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# Scenario Based Project Management: Impact of Resource Unreliability and Non-availability on Project Delays

*Zhassan Baipakbayev, Yerkezhan Shakenova and Ramesh G. Kini**

Kazakh - British Technical University, Almaty, Kazakhstan

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**Abstract:** Conventional project management approaches which focus more on: the activities that the project comprises of; estimates of the duration of each specific task or activity and hence its scheduled start and completion dates; and in turn on the critical path activities that must be completed exactly as scheduled to avoid overall project delays, have tended to ignore questions relating to risk management and the role and value of information in various scenarios that might be obtained. Dynamic modeling and analytical approaches based on system dynamics and fuzzy sets and analysis, for instance, have been offered to counter the possibility of slippages or failures along the time, cost and performance dimensions, and to enable managers to more systematically and comprehensively manage project risks. We seek to focus on the impact of resource unreliability and non-availability on project delays and cost overruns in our efforts to offer a new modeling and analytical framework, which combines conventional project management with scenario analysis, system dynamics and simulation to better analyze the time vs. information vs. cost trade-offs and the benefits in terms of risk reduction as well as increased RoI, etc. We believe that this system dynamics-scenario analysis combination would prove to be a more suitable and valuable tool for such analytics because it would enable the manager to:

–better analyze and understand the various cost, schedule and effort-related dimensions of the project, and especially the resource unreliability and non-availability one,
–more accurately and reliably forecast the future results,
–and "test drive" and evaluate several alternative solutions to any problem or combinations of problems that might be obtained in a "flight-simulator" sort of setting, in a manner of speaking.

**Keywords:** Scenario Modeling, Project Management, Resource Management, Scenario Trees

## 1 Introduction

Conventional project management approaches which focus more on:

–the activities that the project comprises of;
–estimates of the duration, and the scheduled start & finish times of each specific activity;
–and in turn on the critical path activities that must be completed exactly as scheduled in order to meet the target for overall project completion,

have tended to inadequately address, or even ignore, questions relating to risk management, uncertainty and "fuzziness" with respect to the various project-related parameters and variables, the impact of resource unreliability and non-availability on project delays and cost over-runs, and the role and value of information in various scenarios that might be obtained.

We seek to generalize the conventional project management framework by focusing on the role and value of information in:

–analyzing and deciding on: (i) the scope of work that would need to be done; (ii) the schedule that would have to be followed given the estimated duration of each of the activities and the sequential or successor-predecessor relationship between any activity and those that follow or precede it; (iii) linking the role of reliability and the availability of the assets that are deployed during the course of the project, or more specifically the impact of the

* Corresponding author e-mail: kinirameshg@gmail.com

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unreliability and non-availability of these assets, on the delays and cost-overruns that have be planned and budgeted for, before deadlines can be analyzed and agreed upon; (iv) the milestones that would have to be met, each with its own set of deliverables and go-no-go "gates", for instance; and the resources that would be required in order to ensure that the project is and remains on track to be completed as scheduled, within budget and as specified a priori; and in
– evaluating the risks and costs that would have to be borne accordingly, and the 2-way/3-way/ ... cost-benefit trade-offs that are inherent to such decisions.

While project managers have used conventional project management approaches to get a better handle on such questions as "Will the project be completed by the scheduled completion date?," "How much can the completion date potentially vary?," and "Will the cost of the project be within, or overrun, the initial estimates or budget?," etc., questions relating to uncertainty, risk management and the role and value of information and resource or asset management in various scenarios that might be obtained, usually remain unanswered. We seek to offer a new modeling and analytical framework which combines conventional project management with system dynamics, fuzzy analysis, scenario analysis and simulation and which would prove to be a more suitable and valuable tool for project planning, analysis and decision making because it would enable the manager to:

– model the various factors involved in the management of any project, e.g., the degree of difficulty of the programming languages used for the project, the number of users and developers in the team, their qualification, the estimated duration and scheduling of the activities that the project comprises of, etc., for a software project, as fuzzy sets with special properties and intentions for each set and to build those fuzzy sets and implement the inference logic using FRIL language;
– better analyze and understand the various interdependent cost, schedule and effort-related dimensions of the project;
– build a Systems Dynamics model and test various scenarios, and to thus more accurately and reliably forecast the future results as well as analyze the sensitivity of these forecasts to changes in one or more of the endogenous and exogenous variables and parameters;
– and "test drive" and evaluate several alternative solutions to any problem or combinations of problems that might be obtained in a "flight-simulator" sort of setting, in a manner of speaking.

The ultimate goal of the research is to offer a more robust and intelligent approach to project management which would enable project managers to better analyze the time vs. performance vs. information vs. cost trade-offs that are entailed in project management, and the benefits in terms of risk reduction as well as increased RoI, for instance. Given that information has a vital role to play in the management of such projects, there is an urgent need to revisit the conventional project management paradigm and bring a new modeling and analytical framework to the table (which combines conventional project management with simulation and system dynamics to better analyze the time vs. information vs. cost trade-offs and the benefits in terms of risk reduction as well as increased RoI, etc.), and that is what we intend to do with this research initiative.

