presented results can be easily understood by a wider audience than those of the other theories, such as real options.

In today's complex business processes, we need simpler and more effective ways of approaching uncertainty when considering strategic decisions. There has been a barrage of deterministic/stochastic tools/methods from all over, but rarely are understandable at the practitioners' level. The proposed methodology, with UML as a core component, tries to reduce this proliferation of methods. Although there is no ideal tool or theory for the problem addressed in this paper, and the choice of one or another method can depend on the purpose and preferential conditions of the decision-maker, and sometimes, it is even necessary to use several combined methodologies, we think that the framework that we have proposed is worth exploring as an effort to develop theories and tools that are as flexible and easy to apply as possible.

Note added in proof:

For many engineering projects that are submitted to uncertainty, defining the most suitable strategy of execution, which takes into account flexibility, can be the difference between success and failure. This paper explores how UML Activity Diagrams can be constructed for different strategies of execution of an ongoing engineering project and then to value them by simulation, to study how they increase the final profitability of the project.

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