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INTEGRATED QUALITATIVE AND QUANTITATIVE RISK ANALYSIS OF PROJECT PORTFOLIOS

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ABSTRACT

Project portfolio risk management and risk analysis is one of the critical components of ERM. Organizations measure and analyze risks associated with projects, project portfolios, and programs. Such risks can be related to project schedules and affect project durations, completion dates, costs, resources, success rates, etc. The project risks can be also non related to particular project schedules and affecting market, capital, insurance, joint ventures, and other parameters.

The process of project portfolio risk management is started with risk identification. Risks are included to the corporate risk register and presented on the risk matrix. At this step risk probabilities and impacts are defined qualitatively. The second step of the process is quantitative risk analysis of project schedules using Event Chain Methodology (ECM). ECM is a stochastic modeling technique for schedule risk analysis. All risks, including schedule and non-schedule related risks are assigned to a particular project and within this project to the particular activity or resource. Further, ECM allows to model relationship between project risks by defining risks, which cause or trigger other risks. All risks and relationship between them will be presented on the project or portfolio Gantt charts using Event Chain Diagrams.

After risks are assigned to project and portfolio schedule, Monte Carlo simulation of project schedule is performed based on standard scheduling algorithm. Statistical distributions of project cost, duration, finish time, resource allocation and other parameters help to determine the chance that the project can be completed on time and on budget. Risk impact is calculated based on correlation between incremental increase of task's cost or duration and project cost, duration, and other parameters. Risks within a risk register are ranked based on calculated impact and probabilities.

The methodology simplifies complex risk analysis process, which in most cases is performed by project schedulers.

ENTERPRISE RISK MANAGEMENT IN PROJECT-BASED ORGANIZATIONS

Many organizations especially in the construction, aerospace, pharmaceutical and other industries focus their resources primary on projects rather than on operation. Project is a "temporary endeavour undertaken to create a unique, product, service, or result" (Project Management Institute, 2009). Projects are time-related and usually include multiple activities and resources. Many projects have a project schedule with a number of interlinked activities and resources attached to them. The projects are managed by tracking actual project performance versus original project plans. Most organizations have a portfolio of projects which can be related to each other, for example, by sharing the same resources.

Project management includes project scope, time, quality, procurement, and other processes. One of the most important project management processes is risk management. Project risk management include steps of risk management planning, risk identification, qualitative and quantitative risk analysis, risk response planning, risk monitoring and control.

The main difference between enterprise risk management for operation-based organization and portfolio risk management is that in portfolio risk management many risks can be assigned to the activities of project schedules. For example, some risks can affect activity's duration, the same or other risk can affect activity's cost, resource allocation, project success rate, and other project parameters. By assigning risk to project activity and recalculating project schedule it is possible to determine how risk would affect the schedule and portfolio. Risk register in project portfolio includes schedule-related risks, and non-schedule risks. Market, capital, insurance, joint ventures belong to the category of non-schedule risks. They may be assignment to activities of project schedule but they don't affect project schedule directly. Risks related to activity's duration and cost are affecting project schedule.

QUANTITATIVE VS. QUANTITATIVE ANALYSIS OF PROJECT PORTFOLIO

Risk register of project portfolio is a set of risks of opportunities with their properties. The risk properties include:

- Risk attributes, such as risk description, objectives, owner, start and end date, etc.
- Risk costs
- Risk mitigation and response plans
- Risk reviews
- Historical information about risk
- Risk assignments

Risk can be assigned to different projects within a portfolio and to different activities and resources within a project. When risk is assigned to different activity, it must have certain probability and impact. Here is a list of typical impacts for schedule-related risks and opportunities assigned to the activities:

- Cost increase of the activity
- Duration increase of the activity
- Relative income of the activity
- Cancel or end task
- Restart task

For example risk "Supplier did not deliver the components" may affect three different activities of two project schedule within a portfolio. Since components can be different, probabilities of each risk assignment can be different as well:

	Probability	Impact	Impact Value
Activity 1	10%	Restart Task	
Activity 2	30%	Fixed Delay	2 days
	20%	Fixed Cost Increase	$4000.00
Activity 3	25%	Relative Delay	20% of activity's duration
	30%	Reduce Quality	

Reduce quality of a non-schedule risk impact. Other impacts are schedule-related.

