A Framework for Project Management under Uncertainty

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Abstract: We argue that the management style of a project needs to be adapted to the type of project uncertainty: variation, foreseen uncertainty, unforeseen uncertainty, and turbulence (chaos). Widely used project tools are network planning techniques (such as PERT, Critical Path Methods, Gantt Charts) and risk management (risk identification, prevention, contingency planning). These techniques help us to cope with the management of complexity in a project and may also help to address the issue of foreseeable uncertainty.

But projects are often confronted with a high level of unforeseeable uncertainty. Coping with this uncertainty requires another management approach. We propose to start a project with determining a project profile of relevant uncertainty types. Based on the profile, one can endow the project with uncertainty-adjusted infrastructure and responsibilities, as well as extend the project management toolbox with appropriate tools and managerial approaches.

1. INTRODUCTION

In executing operational activities, organizations often find it useful to make a distinction between *processes*, the systematic execution of repetitive activities, and *projects*, the one-time execution of more or less unique activities. In today's new 'new' economy, the second form of operations is gaining in importance as more and more activities are carried out as projects. One can find many reasons for this shift of emphasis. The fast pace of competition requires constant innovation. Better-informed customers require customization. Internationalization and constant mergers and acquisition require more agility. In short, the current business environment requires constant change, and implementing change entails the need to manage projects.

A project can be defined as a unique set of activities with more or less clearly defined objectives, carried out within a limited budget and limited time span. Typically, project management requires paying attention to two major areas of responsibility: (i) *managing tasks*; and (ii) *managing stakeholder relationships*. What makes life difficult for most project managers is project complexity and uncertainty.

Managing project complexity is not the focus of this paper. Herbert Simon defined complexity as a system "made up of a large number of parts that interact in non-simple ways, … [such that] given the properties of the parts and the laws of their interactions, it is not a trivial matter to infer the properties of the whole"[1]. It is important to recognize that the early project management techniques were often developed to help the project manager manage complexity. We commonly observe two major sources of complexity in projects: task complexity and relational complexity[2]. *Task complexity* refers for example to the number of interacting components of the project. These can be activities in the traditional sense, or, more generally, distinct influences on the shape and success of the project. Network activity techniques e.g. PERT[3], the critical path method or the use of Gantt charts are often used to handle this task complexity. The second type of complexity, *relational complexity,* is caused by a variety of multiple stakeholders with conflicting interests. These conflicting interests can lead to disagreements about project goals and about priorities among tasks and features of the project outcome. This type of complexity can be handled with well-known techniques, such as linear responsibility charts or force field analysis.

Uncertainty is, of course, not a neglected concept in project management. Early development of activity network techniques in the 1950s, such as PERT (Program Evaluation and Review Technique), recognized the possibility of variation in task durations. These techniques were extended in the 1960s to incorporate probabilistic branching (e.g. Graphical Evaluation and Review Technique[4]). Qualitative approaches, such as the Synergistic Contingency Evaluation and Review Technique[5], and Analysis of Potential Problems[6], were developed to guide project managers to prepare for uncertainty with risk prevention and contingency planning.

This extensive literature on project planning has developed our understanding of scheduling tasks in complex and uncertain projects, describing such well-known techniques as the critical path method (CPM). There is also extensive knowledge on how to handle the relationships with the stakeholders, utilizing such tools as contract formalization and enforcement, responsibility charts, force field analysis, and conflict management.

Our experience with and analysis of 16 projects (see Appendix 1) from industries as diverse as internet applications, real estate construction, specialty chemicals and pharmaceuticals, aerospace, computers, and telecommunications, indicates that project managers are familiar with these tools and concepts. They master the planning techniques and understand their usefulness for structuring and communicating about the project. However, the most successful project managers have an ability to enhance this by (instinctively) matching their project management style and toolbox to the *nature of uncertainty in the project*.

Warren McFarlan recognized this need in major IS projects back in the 1970s, suggesting that "(w)hile there may indeed be a general-purpose set of tools, the contribution each device can make to planning and controlling the project varies widely according to the project' characteristics."[7] He concluded that uncertainty required adapting the management style to the project uncertainty profile, as measured by the three dimensions of project size, experience with the technology, and project structure.

While many authors (e.g. Shenhar and Dvir[8]) have characterized project uncertainty or uncertainty in terms of the technological environment or market setting, still others, e.g. Schrader et al.[9], have offered a more general characterization, such as differentiating between *uncertainty*—where the influence variables and their relationships are known, only the values of the variables are unknown—and *ambiguity*—where the variables and/or their functional relationships are unknown, requiring changing mental models.

These characterizations have made significant contributions to the theory and practice of project management. But our analysis suggests that, from the standpoint of project management styles and toolbox, it is useful to consider the following four major types of uncertainty when profiling a project (see Table 1): (i) variation; (ii) foreseen uncertainty; (iii) unforeseen uncertainty; and (iv) chaos or turbulence.

INSERT TABLE 1 ABOUT HERE

In order to develop this view, we first define the different types of project uncertainty and propose the project management style and toolbox appropriate for different project characteristics. We then suggest a pragmatic approach to project diagnosis and management under uncertainty.

2. PROJECT UNCERTAINTY AND MANAGEMENT STYLE

We have claimed in the introduction that a project manager's style and toolbox must reflect the uncertainty profile of the project, as measured along four dimensions of uncertainty: (i) variation; (ii) foreseen uncertainty; (iii) unforeseen uncertainty; and (iv) chaos or turbulence. Table 1 summarizes these four dimensions of uncertainty[10].

Categorizing uncertainty may be a nice academic exercise. The real question is whether such a classification has any relevance for project management. We argue that each type of uncertainty requires a *different management approach* in terms of: (i) project management style; (ii) managing tasks; and (iii) managing relationships. Our ideas are summarized in Table 2. In each of the boxes of this table, we have outlined the general approach first and then suggested the methodology to be used below it.