While we do not seek to radically change the way projects are planned at the strategic level or implemented and executed in the "field," we do intend to focus on the use of new and novel tools, techniques and technologies (e.g., fuzzy analysis, system dynamics and discrete event simulation, scenario analysis, etc.), to better mediate between the monitoring, planning and implementation phases at the operational level as depicted at the center of Figure 1 below. The novelty of our approach is in the usage of tools such as fuzzy analysis, system dynamics and scenario analysis and simulation to solve the operational problems faced by project managers. Fuzzy set theory, for instance, provides a fresh perspective as it allows for the gradual assessment of the membership of elements in a set, thus enabling the project manager to plan and monitor the project in a more flexible manner. Project managers who have to use the input values that they expect will result, though the real values cannot be known with certainty until the project ends, and who therefore face difficulties in determining the exact values of the metrics used in input data, can use other approaches, such as fuzzy logic approach, to obtain more accurate input values and to avoid overestimation of activities duration as well as over-committing resources.

The application of fuzzy logic to the effort estimation problem and the initialization of models with expert rules enables model transparency and enhanced interpretability because it accounts for the potential nonlinearity of relations and interactions between dependent and independent variables in the software metric models. The analyst and planner can thus observe, assess, change and customize the model as needed the model will therefore perform much better than the others.

## 2 Modeling approach

In most projects, such as software development or oil and gas industry projects, the process of:

– translating ideas into blueprints, executable project plans and finally executed, delivered projects;
– meeting resource requirements and optimally deploying capacities and capabilities over the duration of the project or program; and thus

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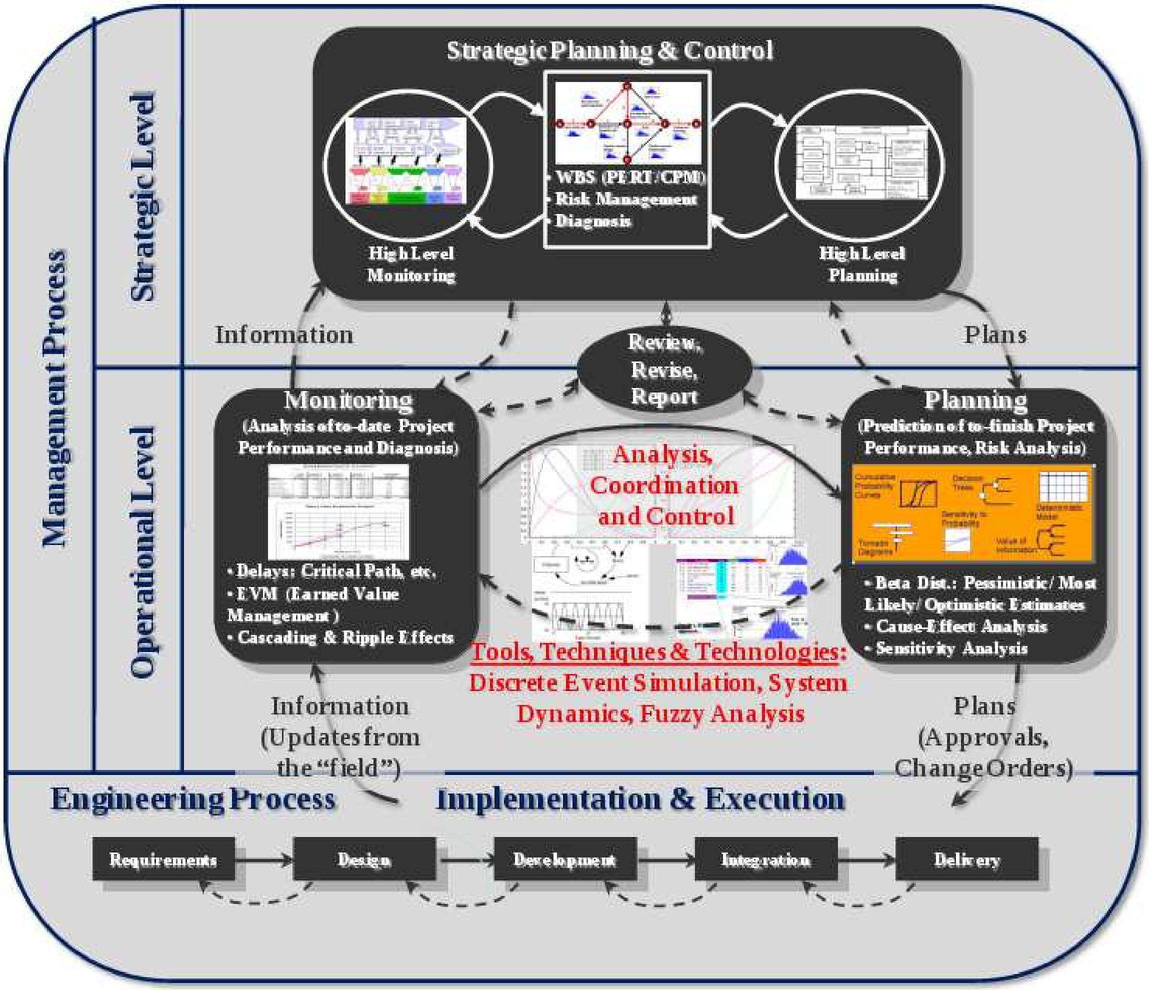