The risk assigned to resources may include increase of hourly rate, re-assigning resource to different activities and others. Risk and opportunity and can be converted to issue, the issue can be converted to lesson's learned. Risk and opportunities can be presented on risk probability vs. impact matrix. The risks can be ranked based on risk score, which is risk probability multiplied on risk impact.

Standard non-schedule risk categories for project portfolio include quality, technology, safety, security, public relations, and other. All schedule-related risks affecting project scope, duration, and cost belong to one category. Schedule-related project parameters are integrated with each other. For example, if duration increases, it will lead to increase of project cost.

Analysis of project portfolio can be performed qualitatively by assigning risk probability and impacts to different risks. However for schedule related risks, calculation of risk impact using qualitative analysis only can be very challenging. Particularly, one risk can be assigned to different projects and activities. Cumulative impact of such risk is difficult to calculate without quantitative analysis. Also if risk is assigned to the activity which is not on the critical path, risk impact on total project can be zero even risk impact on the particular activity can be very significant.

Therefore the process of portfolio risk analysis should include both qualitative and quantitative analysis. The quantitative analysis can be performed using Event Chain Methodology (ECM).

BASICS TO EVENT CHAIN METHODOLOGY

Risks from the corporate risk register may be assigned to different project activities with different probabilities and impacts. In addition to it each risk may have multiple mitigation plans, which can be different for each activity. Risk register, project schedule, and a set of mitigation plans is essentially a probabilistic project model. Since number of activities can be very significant, the overall project model can be quite complex.

Event chain methodology is design to simplify the risk analysis process for the project schedules. Here are some motivations behind developing Event chain methodology:

1. Simplifying the project scheduling with risks and uncertainties particularly though visualization of multiple events and relationship between them.
2. Event Chain methodology takes to an account relationship between risk events, timing of the events, conditions for the events and many others factors. It helps to improve accuracy of quantitative analysis.
3. Event Chain Methodology incorporates actual project performance measurement process. Measuring project performance on different phases of project and incorporating actuals to the project schedule can significantly improve quality of the schedules (Wysocki & McGary, 2003).

The first step of the project risk analysis process is identification of the risks and uncertainties. There are a number of techniques which are used identify risks and uncertainties. The PMBOK® Guide (2009) includes references to such techniques as brainstorming, interviewing, checklist analysis, assumption analysis, SWOT (strengths, weaknesses, opportunities, and threads) analysis, root cause identification, and various diagramming techniques. There are a number of specific techniques and tools, including templates based on historical data, checklists (Clemen, 1996; Hill, 1982). Project management literature includes many examples of different risk templates (Hillson, 2002; Kendrick, 2003).

According to Event chain methodology risk identification must include the following additional steps:

- Identify what activity, resource or project this event is assigned to;
- Identify relationship between risks: risk triggers and risk chain;
- Identify when the risk occurred during a course of activity;
- Determine different states of each activity: some activities may not be subscribed to some risks

The next of the ECM process is a quantitative risk analysis. PMBOK® Guide recommends a few quantitative analysis techniques, including Monte Carlo analysis, decision trees and sensitivity analysis. Monte Carlo analysis is used to approximate the distribution of potential results based on probabilistic activity duration and cost (Hulett, 1996; Goodpasture, 2004; Schuyler, 2001). Each trial is generated by randomly pulling a sample value for each input variable from its defined probability distribution. Calculation is performed using Critical Path Method. The main advantage of Monte Carlo simulation of project schedule is that it helps to incorporate uncertainties into the process of project scheduling. However Monte Carlo analysis without risk events has the following limitations:

1. Project managers perform certain recovery actions when a project slips. These actions may not be taken into account, unless very complex modelling with probabilistic and conditional branching is performed. Because of this, Monte Carlo may give overly pessimistic results (Williams, 2004).
2. Statistical distributions of activity's cost, duration, and other parameters are an input for Monte Carlo analysis. The issue is defining statistical distribution is not a simple process. The project estimator must use significant number of historical data points to come up with the distribution. In most cases this information is not easily available.
3. Monte Carlo suffers from the anchoring heuristic: when project estimators come up with a certain base duration or cost, they don't significantly deviate from it and don't look for different situations why duration and cost may be outside certain limits (Quattrone et al., 1984).