INSERT TABLE 2 ABOUT HERE

We purposefully choose the word 'uncertainty' as opposed to 'risk' to emphasize that we are concerned here with factors that influence project outcomes, not the outcomes themselves. It is important to note that uncertainties do not only represent threats, they can also offer opportunities. The extent to which these threats and opportunities manifest themselves in terms of either negative or positive outcomes to the project (i.e. risk) can be managed, somewhat, by good project management. For example, a "side-effect" in drug development may indicate an alternative application of the drug to an unrelated indication. Our claim is that successful project managers manage project uncertainty by tailoring their project management style and toolbox to the particular project's uncertainty profile.

Variation

Variation in activity durations, costs and the exact performance level delivered by resources is a common source of project uncertainty. This means that the nature and sequence of the relevant activities, as well as the objectives of the project, are well known, and thus, the project plan is detailed and stable, but project schedules and budgets exhibit variation around their projected values.

A typical example would be the implementation of a construction project. The experience of previous projects allows the manager to develop a detailed plan, but the exact project duration and cost will vary, more or less, around their projected values. A myriad of small influences play a role, each too small to be considered separately. For example, the construction schedule of INSEAD's new Singapore campus was influenced by events such as worker sickness, weather, individual errors, parts not delivered by a contractor, or some problems being harder than anticipated.

What happens if the project is confronted with variation in activity durations, costs and/or performance? The manager may start with a detailed plan (Gantt chart, Critical Path), but must realize that variations in schedule, cost or performance may cause the critical path to shift during project execution. To avoid unnecessary fire-fighting, the project manager will need the capability to simulate different scenarios of timing, and may want to build in *buffers* at strategic moments in the project (as proposed by Goldratt[11] and applied routinely in software projects, see Cusumano and

Selby[12]). The project also needs appropriate control procedures to authorize changes[13].

We have chosen to label this 'variation', because it is parallel to common cause variation in total quality management (TQM), where statistical methods are available (e.g., control charts) to monitor variations without having access to all the numerous, small, underlying causes. A tracked performance variable—such as days ahead/behind schedule—can be used analogously to a Statistical Process Control (SPC) chart; as long as the variable stays within an acceptable range, no action is taken. However, once the tracked outcome falls outside of the control range—for example, more than x% behind schedule—problem analysis is performed to identify assignable causes, and preventive actions are taken to bring the project back on track to the target.

Another widespread approach is that of Earned Value Management: the difference between the budgeted and the earned value (or cost) of the project to date can be an indicator of potential deviation and the efforts needed to mitigate this deviation (a danger is that progress measures may be misleading)[14].

In projects where variation is high, the project manager is first and foremost a trouble-shooter, someone who can identify when deviations arise and who will expedite the solutions to get the project back on track if and when necessary. Relationship management involves monitoring performance to identify 'casual deviations' from targets, and stimulating sufficient flexibility among suppliers, subcontractors and partners so that variations do not snowball during the project.

Consider, again, INSEAD's construction of the new Singapore campus: a delay may cause the non-availability of equipment that must be used elsewhere. Or the late delivery of window frames during the rainy season may halt all architectural work requiring a dry environment. A technique that can be useful here is the Linear Responsibility Chart, based on a detailed Work Breakdown Structure (tracking interactions among tasks).

Foreseen Uncertainties

Foreseen uncertainties are identified, but uncertain, influences in a project. Whereas variation may lead the project manager to expect a range of possible activity durations—for example, "activity x of the project may take anywhere between 32 and 48 weeks" due to a combination of a lot of small influences—foreseen uncertainty refers to a distinct and identifiable project influence that may have a singular impact on the project plan. That is, unlike variation, which foresees one single course of action (with "noise" around some outcomes), foreseen uncertainties may require anticipated "contingent paths" in the project plan ("let's switch from Plan A to Plan B").

For example, pharmaceutical development (e.g., see the Nopane project in the Appendix), is geared toward detecting and managing 'risks', mainly drug side effects. A drug typically has a small number of "probable" side effects that have been previously observed in related drugs. A side effect prompts, for example, a dosage change or a restriction on the drug usage to well controlled circumstances. In the context of risks, the side effect and the response to it are both *anticipated*. What is uncertain is whether this anticipated event (the side-effect) occurs or not. If it occurs, the anticipated "Plan B" is taken (the dosage change). In the context of anticipated risks, the occurrence "triggers" a previously planned response, but does not strictly require new original problem solving.

While it is still beneficial to utilize critical path methods for developing the project plan, it is now necessary to represent the influence of foreseen uncertainties as alternative, though possibly similar, project plans. Foreseen uncertainties can be represented in a decision tree (second box of Table 2). This has the advantage of forcing the project manager to consider the effects of early decisions on later risks, and thus, later decisions. Branches in the tree reflect discrete outcomes, and may lead to different decisions being taken. Decisions—that is, responses to random outcomes—then influence future risks, and so on.

While it is straightforward to evaluate the options inherent in a decision tree, exercising these options does not come "natural" to many project managers. Their instinct is to chart a good course of action (formalized in a Gantt chart) and to try everything possible to successfully execute that course of action. Project teams are often reluctant to provide for multiple, parallel approaches and project targets, as this typically increases their own workload, and additional investments are required. In the Nopane example, the side effects of the drug could have been documented, and the impact on the success of the drug could have been managed. But the pressure to launch the (very promising) product, more or less according to the original schedule, ultimately contributed to neglecting some information that could have helped them create a successful product.

Foreseen uncertainty also affects how project management should approach stakeholder management. The project team in one of our samples liked to utilize the phrase "proactively occupy the white spaces in the contract." This meant that, through anticipating uncertainties, they could proactively write in the contingencies reflecting these uncertainties, possibly staking out a claim before other stakeholders had thought of it.

Thus, foreseen uncertainty requires disciplined risk management: the identification of potential events that could affect the project (as downside risks or upside opportunities, for example, with “risk lists”), followed by the planning of (a) preventive measures to block adverse events, and (b) multiple contingent courses of action that are then “triggered” by the events.