**Fig. 1:** Embedding our Approach in the Project Management Context: adapted from a figure in Rodrigues [4]

–better organizing the fulfillment/ execution processes so as to consistently meet, or exceed, the customers' expectations;

is very complicated. Most such projects are inherently risky and significant slippages along the time, cost and performance dimensions are very much the norm rather than the exception in such projects not just in Kazakhstan but elsewhere in developing and developed countries around the world, too. To counter the possibility of such slippages, or even outright failures, and to enable managers to more systematically and comprehensively manage project risks, dynamic modeling and analytical approaches based on system dynamics, for instance, have been offered in the past. As an example, Abdel-Hamid and Madnick software project model used the system dynamics framework to analyze the relationships between human resources (with differing capacities and capabilities), software requirements and quality on the one hand, and project planning and management on the other [1]. We feel that the more effort the project management team puts into trying to anticipate, budget and plan for all possible future events and eventualities (so that they have resolved or addressed as many sources of VUCA, or variability, uncertainty, complexity, and ambiguity, all of which contribute to the risks inherent in the project management process as they possibly could a priori, and so that they have fewer or no nasty surprises awaiting them down the road), the better their ability to control and manage the project, and the more successful they will be in delivering the "deliverables" at each milestone, as well as the overall project, on time, i.e., as scheduled, within budget, and as per "spec.," as a result.

Dynamic modeling and analytical approaches based on fuzzy sets & logic and system dynamics, for instance, have been offered to better analyze and manage these uncertainties, to counter the possibility of slippages along the time, cost and performance dimensions, or even outright failures, and to enable managers to more systematically and comprehensively manage project risks.

Because the system dynamics approach enables us to better capture the effects of the reinforcing and balancing feedback loops inherent in the system and to better explore the nonlinear, dynamic, history-dependent and tightly or loosely coupled nature of the relationship between the various stocks and flows in the system and the other variables or factors that need to be taken into account, we intend to use it to underpin the analysis of various scenarios that would be hypothetically of interest to the manager of any project. Additionally, she might also want to evaluate the cost-benefit trade-offs entailed in investing in new technology or in information acquisition that could on the one hand reduce the probability of failure and lead to better performance over time on the other, even if this resulted in project delays and the related costs that would have to be borne, accordingly.

### *2.1 Modeling and Analysis Approach*

We specifically have the following aims in this initiative:

- –To estimate the duration of any project as well as the optimal project cost by analyzing the impact of uncertainty on resource requirements and resource availability, and on project performance, the costs borne and the time taken for completion at the activity level as well as for the project as a whole.
- –To build a Systems Dynamics model and test various scenarios, and to thus generate accurate and reliable forecasts and analyze the sensitivity of these forecasts;
- –Develop an intelligent expert system for future decision-making and more efficient and effective project budget planning, analysis and control.

Consider, for instance, the issues that the manager of an oil and gas industry project, say XYZ, may have to tackle. As depicted in Figure 2 below, she may have:

- –one or more specific objectives (e.g., launching an E&P, or exploration and production, program for a new “play”, building a drilling rig or pipeline, and so on)
- –that need(s) to be attained over some definite length of time (say, within a year or two, for instance),
- –with resource requirements that need to be met in a phased manner (money, machinery, manpower, space, hardware and software, steel, etc.), and
- –with numerous factors - that may or may not be within the control of XYZ’s stakeholders or the members of the team charged with implementation of the project - which could help or hinder the implementation team’s ability to succeed in this project, and so on.

Additionally, she might also want to evaluate the cost-benefit trade-offs entailed in investing in new technology or in information acquisition that could on the one hand reduce the probability of dry holes and lead to higher recovery rates on the other, even if this resulted in project delays and the delay related costs that would have to be borne, accordingly. Furthermore, she would need to know how the reliability and availability of the various assets or resources that are needed for the numerous tasks, activities, etc., of the project, affect the cost and time dimensions of the project. Because fuzzy analysis allows analysts to better factor in the effects of uncertainty and randomness on the project, and because system dynamics approach enables them to better capture the effects of the reinforcing and balancing feedback loops inherent in the system and to better explore the nonlinear, dynamic, history-dependent and tightly or loosely coupled nature of the relationship between the various stocks and flows in the system and the other variables or factors that need to be taken into account, we intend to use these approaches to underpin the analysis of various scenarios that would be hypothetically of interest to the manager of the XYZ project.