Goldratt (1997) applied the theory of constraints to project management. The cornerstone of the theory is resource constrained critical path which he called a critical chain. Fundamentally Goldratt's approach is based on a deterministic critical path method. To deal with uncertainties, Goldratt suggests using project and feeding buffers and encourages early task completion. In many cases critical chain has proved to be an effective methodology for a wide range of projects (Srinivasan, Best, & Chandrasekaran, 2007; Wilson & Holt, 2007). However many organizations don't embrace critical chain because it requires changing of established project management processes.

To address the challenges with the classic Monte Carlo simulation technique, risk events or "risk drivers" were incorporated to the Monte Carlo analysis (Hulett, 2011). The method of risk drivers has close relationship with Event chain methodology: it allows performing Monte Carlo simulations with risk events. The method of risk drivers does not include event and events chain visualization, analysis of moment of risks, identification of critical event chains, states of activities and other features.

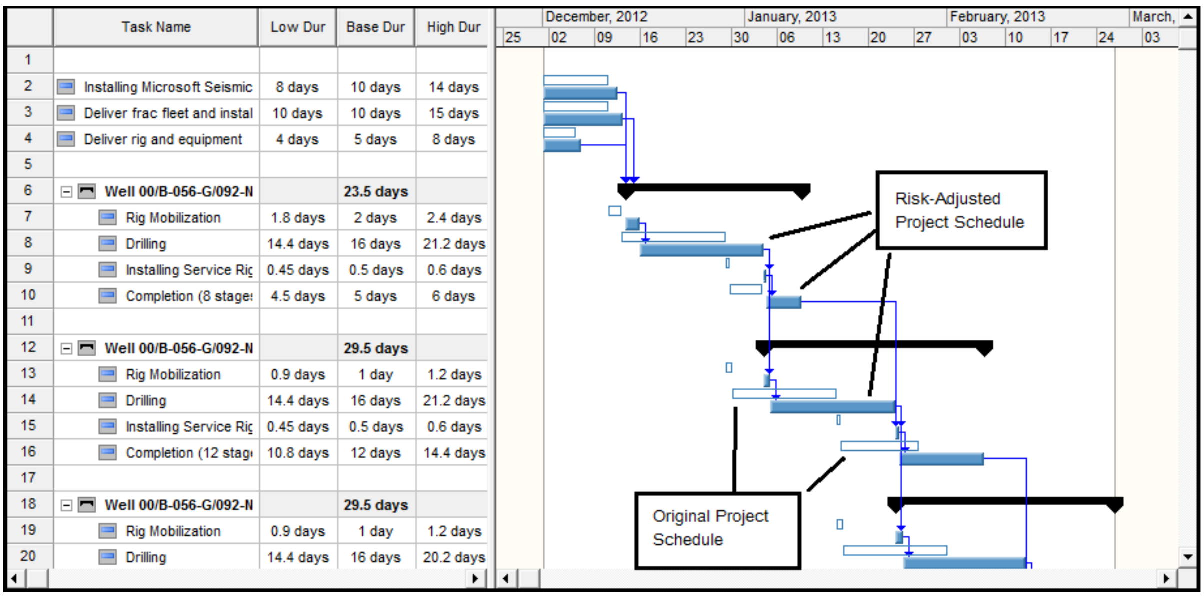
Visualization of project plans with uncertainties is critical for modelling project schedules with risks and uncertainties. Traditional visualization techniques include Gantt charts and schedule network diagrams (Project Management Institute, 2009). Visual modeling tools for business problem are actively used to describe complex models in many industries. Unified modeling language (UML) is actively used in the software design (Arlow & Neustadt, 2003; Booch, Rumbaugh, & Jacobson, 2005). In particular, this visual modeling language approach was applied to defining relationships between different eavents. Visual modeling languages are also applied to probabilistic business problems (Virine & Rapley, 2003; Virine & McVean, 2004).

Here is a typical Event chain methodology workflow:

1. Create a project schedule. For each activity identify different state.
2. Identify risks and opportunities and add then to the Risk Register.

3. Assign risk to tasks and resources and define probabilities and impacts
4. Visualize the risks and perform quality control
5. Run a simulation, perform an analysis and generate a report of the results. .
6. Update risks and uncertainties as necessary.
7. During project execution, perform project tracking with risks and uncertainties at key phases or milestones to update forecasts.
8. Report results

The result of analysis is risk adjusted project schedule (Figure 1). Project cost with and without risks is shown on Figure 2.