Progress tracking demands monitoring not only which activities have been completed, but also “which branch of the tree has materialized”. The project manager must not only be able to trouble shoot, but also function as a ‘reactive’ consolidator of what has been achieved up to a certain stage in the project. All risks (e.g., incidents in the environment, or certain outcomes of the project work) must be constantly monitored and communicated to project stakeholders. Flexible contingent actions, depending on outcomes of key influence parameters, should be anticipated in the decision tree.

Unforeseen Uncertainty

Unforeseen uncertainty is not formally identified in the project planning stage, that is, it is not anticipated, and a “Plan B” has not been formulated. While foreseen uncertainty is a major influence that can be anticipated (although the project manager can only estimate a probability of its occurrence), there are at times influences that cannot or are not foreseen. In the case of unforeseen uncertainties, the project manager does not have a predefined response to the event, either because the manager is not aware of the possibility of the event, or that the event has such a low probability of occurrence that it is not worth creating contingencies in the original project plan.

A typical reaction we often hear at this point is “what’s the difference between foreseen and unforeseen uncertainty — that is, why can’t we call it simply uncertainty?” Indeed, some can. Conscientious companies develop “risk lists” of all the things that can go wrong in principle in their projects. Thus, unforeseen uncertainties can, to a certain extent, be transformed into foreseen uncertainties if the project team is willing to invest the effort. However, some of these risk lists can get very long, and it may be impossible to anticipate all that can happen to a project plan.

For example, the designers of the Ford Aerostar minivan could not reasonably foresee the crash of the Challenger shuttle in 1986, making customers reluctant to buy the car that reminded them of it. Or when Minitel was introduced in France in the mid-1980s, one could not expect that its biggest use would be for chat-rooms on sexually related topics (though, interestingly enough, one could have been expected to anticipate this phenomenon 10 years later for the Internet). Whenever a project team pushes the envelope of their technology, or enters a new market (even if it is not completely unknown), it would be inappropriate to pretend that it can anticipate all possible project influences in the project planning phase.

Unforeseen uncertainty makes contingency planning more difficult because not all influence factors can be anticipated, and thus, prevent including all branches of the project decision tree. The *decision tree will evolve* over the course of the project. Thus, the project team needs to constantly scan for the emergence of new influence factors. Moreover, when significant new information arises, the team must be willing to *learn* — that is, to add branches to the tree, and to perform new problem solving and determine courses of action appropriate to the new tree branches. This may require significant modifications — a redefinition of the course of action, or even of the project objectives.

Therefore, the project manager has to be an opportunistic orchestrator and networker who can detect the new options or threats very quickly — for example, possible new branches in the decision tree. Continuous scouting of markets and relevant technologies will be an essential task to be carried out in the project, and the deployment of new options may require the mobilization of new partners. Therefore, the project manager often needs a powerful network of relations both inside and outside the organization.

While unforeseen events are, by definition, unforeseen, the project manager is not completely at the mercy of unpredictable events. Consider the example of the pharmaceutical company Best Pharma[15]. Their research organization had to decide which of several possible central nervous system drug research projects to pursue. A serotonin-based molecule looked more attractive in the standard analysis than a calcium-based molecule. But one researcher dug up company statistics of past projects, showing that the chance of additional (non-anticipated) indications discovered later, during clinical development, was surprisingly high. Moreover, it was much higher for the calcium molecule class than for serotonin-based molecules (60% vs. 40%) because of less "specificity" of the chemical mechanism of action. No particular additional indication could be predicted, but based on past statistics, the researchers could estimate the *overall* chance of one occurring. Moreover, the statistics showed that additional indications tended to be as profitable, on average, as the primary indications. Now, the calcium project looked much more attractive. Thus, the project's value could be significantly enhanced by providing for the inclusion of an additional drug application during clinical testing.

In many cases, stakeholders may resist the changes required in order to cope with the new contingencies. For example, a supplier may have considered its design and delivery of a particular subassembly to be a project with limited or no uncertainty. After all, he had a contract! But the reality of the project may require that the design specifications be adapted mid project. In such cases, several approaches should be combined.

a. Get a complete picture of the resistance that stakeholders may put up (e.g., through force field analysis).

b. Co-opt stakeholders through regular information and coordination meetings, convincing them of the advantage of changing. In one project, the main contractor invited his suppliers and vendors regularly for general information briefings about market conditions and the evolution of the technology. While these meetings did not go into the detail of the project, they helped the suppliers to understand the uncertainties of the project and the flexibility required.

c. Formulate flexible contracts. If the contract does not provide the flexibility to modify actions or even targets appropriately, it leaves the project vulnerable to stakeholders rolling all downside over to the project manager. This in turn may lead to perverse behavior (e.g., low-balling)

Providing this level of project management flexibility is a major managerial decision that is often resisted. Sometimes the new information is not tracked or not understood, the team cannot develop an effective response plan in time, or it has no incentives to spend the effort. For example, target "hitting" is sometimes valued more highly than doing the best possible. It must also be clearly recognized that putting in place such flexibility is costly in terms of management attention, systems, and resources, as we further explain in Section 3.

Chaos or Turbulence

Chaos, or turbulence, refers to the fundamental uncertainty about the basic structure of the project plan itself. In totally novel projects, where conceptual understanding is lacking, the project plan itself cannot be fully formulated. Projects that occur in periods of technological discontinuity (e.g. recent experiments in ecommerce), as well as Research (as opposed to Development) projects are characteristic of this situation. In this case, one works with temporary conceptual models of the project, while, in reality, the project plan is unknown.

A well-known example is Sun's development of Java. It was conceived in 1991 as the driver of a controlling device for household appliances (a "super remote control with GUI"), but in 1995 ended up as a page programming language for the world-wide web, something that did not even exist in 1991 at the start of the project.

Another example is IhrPreis.de, an Internet startup that introduced customer-driven pricing into Germany ("name your price", as Priceline in the US). It turned out that German consumers behaved very differently than US consumers. The company first radically restructured its sales process in different ways. When none of them worked, they pursued a completely different idea of providing an Internet-based ticketing solution for travel agents, which could dynamically offer the best connection from multiple airline reservation systems in parallel (this attempt is ongoing).