In the first phase, using static-deterministic and stochastic-dynamic approaches, we intend to analyze and to better understand the various factors that affect completion times and completion time variability for each activity - whether on or off the critical path - as well as for the project as a whole. By repeatedly extracting information inputs relating to the expected (most likely), pessimistic and optimistic estimates for the duration of each remaining activity, we will obtain the best-fit beta distributions for each activity (the so called “PERT-beta” estimates), and simulate each project for a number of different scenarios (that the project manager wishes to explore) - we note that these scenarios may have to explored iteratively as depicted in Figure 2 .

Figure 3 above, which illustrates the links between the project network and plan, the 7P-5W-2H mapping and the overall strategic plan for XYZ, highlights the recursive nature of the process, with numerous assumptions and estimates of activity duration, costs, resource requirements, etc., subject to being reviewed and revised repeatedly, till the planners and the key stakeholders of XYZ are satisfied. Such an exercise in cross-linking and mapping the phases and steps, mentioned in the tables and figures above, in greater detail may help those involved in drawing up such plans:

- –to better understand the information needs of the various organizations and individuals involved with the project (“making sure that the right person or department or organization gets the right information at or before the right time” is half the battle, according to one “battle-scarred” veteran with more than three decades of oil and gas industry project experience in the field)
- –to analyze and improve the process of budgeting for time and resource requirements needed for each stage;
- –to better assess and interpret:
  - –the “weak links” in the “chain” (or the stages or phases where the project is more vulnerable to

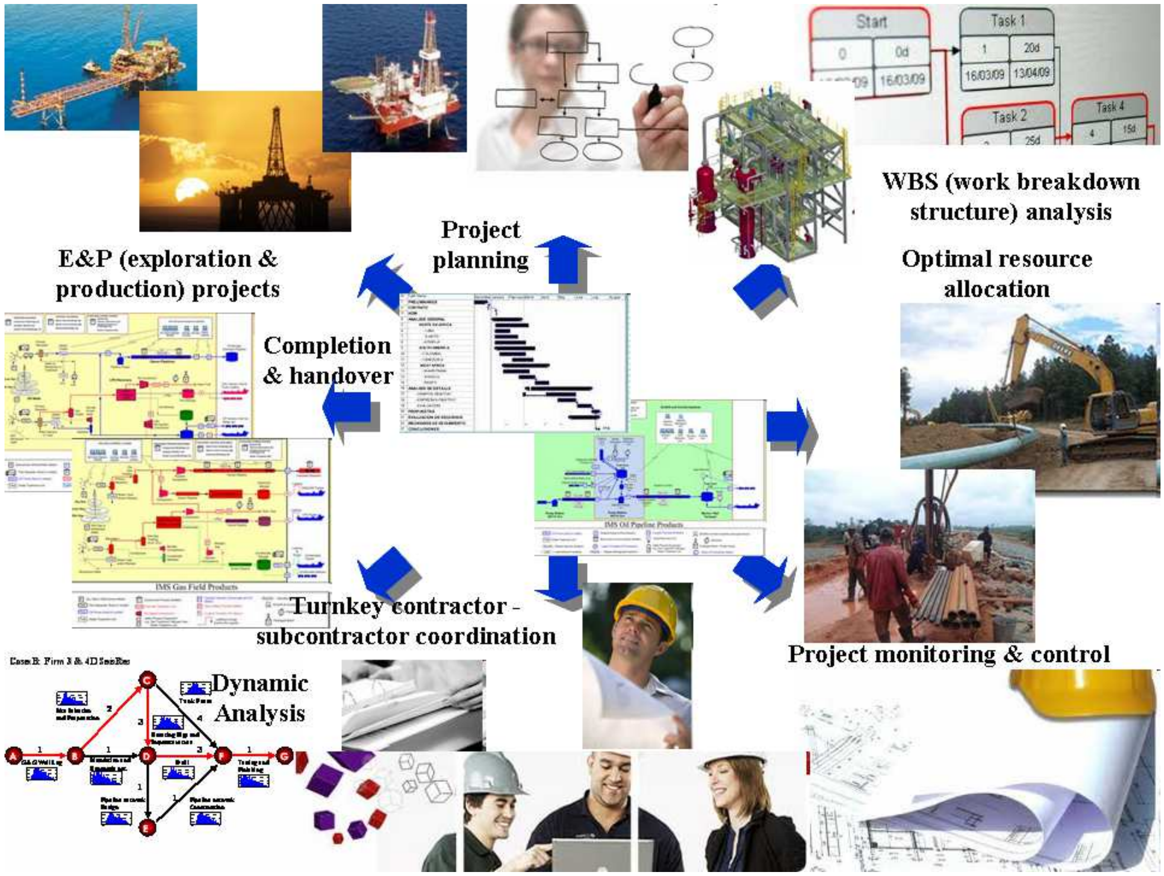


**Fig. 2:** Project Management in the Oil and Gas Industry: Scope, Span and Scale Issues

slippages, if any, along the time, cost and performance dimensions),

- –the progress made to date along the critical dimensions as compared with the goals that were set earlier,
- –the causes and effects of those slippages along one or more of those critical dimensions, and especially the non-availability and unreliability of the resources that have been acquired or procured and deployed for the various tasks or activities that the project is comprised of,
- –the relative degree of success or failure in achieving project-milestones to date, and
- –the relative implications of the slippages, if any, for the remainder of the project; and