	Task Name	Low Dur	Base Dur	High Dur
1				
2	Installing Microsoft Seismic	8 days	10 days	14 days
3	Deliver frac fleet and instal	10 days	10 days	15 days
4	Deliver rig and equipment	4 days	5 days	8 days
5				
6	Well 00/B-056-G/092-N		23.5 days	
7	Rig Mobilization	1.8 days	2 days	2.4 days
8	Drilling	14.4 days	16 days	21.2 days
9	Installing Service Ric	0.45 days	0.5 days	0.6 days
10	Completion (8 stage:	4.5 days	5 days	6 days
11				
12	Well 00/B-056-G/092-N		29.5 days	
13	Rig Mobilization	0.9 days	1 day	1.2 days
14	Drilling	14.4 days	16 days	21.2 days
15	Installing Service Ric	0.45 days	0.5 days	0.6 days
16	Completion (12 stag	10.8 days	12 days	14.4 days
17				
18	Well 00/B-056-G/092-N		29.5 days	
19	Rig Mobilization	0.9 days	1 day	1.2 days
20	Drilling	14.4 days	16 days	20.2 days

Figure 1: Risk Adjusted Project Schedule

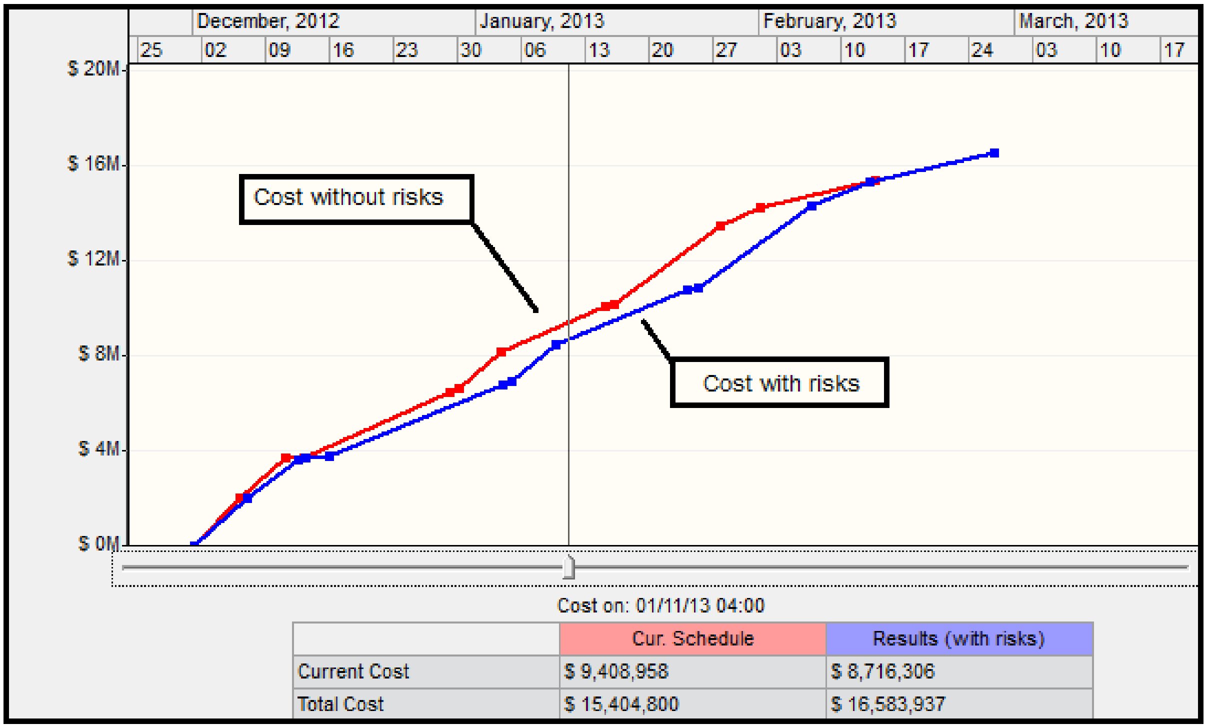


Figure 2: Project cost with and without risks

MOMENT OF EVENT AND EXCITATION STATES

An task in most real life processes is not a uniform procedure. Activities are affected by external events that transform them from one *state* to another. For example, the task is painting the building's wall. It is done by many crew. One crew can complete job earlier and move to another task. As a result the state of the task changed: number of crews has reduced. As a result, this may alter the activity's cost and duration.