Chaos or turbulence requires flexible approaches and a constant learning from feedback. A fundamental change in the project structure cannot be handled as an additional alternative in a decision tree. It requires a complete redefinition of the project. In addition, the project team may not be able to rely on only one approach because the failure probability may be too high. Rather, the team may have to define several alternative projects in parallel, "options" to be pursued at the same time. The team then needs to *iterate* and select the 'surviving solution' (see bottom of Table 2).

Iteration requires a high degree of autonomy for the project team, to give it the flexibility to re-define the project. Coping with constant change will require the project manager to be an entrepreneur, who develops close contacts with customers and opinion leaders in the field. A project of this nature cannot be planned, but requires a continuous verification of the hypothesis on which the original project was based. Planning may be important in order to check the hypothesis of the project, but events may well be fortuitous and thus the plan itself relatively irrelevant. More important than a plan is the ability to run "experiments" very quickly and consolidate the learning from these experiments for further use in the project. This is similar to the description that Iansiti and West provided of internet based projects[16]. Many of the examples of rapid prototyping indicate how one can support such an 'experimental' attitude to project management.

The autonomy of an entrepreneurial team must, however, be balanced by an organizational discipline of cutting projects ruthlessly when their chances of any success have become too small. History is littered with organizations that let their project portfolio balloon out of control, and only a painful restructuring could get them back to a sustainable mix of efforts.

With the sort of traumatic changes that turbulent projects have to go through, the "explain the deviation" approach to stakeholder management (that we recommend for unforeseen uncertainty) no longer suffices. Parties can continue to collaborate through threatening experiences, without opportunistically "saving their own skin", only if they have a *long-term relationship of trust*. One way to foster trust is to mutually invest in "dedicated assets": they cause dependence stemming from investments in specific equipment, training, or systems that are useless except in interaction with the current partner, and thus are lost when the partner withdraws. Studies have shown that partners work best together if the dependence is mutual, and thus neither party has an incentive for short-term selfish behavior. For example, in projects performed by companies jointly with their suppliers, efforts to improve project performance were highest when neither side had the power to appropriate all the benefits alone[17].

Mutual dependencies as well as personal relationships allow the establishment of an atmosphere of accountability and trust, where all parties can make an effort to achieve the project objectives. Once such a spirit of collaboration has been achieved, arising problems can be resolved collaboratively to the best of the project as a whole. The project manager often plays a critical role in establishing a network of relationships, within which project "crises" can be resolved constructively. In many organizations, the project manager is an important ambassador for the project in this sense[18].

3. A ROAD MAP FOR ACTION

Now that we have an idea of how uncertainty influences the management style and the focus of project management, we propose a road map for action. It consists of three steps: (i) a *diagnosis phase* where the profile of the project is determined; (ii) an *organizational phase* for building the infrastructure for project management; and (iii) an *assignment phase* where accountability for the project results are clarified and communicated.

Project Diagnosis

We have presented the main uncertainty types one by one. But in practice, they occur *together*. For example, a project may combine schedule variation with one or several foreseen uncertainties. The manager may have to use a *combination* of approaches to successfully manage the project. Moreover, the different uncertainty types can, to some extent, be converted into each other. For example, better upfront analysis may help us to translate unforeseen uncertainty into foreseen uncertainty, or a detailed examination of the myriad of sources of variation may translate variation into foreseen uncertainty. These are *managerial decisions* incorporating tradeoffs between upfront planning costs and execution effectiveness. Not only may up-front costs be tremendous, but a false sense of security may also lead to complacency in execution: the project team, assuming the project plan and all its contingencies is now the 'bible', may no longer sufficiently scan the horizon for unforeseen project influences. Thus, the conversion is usually incomplete.

Traditionally, one would start the project by determining what tasks one has to perform, and what resources are needed (e.g., in a work breakdown structure). But this may determine only one possible set of tasks, reflecting influences that are certain to arise, but neglecting potential influence factors creating risk or unforeseen uncertainty.

Therefore, we argue that project management teams should first determine an *uncertainty profile* for their project. Tasks are secondary, the result of the best response to uncertainty. When uncertainty is high, one may add tasks that guard against adversity or are geared toward learning, not only output. Figure 1 depicts four classic uncertainty profiles, and list examples of projects (from Appendix 1) that fall under each.

This is, of course, a qualitative estimation. It is usually impossible to have an exact number for this importance, although sometimes even this can be done. Recall the example of the pharmaceutical company Bestpharma who could estimate the impact of an unexpected and unknown drug indication. This shows that with good analysis one can get an estimate for the size of the threat to the project. Moreover, thinking through the uncertainty profile helps to prepare the project team for the uncertainty challenges they can expect in the project.

Project managers often do have an intuition whether they are low ("we understand the influences on project outcome very well") or high ("we do not have a good understanding of project influences, and we may be in store for large surprises"). What is the team sure of, and where are information gaps that could allow surprises? Obviously not only gut feel will help in refining the uncertainy profile. Experience from previous project case studies, statistical analysis of previous sets of projects, technology and market forecasts, scenario planning, some techniques borrowed from creativity management, etc. may help in unearthing the dominant type(s) of uncertainty.

One way of doing this systematically consists of designing lists of areas of potential uncertainty or questions about sources of uncertainty, and then systematically evaluating whether these areas of uncertainty are expected to cause common cause disturbances (variation), assignable cause disturbances (foreseen uncertainty), whether they are sources of unexpected opportunities (unforeseen uncertainty), or whether the whole set of hypotheses on which the project is built could be false (turbulence). Several of the ranking and scoring lists that have been used in project selection in R&D management can also provide a comprehensive list of uncertainty factors. These lists are industry specific and never complete, but give the project manager a possibility to thoroughly think through possible risks and opportunities.

We provide a few examples based on our sample of projects of such profiles in Figure 1. We classify the 15 projects in our sample according to the dominant type of uncertainty present.