–to anticipate what else could go wrong vis-a-vis slippages along the major dimensions, and to decide on course corrections if any are needed, and on what else needs to be done in XYZ's best interests over time.

In the larger scope of things, we hope to extend the existing literature by also including the effects of information on the various drivers of value, such as search costs, cycle time, project completion time, success ("hit") ratio, higher recovery rates/lower depletion rates, asset utilization, and equipment reliability, availability & maintenance policies, etc. Here, we will focus only on the asset or resource reliability and availability aspects.

Shakenova [5], for instance, sees inadequacies in the experience and knowledge of person estimating the duration of tasks or activities comprising the project as the limiting factor in effective project planning and control along with the fact that his/her opinion is subjective at best. Because Oil and Gas projects are very large and have many activities, she suggests addressing this problem by surveying a number of experts, using linguistic variables to elicit their views on activity durations in intervals, not in exact numbers - deffuzifying the fuzzy numbers calculated from their responses can then provide more reliable activity durations that can serve as inputs for the simulation and analysis of the project as a whole.

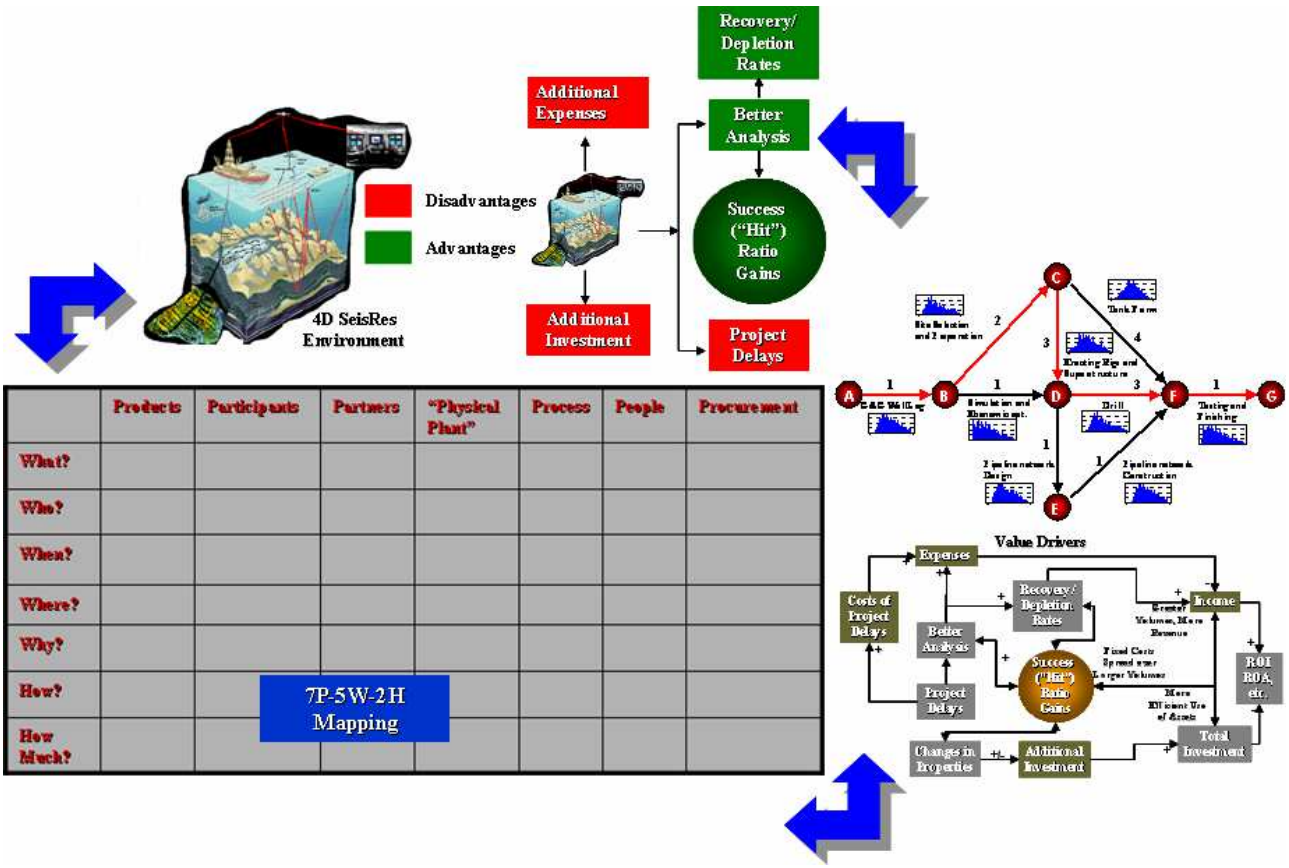


**Fig. 3:** Strategy Formulation, the 7P-5W-2H Mapping and Project Management as an Iterative, Recursive Process

## 3 Modeling and Analysis of Resource Reliability and Availability

Of the 7M resources that have to be acquired or procured and deployed for the various tasks or activities that the project is comprised of, viz., (i) manpower; (ii) materials; (iii) machinery; (iv) meter$^2$ or meter$^3$ space for use by the personnel deployed on-site or off-site, for storage of parts or components, tools, etc., and for ancillary services such as security, housekeeping, support services, etc.; (v) method; (vi) management; and most importantly, (vii) money, we will focus only on machinery, or plant and equipment, and so on, in what follows. More specifically, we aim to analyze the impact of unreliability of the resources and non-availability, stemming from equipment failure, on project delays and cost-overruns.

For each of the resources that have been or which need to be acquired or procured and deployed during any phase of the project - and noting that the same resource may be needed with varying requirements during multiple tasks or activities that the project is comprised of - we ask the following questions in keeping with the technical standard SAE JA1011 (which defines the minimum criteria for the evaluation of RCM processes and which begins with the below seven questions in consecutive order):

- Function - What is the resource or item supposed to do? What are its associated performance standards?
- Failure modes - In what ways can it fail to provide the required functions?
- Failure causes - What are the events that cause each failure?
- Failure results - What happens when each failure occurs?
- Importance - In what way does each failure matter?
- Preventatives - What systematic task can be performed proactively to prevent, or to diminish to a satisfactory degree, the consequences of the failure? What can be done proactively to prevent/diminish consequences of the failure?
- Alternatives - What must be done if a suitable preventive task cannot be found?

Alternately, we can follow Moubray who laid out the basis of Reliability Centered Maintenance, or RCM, as what equipment owners and operators do in order to ensure that the equipment maintains its function and the process, and which requires the following seven questions to be answered [3]:

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– What is the function of the equipment and what are the required performance standards?
– In what ways can it fail to perform its function?
– What could cause each functional failure?
– What happens when the failure occurs?
– In what way does the failure matter?