In other word activity will be performed differently as a response to the event. This process of changing the state of an activity is called *excitation*. The term comes from quantum mechanics: the notion of excitation is used to describe elevation in energy level above an arbitrary baseline energy state. In Event chain methodology, excitation indicates that something has changed the manner in which an activity is performed.

The original or planned state of the activity is called a *ground state*. Other states, associated with different events are called *excited states* (Figure 3).

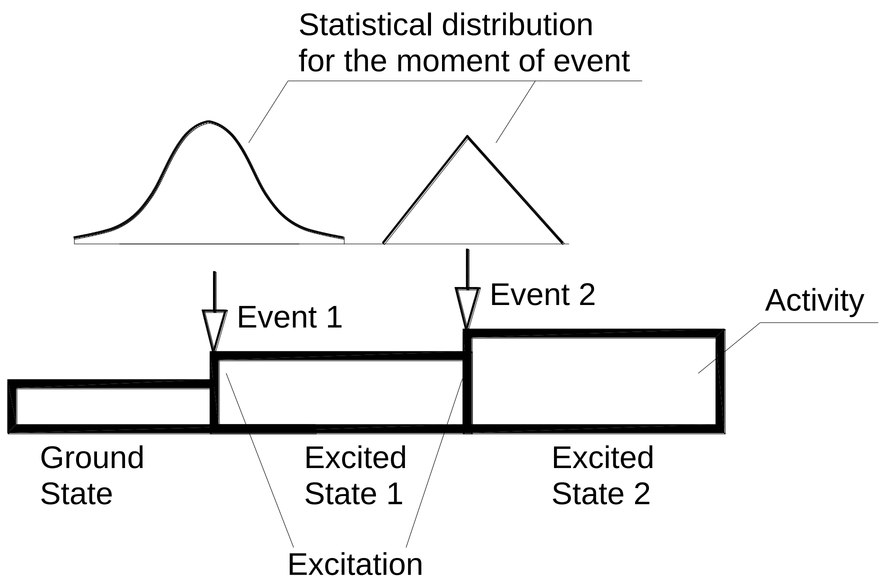


Figure 3. Activity is transformed from ground states to excited states by events

Similarly to tasks, resources assignments, lags, and calendars may have different grounded and excited states. For example, the event "Bad weather" can transform a calendar from a ground state (5 working days per weeks) to an excited state: non-working days for the next 10 days.

Each state of activity in particular may *subscribe* to certain events. Event can affect the activity only if the activity is subscribed to this event. For example, an assembly activity has started outdoors. The ground state the activity is subscribed to the external event "Bad weather". If "Bad weather" actually occurs, the assembly should move indoors. This constitutes an excited state of the activity. This new excited state (indoor assembling) will not be subscribed to the "Bad weather": if this event occurs it will not affect the activity.

Event subscription has a number of properties:

- *Impact of the event* is the property of the state rather than event itself. The impacts of events are characterized by some additional parameters. For example, a parameter associated with the impact "Fixed delay of activity" is the actual duration of the delay.
- *Probability of occurrence* is also a property of subscription;
- *Moment of event*: the actual moment when the event occurs during the course of an activity. The moment of event can be absolute (certain date and time) or relative to an activity's start and finish times. In most cases, the moment when the event occurs is probabilistic and can be defined using a statistical distribution (Figure 3).

Events can have negative (risks) and positive (opportunities) impacts on projects. Mitigation efforts are considered to be events, which are executed if an activity is in an excited state. *Mitigation events* may attempt to transform activity to the ground state.

The impact of events associated with resources is similar to the impact of activity events. Resource events will affect all activities this resource is assigned to. If a resource is only partially involved in the activity, the probability of event will be proportionally reduced. The impact of events associated with a calendar changes working and non-working times.

EVENT CHAINS

Some events can cause other events. These series of events form event chains, which may significantly affect the course of the project by creating a ripple effect through the project (Figure 4). Here is an example of an event chain ripple effect:

1. Problem with supplier changes cause a delay of an activity.
2. To accelerate the activity, resources are diverted from another activity.
3. Diversion of resources causes deadlines to be missed on the other activity
4. Cumulatively, this reaction leads to the failure of the whole project.

Here is how the aforementioned example can be defined using Event chain methodology:

1. The event “Problem with supplier” will transform the activity to an excited state which is subscribed to the event “Redeploy resources”.
2. Execute the event “Redeploy resources” to transfer resources from another activity. Other activities should be in a state subscribed to the “Redeploy resources” event. Otherwise resources will be not available.
3. As soon as the resources are redeployed, the activity with reduced resources will move to an excited state and the duration of the activity in this state will increase.
4. Successors of the activity with the increased duration will start later, which can cause a missed project deadline.