Example 1: ACER in Taiwan

In the development of notebook computers by ACER in Taiwan, the major challenge is the coordination internally (between electronic and mechanical designers and manufacturing) and externally (with suppliers of core electronic components and OEM customers). Variation is the main source of uncertainty. Although there is likely to be some foreseen (e.g. a market change or a new generation of microprocessors launched by INTEL) and unforeseen uncertainty (the financial crisis in Asia in 1997, which disrupted the market equilibria), they are unlikely to be of a magnitude to change the nature of notebook development. A major unforeseen uncertainty is unlikely, except for a drastic change in technology or an unexpected crisis on political level. Excellent application of conventional project management methods and an investment in coordination with suppliers and customers is essential.

Example 2: Ladera Ranch

Consider a large scale infrastructure developments such as the Ladera Ranch, a multi-year, several hundred million dollar earth-moving project for the construction of a residential community in Southern California. Projects like this often face not only variation due to complexity but also greater uncertainty (both foreseen and some unforeseen), as the nature of the soil masses to be moved may pose unexpected problems. The range of soil conditions may or may not be known, so the management profile is concentrated on anticipating risks and scanning to reduce unforeseen uncertainty. In this case the number of interested parties is lower, as well as the complexity created by the number of tasks to be performed.

Example 3: British Telecom

Finally, had British Telecom not been willing to redefine the revenue model of their "callback" service, the project would not have achieved success: it started out as a project to develop a digital display phone, then changing into a service that customers could call (for a fee) to find out who had called them last. Finally, the product did not charge a fee, but derived its revenue from the added traffic of customers calling back the number that had called them last.

When the influence parameters are interdependent, the project team cannot construct a reasonably informative project decision tree. Checking for possible new influences in isolation is not helpful, as the later realization of other influences may make the assessment obsolete. It is necessary to hypothesize the whole project at once as a system, to proceed based on rough assumptions, and try to falsify them. If the hypothesized system constellation does not materialize, the project must be stopped in terms of its original assumptions. This implies choosing a completely new course of action, starting as if it were a new project.

Developing the Project Infrastructure

Having determined the project uncertainty profile, the second job consists of developing the appropriate infrastructure to manage the project. This includes the *planning system*, the *coordination and incentives* that keep the parties aligned, and the *tracking systems* for monitoring progress. A challenge in architecting the infrastructure is finding the right balance between planning and learning. Table 3 summarizes how that balance may have to shift depending on the uncertainty type.

INSERT TABLE 3 ABOUT HERE

Planning systems always have some type of task scheduling at their heart, including the coordination among them. Even without complexity, this may be very challenging in complex projects[19]. The presence of variation requires the ability of adding schedule buffers (owned by the project manager), and simulating budget or schedule distributions (which available commercial software can provide). Foreseeable uncertainty requires flexibility. While a project schedule may be needed, it is equally necessary to anticipate risks and opportunities, using risk management tools (prevention and contingent plans, e.g., in decision trees).

Unforeseen uncertainty requires the dynamic flexibility of learning and re-planning when new information arises. The team must have extra capacity to work out responses to sudden events, both on the up- and the downside. Actions are, thus, only "tentative" and geared not only to best results as currently seen, but should also be robust to changes. Finally, project turbulence requires the capability of a rapid turnaround of experiments or iteration and on the spot decision-making. Very often it makes a lot of sense to split up the project in a series of smaller incremental projects[20]. Yet we are trying to manage projects, not to enhance the general state of knowledge. So it is important that the sequence of experiments and the learning are guided by an overall vision, not unconstrained.

We now turn to *coordination and incentives*. In the presence of variation, a good project 'contract' including deliverables, schedules of time and resources, and conflict resolution rules, agreed upon by the stakeholders at the outset, can usually be formulated. However, it is dangerous to insist on a deterministic deliverable if the schedule is really a probabilistic distribution (because of variation). Deliverables that are subject to variation should either be promised in the form of a service level ("x% of the projects with this uncertainty profile come in on schedule"), or significant buffers (and thus, potential "low-balling") result.

Tracking through standard metrics, e.g. number of tasks accomplished, serves a double purpose of coordinating multiple parties and providing the incentives to deliver to their commitment. A hierarchical organization with a capability to quickly mobilize additional capacity to respond to delays is normally able to do the job, as task coordination has been done initially, except for schedule deviations.

When foreseeable uncertainty is present, targets and deliverables become contingent to the realization of the decision tree. All parties must be informed of the contingencies and buy into the alternative plans and outcomes at the outset. Under unforeseeable uncertainty, stakeholders must accept even unplanned changes. Thus, they should be informed initially of the project profile ("unexpected things CAN happen!"), and then in real time of the latest status and its reasons, and be convinced to support changes. Top management support, negotiation techniques, team-building exercises, or the charisma of the project manager can help to overcome conflicts of interest. A hierarchical organization is usually unable to master the frequent ongoing coordination and mutual adjustment of the stakeholders. The project organization should be lateral, resembling more a network or a bundle of capabilities.

In a turbulent project, the project manager should realize that while a learning and experiment driven strategy is necessary, the sequence of failed experiments can be very de-motivating in practice. We all know that we learn often more from mistakes than from successes, but the poor project manager who goes through a series of failures is probably not happy with that knowledge. A motivating environment and above all a capacity to persevere are essential elements. This requires that rewards and recognition are based not only on output, but also on the quality of the process and effort that was put in[21]. It also requires stakeholders who are committed to and trust one another; only then will they have the stamina to go though up and downs, without guaranteed success, together.

Tracking is well-understood for variation and foreseeable uncertainty: there exist engineering tools for measuring target achievement and progress (e.g., "% complete"), and in a decision tree, the realization of uncertain variables as well as the progress in the currently realized tree branch can be measured.