– What can be done to prevent the failure?
– What has to be done if the failure can't be prevented?

As depicted in Figure 3 , we feel that the conventional PERT/CPM and Earned Value Management approaches will have to be modified to enable the project planners and analysts and project managers to better track and analyze the impact of resource unreliability and non-availability on the time and cost dimensions of the project. We see that as the key decision makers for any project sequentially allocate resources to some subset of the various tasks and activities that may follow one another or which may be executed simultaneously if they are not predecessors or successors to each other, they would have to: (i) examine the resource availability and loading conditions and constraints for each of the resources being deployed; and (ii) either modify the original plan in case the resource constraints are being violated, or arrange for additional units of resources to be procured and made available when needed. Additionally, they would have to allow for unscheduled downtime and unscheduled maintenance, i.e., for resources to become non-available because of current or anticipated failures and for repairs to be performed thereafter (and this would depend on the availability of service parts or spare parts and qualified maintenance personnel), and budget accordingly for the impact of resource non-availability on both time and cost dimensions. Since our aim is to analyze the impact of resource unreliability and non-availability on project delays and cost overruns, we ask the following additional questions in both cases:

– What are the implications of the failure and ensuing downtime of any piece of plant, equipment or machinery, in particular, on the duration of the activity or task for which it is currently deployed, i.e., by how much will that activity or task be delayed, depending on whether it is on the critical path or not, how much slack is associated with the activity or task in the latter or non-critical case, and the mean time to repair, or MTTR, that is expected and planned for, and actually attained in reality?;
– What are the implications of the failure and ensuing downtime of any piece of plant, equipment or machinery, in particular, on the duration and the early or late start and finish times of all resource-relevant successors, or activities or tasks for which it will be deployed in the future, i.e., by how much will those activities or tasks be delayed, depending on whether they are on the critical path or not, how much slack is associated with those activities or tasks, and the number of additional units of resources that currently are, or will be made, available when those activities or tasks are started?;
– How can we best model and incorporate such resource related dimensions as MTTF or MTBF (or mean time to fail or mean time between failures, respectively, which are typically based on the Weibull distribution, whose shape and scale parameter estimates would have to be calculated based on historical data) into our analysis? Do these MTTF or MTBF estimates depend on the current loading and ambient conditions, and if so as is likely to be the case, can these estimates be updated based on how much of the remaining "life" of the equipment (before the next scheduled maintenance) is being used up by the task or activity for which it is currently deployed, and how much remains available for use for the tasks or activities for which it will be deployed in the future, before equipment failure can be expected?
– Can investing additionally in resource redundancy and service or spare part availability ameliorate the adverse impact of resource unreliability and non-availability on the time and cost dimensions of the project? If so, how best can we capture the cost-benefit trade-offs that are inherent in such decisions?
– Given the ability to specifically incorporate and analyze the impact of resource unreliability and non-availability on project delays and cost overruns, how can project managers factor these implications into their budgeting and planning processes along the time and cost dimensions?