An event that causes another event is called the *trigger (sender)*. The trigger can cause multiple events in different activities. This effect is called *multicasting*. For example a broken component may cause multiple events: a delay in assembly, additional repair activity, and some new design activities. Events that are caused by the sender are called *receivers*. Receiver events can also act as a sender for another event.

EVENT CHAIN DIAGRAMS AND STATE TABLES

The relationships between events can be visualized using event chain diagrams. Event chain diagrams are presented on the Gantt chart according. There is specification or a set of rules for event chain diagrams.

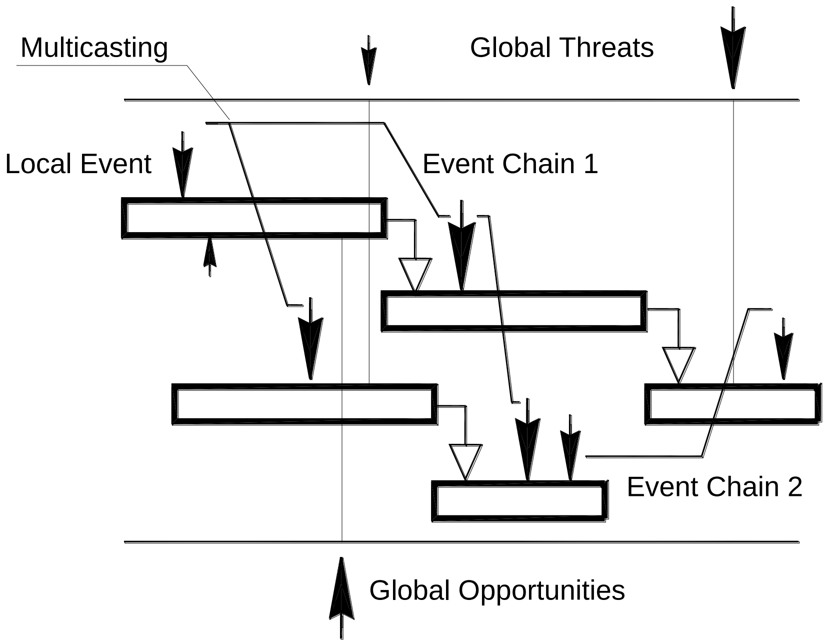


Figure 4. Example of event chain diagram

1. All events are shown as arrows. Names and/or IDs of events are shown next to the arrow.
2. Events with negative impacts (risks) are represented by down arrows; events with positive impacts (opportunities) are represented by up arrows.
3. Individual events are connected by lines representing the event chain.
4. Events affecting all activities (global events) are shown outside Gantt chart. Threats are shown at the top of the diagram. Opportunities are shown at the bottom of the diagram.
5. A sender (trigger) event with multiple connecting lines to receivers represents multicasting.

Often event chain diagrams can become very complex. In these cases, some details of the diagram do not need to be shown. Here is a list of optional rules for event chain diagrams:

1. Horizontal positions of the event arrows on the Gantt bar correspond with the mean moment of the event.
2. Probability of an event can be shown next to the event arrow.
3. Size of the arrow represents relative probability of an event. If the arrow is small, the probability of the event is correspondingly small.

4. Excited states are represented by elevating the associated section of the bar on the Gantt chart (see Figure 3). The height of the state's rectangle represents the relative impact of the event.
5. Statistical distributions for the moment of event can be shown together with the event arrow (see Figure 3).
6. Multiple diagrams may be required to represent different event chains for the same schedule.
7. Different colors and different sizes of arrows cab be used to depict probabilities and impacts of different events.

Another tool that can be used to simplify the definition of events is a *state table*. Columns in the state table represent events; rows represent states of activity. Information for each event in each state includes four properties of event subscription: probability, moment of event, excited state, and impact of the event. State table helps to depict an activity's subscription to the events: if a cell is empty the state is not subscribed to the event.