In presence of unforeseeable uncertainty, a scanning mechanism must be put in place. As noted by the project manager of the Ladera Ranch earth-moving project,

> *"Fifty percent of my job is managing relationships with our subcontractors, regulatory agencies and the landowners. Thirty percent is what I call vision: scanning the horizon more than three months out to identify potential problems while we can still do something about them. The final twenty percent is driving the site and keeping track of what is really happening out there. The Gantt chart is more a reflection of what happened last week, and what someone hopes will happen next week. ... The problem is that every play we run is an option play (and the Gantt chart fails to reflect that)."*

In addition, an extended network of 'informers' or partners may help to alert the team to changes as soon as possible. If the market is a source of unforeseen events (which is very often the case), feedback about customer reactions typically become an important management tool. Finally, in a turbulent project the achievement of the currently set learning goals are the only thing that can be tracked, and then evaluated to decide on continuation.

Assigning Accountabilities

It is extremely important to understand that putting in place any of the above systems can be very costly in terms of management attention, systems, and resources. The uncertainty profile of a project is not God-given, but the result of a managerial decision and ambition level. It is often possible to scale back ambition, for example, using a proven technology, at first targeting a market that one knows, or first avoiding a country with political risks etc. This may greatly reduce project costs and exposure, resulting in better results than heroically taking on the great challenge.

Different types of uncertainties require different types of project managers. What happens if the team discovers during the analysis of the uncertainty profile that it is ill equipped to carry out the task? What do we do if the project manager has the wrong personality traits or skills? Thus, the definition of the project profile should be iterative: the ambition and the team capabilities must match.

By committing oneself to a particular uncertainty profile, one not only determines the focus of the project management, but also the implication of the different power levels in the organization. Managing variation, including the coordination of task complexity, can be accomplished within the project team if the team has control over all the influences and tasks associated with the project. This is often violated: a sub-project manager often has accountability for events that are outside his/her control, and schedule buffers are sometimes treated by top management as bargaining chips and recklessly taken away.

Responsibility and accountability for the decisions that are required to cope with unforeseen uncertainty or significant stakeholder conflicts have to go beyond the project management team, for authorization of changes or arbitration. We alluded previously to the need to constrain the learning with a vision, or to the fact that perseverance requires a favorable context. These are requirements that usually require the intervention by the top of the organization, and go beyond the confines of the project.

While unforeseen uncertainty requires the possibility to make major modifications to the project plan, the team may also overreact to changes. Therefore the authority to complement major changes may have to be somewhat restrained. A steering committee or oversight process can be put in place in order to provide sufficient organizational authority to change the path of the project or the target. As an added benefit such a steering committee may also ensure that the project team does not declare a mistake on their part as an external “uncertainty”.

Changing the basic concept of the project, as in turbulence, requires involvement and taking responsibility by the leadership of the organization. A redefinition of the project may involve major decisions on resources committed and strategic target setting. This is the responsibility of upper management, who must be closely involved.

4. CONCLUSION

To recognize that a project manager’s management style and toolbox need to be contingent on the characteristics of the project is not new. However, we believe that our characterization of uncertainty a into the four dimensions of *variation*, *foreseen uncertainty*, *unforeseen uncertainty* and *chaos or turbulence* offers both a widely applicable and practical approach to the project manager. These dimensions are derived from our combined experience across many projects and industries. It was not our intention to refine once again the traditional project management techniques. We wanted to show that the toolbox of a project manager is more comprehensive than activity networks and uncertainty management, and must be contingent to a large extent on the type of uncertainty with which the project manager is confronted. The core message of the article can thus be summarized in the following four statements:

a) Project management is about managing tasks and managing stakeholder relationships. Based on a sample of 16 projects we studied we argue that the way one manages these two areas is influenced by the type of uncertainty with which the project is confronted.
b) Before one determines the tasks to be carried out in the project, it is necessary to determine the project's uncertainty profile.
c) This uncertainty profile will enable management to define the infrastructure (planning, coordination and incentives, monitoring) needed to manage the project and to assign accountability for the success of the project.
d) The toolbox of a project manager is not limited to activity network planning and uncertainty management, but includes decision trees, dynamic problem solving, and rapid experimentation combined with learning. We suggest a partial integration of different techniques that are available to support the project manager and a conceptual model of where to use them.

While our framework will require more large-scale empirical research to confirm its applicability, our work to date with project managers suggests that our contingent approach is a powerful tool for adapting management approaches to the circumstances. We believe that enhancing the project manager's intuition can significantly contribute to project management performance.

Figure 1: Project uncertainty profiles.

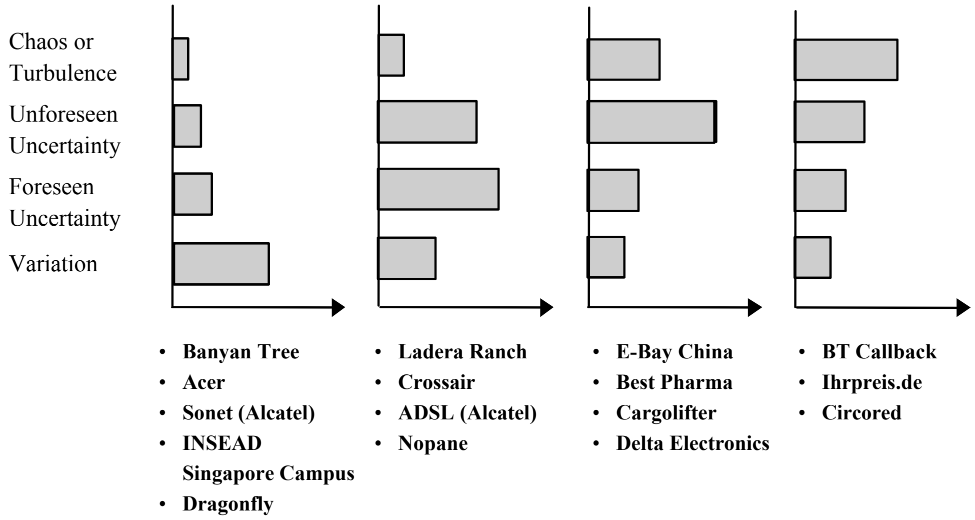


Table 1: Types of project uncertainty.