Figure 5 , for instance, depicts the time-cost trade-offs associated with resource redundancy and the availability of service or spare parts on the time and cost dimensions of the project. That is, if the project managers had invested in standby or redundant equipment, especially for those types of equipment that are more prone to failure, would this result in reduced downtime? Similarly, if they had invested in additional inventory of service or spare parts, would this reduce the MTTR (or mean time to repair) associated with those equipment failures? In both cases, would such a strategy ameliorate the adverse impact of resource unreliability and non-availability and be beneficial to the organization as a whole? (Notice that reduced downtime would result in fewer delays and hence lower penalty costs for delays, and thus in probably more income, but since the investment in equipment and spare parts is higher, it is not clear whether the ROI, or return on investment, and ROA, or return on assets, be higher.)

By integrating project management with scenario analysis, Baipakbayev [2] aims to provide managers of projects, and especially large projects, with tools that be used proactively to assess, manage and perhaps even prevent all possible sources of variability, uncertainty, ambiguity and risk. More specifically, by mapping the MiniMax algorithm to project management, his hybrid model, which combines resource state trees with decision trees, enables the decision makers to arrive at optimal

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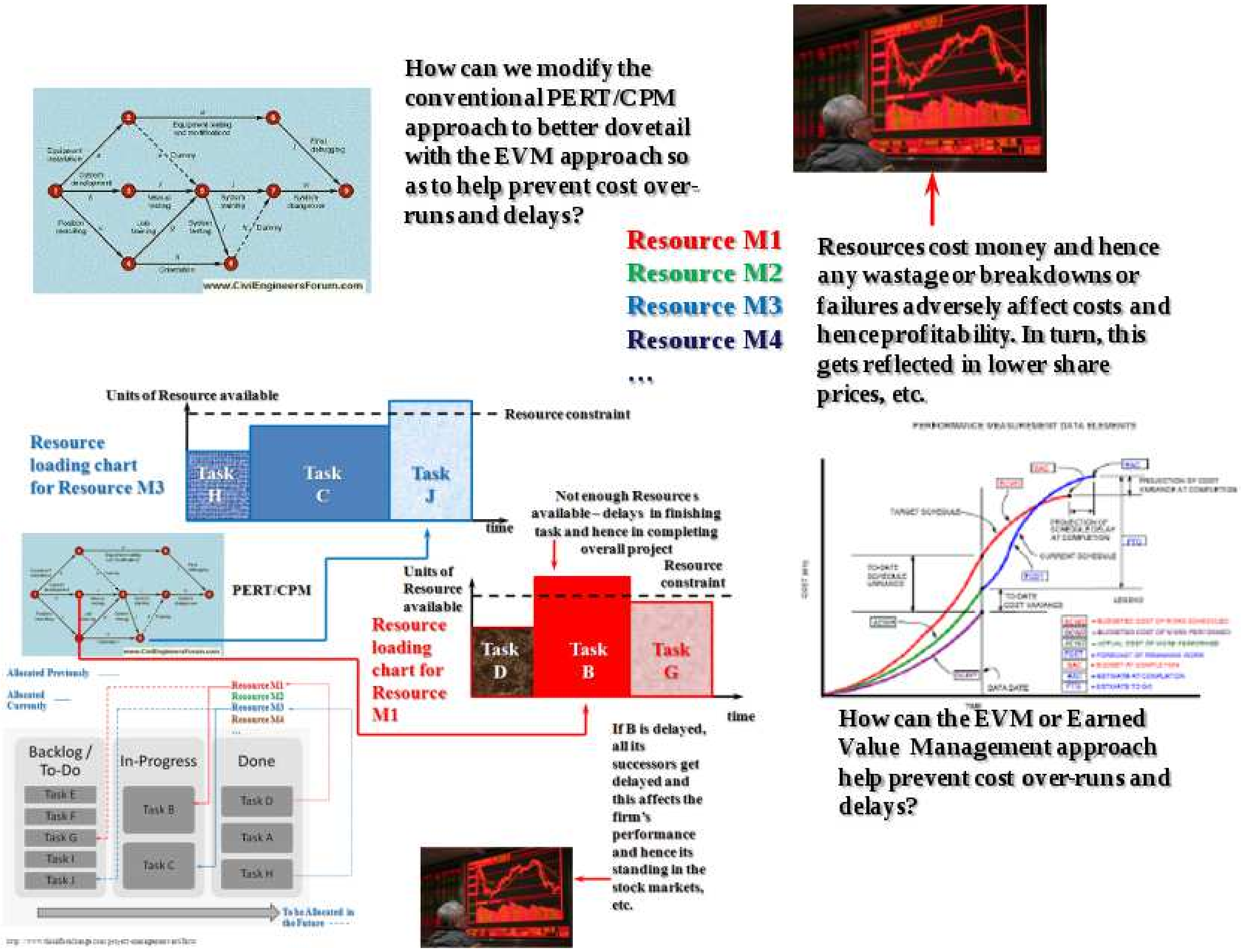