Uncertainty Type	Description	Management Style	
Variation	Cost, time, and/or performance levels vary stochastically within a range.	• Plan with buffers • Disciplined execution	**Planning**
Foreseen Uncertainty	Major influence on the project from a few individually identifiable factors. The factor is known, but not which *value* it will take.	• Risk identification • Prevention • Contingency Planning	**Planning**
Unforeseen Uncertainty	A major influence factor (or a few of them) is not at all anticipated by the project team, not planned for and no contingency incorporated.	• Learning: new problem solving, with modifications of targets and execution	**Learning**
Turbulence, Chaos	The project target, strategy, and approach are completely invalidated by unforeseen events, and the project must be re-defined from scratch.	• Repeated complete redefinition of project	**Learning**

Table 2: Focus of project management as a function of uncertainty type.

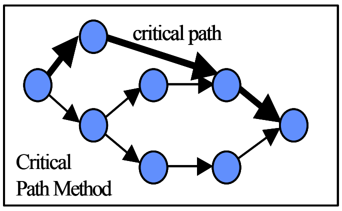
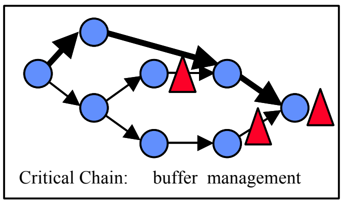
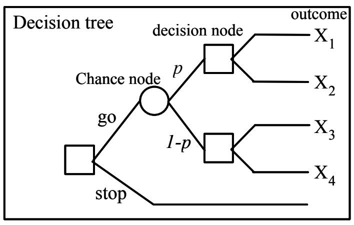
Type of uncertainty	PM Style	Managing Tasks		Managing Relationships	
		Planning	Execution	Planning	Execution
No uncertainty (only task and relational complexity) 	Coordinator & master scheduler.	Plan the nature and sequence of tasks based on experience. Work break-down structures, Activity networks (CPM, PERT, etc.)	Monitoring of project progress against project plan. Gantt Chart	Identify interest conflicts, and codify responsibilities and deliverables. Contract design and enforcement Linear responsibility charts	Coordination of stakeholders and suppliers Enforcement of deliveries by parties with conflicting interests
Variation 	Trouble shooter and expeditor	Buffers at strategic locations in critical path; control limits for corrective action; Simulation of scenarios. Change control procedures	Monitor deviation from intermediate targets Use of control charts	Clearly identify and communicate expected performance criteria. Monitoring of linear responsibility charts	Monitor performance against performance criteria. Maintain some flexibility with key stakeholders.
Foreseen uncertainty 	Consolidator of project achievements	Anticipate alternative paths to project goal through decision tree techniques Developmen t of thorough risk lists Contingency planning, decision analysis.	Identify occurrences of foreseen risks and trigger contingency Monitor uncertainty through indicators e.g. Earned Value Assessment	Increase awareness for changes in environment along known criteria or dimensions Occupy the "white spaces"in the contract; share 'risk lists' with stakeholders	Inform and motivate stakeholders in order to cope with switches in project execution Force field analysis

Table 2 (*cont*): Focus of project management as a function of uncertainty type.

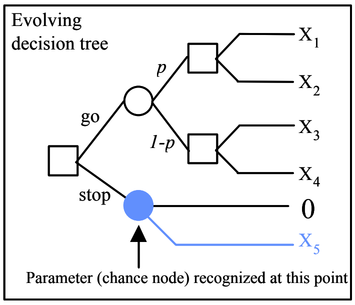
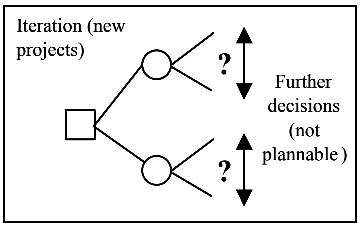
Type of Uncertainty	PM Style	Managing Tasks		Managing Relationships	
		Planning	**Execution**	**Planning**	**Execution**
Unforeseen uncertainty 	Flexible orchestrator and networker as well as ambassador	Build in the ability to add a set of new tasks to the decision tree Iterative planning	Scan the horizon for early signs of non-anticipated influences. Build and mobilise network for scanning and technology watch	Ability to mobilise new partners in the network who can help solve new challenges Plan for mutual dependencies e.g. dedicated assets	Maintain flexible relationships and strong communication channels. Favour personal relationships and build mutually beneficial dependencies
Chaos 	Entrepreneur & Knowledge manager.	Iteration and gradual selection of final approach. Plan for parallel development	Repeated verification of learning goals; detail plan only to next verification Rapid prototyping and ruthless go/no go decisions	Build long-term relationships in order to create interest alignment Replace codified contracts with partnerships	Close linking with users and leaders in the field. Direct and constant feedback from markets and technology providers.

Table 3: Uncertainty types and project infrastructure.

	Planning Systems	**Coordination & Incentives**	**Monitoring Systems**
Variation	• Task scheduling • Buffers • Simulation	• Target setting • Workstructure, responsibilities • Coordination in hierarchy	• Target achievement • Progress tracking (e.g., % complete)
Foreseen Uncertainty	Uncertainty Management: • Risk lists • Preventive actions • Contingency plan (decision tree)	• Contingent targets and contracts • Mutual adjustment according to events	• Contingent target achievement (per tree branch) • Monitor risk realization
Unforeseen Uncertainty	• "Tentative" tasks • Robustness • scanning actions • dynamic learning	• Relationship management, flexible response in mutual interest • Team coordination (lateral)	• Ongoing evaluation of new events • Track asssured achievements • Track effort/ process used
Chaos or Turbulence	• Overall vision • Tasks to learn • Iteration, rapid turnaround of experiments	• Long-term trust-based relationships • Sharing of effort and results	Track "experimentation cycles": • What has been learned? • What problem to solve next, guided by vision?

Appendix: Project Database

Our research is based on detailed experience with the following projects:	
Acer notebook computer development[22]: under extreme time to market pressure, Acer had to get schedule variation under control. They reduced the number of correction loops during product development and improved manufacturing ramp-up quality (variation). They also concentrated the responsibility for product specifications in one group (interest complexity), reducing negotiation loops.	*Banyan Tree Resort and Hotels* [23] describes how the Banyan Tree Group, a Singapore based Life Stle company designs and builds its hotels. The challenge here is mainly one of managing variation, typical for construction and real estate development, and to some extent some unforeseen uncertainties, e.g. a three month ban on shipping from India to the Maldives of sand, or the Asian financial crisis.
Alcatel SONet[24]: a new optical transmission system failed because of interest complexity: multiple national subsidiaries faced different markets, and thus had conflicting product requirements. Failure to resolve conflicts compromised the project. Alcatel reorganized according to world-wide product lines two years later.	*Dragonfly*[25]: Uninhabited Aerial Vehicle (UAV) project with extreme variation (loops of activities that may have to be re-done). Stochastic loops make critical path planning impractical (the loops dominate any critical path). Rather, planning must be done with simulation, specifying "confidence intervals" of completion times.
INSEAD's Singapore Campus[26]: in the last part of the nineties, INSEAD, a leading international business school, decided to implement the innovation concept of 'one institution, two campuses'. Therefore it had to construct new campus facilities, launch new programs, create a permanent faculty body, integrate itself in the networks, etc. While there were many hick-ups during the course of the project, it was delivered on time and within budget. While there were some foreseeable uncertainties, the project was confronted with one major unforeseeable uncertainty, i.e. the Asian Financial crisis.	*Crossair DGPS*[27]. Crossair worked with a small supplier, an entrant into avionics systems, to develop differential GPS (DGPS). The project was subject to uncertainties from competitive actions of other avionics companies against the supplier. Ultimately, the competitors prevented the system from being marketed, but Crossair could apply the expertise acquired during the project for other purposes (unforeseen upside).
Nopane[28]: a highly effective painkiller with blockbuster potential caused side effects after market introduction: low blood pressure caused some patients to collapse. The side effect occurred only when patients engaged in physical exercise too quickly after taking the drug. Yet, the drug was restricted to a niche product by a risk-averse regulatory agency. The company failed to anticipate this, in principle foreseen, uncertainty (related drugs had shown the same side effect) because interest conflicts within the organization caused pre-warning systems to break down.	*Ladera Ranch* Community Construction (extensive personal communications): a multi-year, several hundred million dollar earth-moving project for the construction of a residential community in Southern California. The project manager saw his job as 50% managing relationships, 30% scanning the horizon for early warning signs of risk, and the final 20% keeping track of project activities. While the Gantt chart is seen as a valuable form of communication, little formal analysis is ever conducted on comparing the state of the critical path activities with the original project plan. This project has become an exemplar for similar projects on the west coast of the US.
Alcatel (ADSL)[29] is the case description of the development of a new and very innovative technology for multi-services network access. The story is one of many foreseeable uncertainties, as well as high complexity due to the very complicated organizational structure of Alcatel. In the end the project became a success because the company organized the project as a 'virtual company', simulating the conditions of a small entrepreneurial company within the resource base	*Delta Electronics*[30]: a car entertainment systems supplier develops a navigation system integrated with the car entertainment system for a large automotive manufacturer. The project faces strong uncertainties, as Sun's Java and Windows CE push into the market as software platforms. The project faces substantial unforeseen uncertainties as well, as the market needs of such a new system cannot be foreseen or planned.

of a large organization.	
Cargolifter[31]: This start-up is in the process of developing the largest airship since the 1930s, for point-to-point transport of heavy and outsized cargo. The company faces schedule variation (the schedule is slipping), many known uncertainties as they integrate new materials and components for the first time, as well as unforeseen uncertainties, as the market is unproven. Interest complexity has been mitigated by attracting a large number of small and enthusiastic shareholders, reducing the dependence from a few large investors with strong interests.	*BestPharma*[32]: the development of new drug molecules faces many known uncertainties (e.g., lack of efficacy, or side-effects). In addition, events may occur that cannot be anticipated. BestPharma managed to estimate the opportunity from possible additional indications that cannot be identified in detail beforehand. Thus, they could estimate the value of unforeseen uncertainties.
E-Bay China (based on conversations with management): this case illustrates the ambiguity caused by applying a known business concept to a new market. E-bay failed in China because they used the same settlement mechanisms used in the US (credit card, bank transfer). But these do not work reliably and ubiquitously in China. E-bay was beaten by a local start-up who successfully used local financial brokers for settlement.	*Circored* (personal conversations with management): in 1995, the German metallurgy company L. had a new technology to produce half-refined ore that could directly be used in a furnace. They started a joint venture with 2 US partners to build a plant in Trinidad. However, the project management subcontractor overestimated its capabilities, world market prices for the product fell, Trinidad contractors did not perform, and the technology did not work. One partner insisted on being bought out in 1999. In 2000, the partners almost fell out, but worked through conflicts with the help of an external facilitator. In 2000, they found a technological breakthrough, and are producing in 2001. "*All risks we thought we faced did not materialize, but the ones that hit us were unexpected. What came out at the end was not what we expected at the beginning*."
BT Call Back (personal conversations with BT managers). In 1995, BT decided to develop a display telephone with number identification. The project was redefined several times (chaos): In test markets, they found that consumers wanted the service of knowing who called them last, but were not interested in the physical display telephone. Subsequent market testing caused a PR battle between opponents (threat of privacy when anonymously inquiring information from companies) versus proponents (protection of women from dirty phone calls). Finally, it turned out that BT did not need to charge for the callback service because the additional traffic from consumers calling back the last caller provided an attractive profit.	*Ihrpreis.de* (based on conversations with management): this German Internet startup applies the Priceline business model in Germany. They had to modify their process because German consumers were not willing to make an offer before knowing whether they would get the product. They also had to move in additional services because the market grew much more slowly than it had grown in the US. The final product idea (attempt ongoing) involves an Internet-based flight ticket search engine for travel agents, which dynamically optimizes offers from multiple airline reservation systems.

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