**Fig. 4:** Modifying the conventional PERT/CPM and Earned Value Management Approaches to better Track and Analyze the Impact of Resource Unreliability and Non-Availability on Time and Cost Dimensions

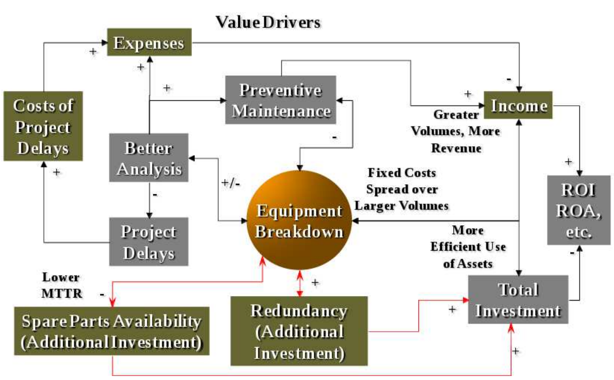


**Fig. 5:** Equipment-redundancy-related trade-offs in Oil and Gas Industry Projects

resource related decisions in all the possible states of resources that can be identified and analyzed a priori, as well as a posteriori. That is, new information relating to the states of resources can be assimilated in a Bayesian sense into the hybrid model very easily and flexibly, allowing for such approaches as investing in redundant resources to be incorporated into the analysis and evaluated more thoroughly.

## 4 Conclusion

In an overarching sense, we seek to offer a new modeling and analytical framework, which combines conventional project management with scenario analysis, system dynamics and simulation to better analyze the time vs. information vs. cost trade-offs and the benefits in terms of risk reduction as well as increased RoI, etc., but here we have chosen to specifically focus on the impact of resource unreliability and non-availability on project delays and cost overruns.

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We believe that if the key decision makers for any project aim to better plan and control the project, and thus deliver the "deliverables" for each milestone, as well as for the overall project, on-time, within-budget, and to-"spec.," the project management team would have to invest a substantial amount of time and effort, a priori, into trying to anticipate, budget and plan for all possible future events and eventualities (so that they can resolve or address as many sources of VUCA, or variability, uncertainty, complexity, and ambiguity, all of which contribute to the risks inherent in the project management process, as they possibly can, and so that they have fewer or no nasty surprises awaiting them down the road). This would enable them to also adapt and respond better if they have to cope with one or more unanticipated surprises during the course of the project, which might otherwise have thrown the project execution processes "out-of-kilter", and caused costly delays in finishing and handing over the completed project.

A vital component of this $360^o$ anticipation, budgeting and planning approach that we are advocating would involve analyzing the impact of equipment breakdowns and failures in one or more of the various known failure modes, on the duration or cycle time for each task or activity and, in turn, on the overall project completion time. The better their understanding of the value drivers and factors that determine equipment reliability, availability and utilization (i.e., the MTTF or MTBF, or mean time to failure or between failures, and MTTR, or mean time to repair, and so on, as estimated a priori and updated a posteriori, in a Bayesian sense, based on new information inputs as and when they are provided from the site or field or any office or other location related to the project, by the organization in question, the equipment vendors or suppliers, or any other turnkey contractor, sub-contractors, etc.), the more informed would their decisions be relating to preventive or preemptive maintenance policies, investment in equipment redundancy and additional spare or service parts, and so on. It follows that such an approach would be instrumental to their efforts to reduce equipment breakdowns and failures, and thus avoid project delays and costs or penalties associated with those delays.

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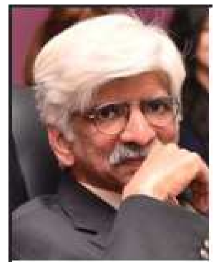

**Ramesh G. Kini** with an MS and PhD from Tepper School of Business, Carnegie Mellon U., is a Professor of Information Systems Management at KBTU. His research interests include modeling and analysis, system dynamics, healthcare information systems, and entrepreneurship eco-systems.

**Zhassan Baipakbayev** received the bachelor degree in Information Systems at Suleyman Demirel University in Almaty. His main research interests are: modeling of resource management process, big data, machine learning, algorithms.

**Yerkezhan Shakenova** received the bachelor degree in Information Systems at Kazakh-British Technical University in Almaty. Her main research interests are: fuzzy logic, project management, reliability management, Oil and Gas projects, web application development.

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