	Event 1: Software Architecture changes	Event 2: Development tools don't work	Event 3: Minor change in the software requirements
Ground state	*Probability*: 30% *Moment of event*: any time *Excited state*: Major code changes *Impact*: delay 1 month	*Probability*: 20% *Moment of event*: any time *Excited state*: Major code changes *Impact*: delay 1 week	
Excited state: Major code changes			*Probability*: 15% *Moment of event*: beginning of the activity *Excited state*: minor code change *Impact*: delay 2 days
Excited state: Minor code change			

Table 1: Example of the state

MONTE CARLO ANALYSIS

Once events, event chains, and event subscriptions are defined, Monte Carlo analysis of the project schedule can be performed to quantify the cumulative impact of the events. Probabilities and impacts of events are used as an input data for analysis. The results of the analysis are similar to the results of classic Monte Carlo simulations of project schedules. These results include statistical distributions for duration, cost, and success rate of the complete project and each activity or group of activities.

In most real life projects, even if all the possible risks are defined, there are always some uncertainties or *"noise"* in duration and cost. To take the noise into account, distributions related to activity duration, start time, cost, and other parameters should be defined in addition to the list of events. These statistical distributions must not have the same root cause as the defined events, as this will cause a double-count of the project's risk.

CRITICAL EVENT CHAINS AND EVENT COST

Single events or event chains that have the most potential to affect the projects are the *critical events* or *critical event chains*. By identifying critical events or critical event chains, it is possible mitigate their negative effects. These critical event chains can be identified through sensitivity analysis: by analyzing the correlations between the main project parameters, such as project duration or cost, and event chains.

Critical events or critical event chains can be visualized using a sensitivity chart or using risk register as shown on Figure 5.

	Risk Name	Open...	Risk/Issue	Threat/O...	Probability ...	Impac...	Score ...	Score
1	Mechanical problem with instrument: additional trave	Opened	Risk	Threat	67.4%	65.2%	44.0%	
2	Delay with delivery of drilling supplies (mud, etc.)	Opened	Risk	Threat	49.0%	34.4%	16.9%	
3	Delay due to weather	Opened	Risk	Threat	10.0%	52.7%	5.3%	
4	Mechanical problem with rig	Opened	Risk	Threat	28.6%	13.4%	3.8%	
5	Problem with water delivery for fracturing process	Opened	Risk	Threat	34.4%	9.8%	3.4%	
6	Problem with installation of seismic microphones	Opened	Risk	Threat	15.0%	0.0%	0.0%	

Figure 5. Critical events and event chains

PROJECT PERFORMANCE MEASUREMENT WITH EVENT AND EVENT CHAINS

Monitoring the progress of activities ensures that updated information is used to perform the analysis. While this is true for all types of analysis, it is a critical principle of event chain methodology. During the course of the project, using actual performance data, it is possible to recalculate the probability of occurrence and moment of the events. The analysis can be repeated to generate a new project schedule with updated costs or durations.

There are four distinct approaches to this problem:

1. Probabilities of a random event in partially completed activity stay the same regardless of the outcome of previous events. This is mostly related to external

events, which cannot be affected by project stakeholders. It was originally determined that “bad weather” event during a course of one-year construction project can occur 12 times. After a half year, bad weather has occurred 10 times. For the remaining half year, the event could still occur 5 times.

2. Probabilities of events in a partially completed activity depend on the moment of the event. If the moment of risk is earlier than the moment when actual measurement is performed, this event will not affect the activity.
3. Probabilities of event can be calculated based on original probability and historical data related to accuracy of previous assessment of the probability using Bayesian Theorem.
4. Probabilities of events need to be defined by the subjective judgment of project managers or other experts at any stage of an activity.

IMPLEMENTATION OF INTEGRATED QUANTITATIVE AND QUANTITATIVE RISK ANALYSIS AND ECM

The described methodology and software for integrated qualitative and quantitative risk management and analysis is actively used by many organizations, including US Department of Energy, NASA, USDA, FAA, FDA, Boeing, Lockheed Martin, L-3Com, HP, P&G, IBM, Syncrude, BP, Mosaic, Ericson, Novartis, Schlumberger and many others. These and many other companies integrated project portfolio risk analysis and risk management process to their ERM processes.

Event chain methodology allows taking into an account factors, which were not analyzed by other schedule network analysis techniques: moment of event, chains of events, delays in events, execution of mitigation plans and others. Complex relationship between different events can be visualized using event chain diagrams and state tables, which simplifies event and event chain identification. Event chain methodology includes techniques designed to incorporate new information about actual project performance to original project schedule and therefore constantly improve accuracy of the schedule during a course of a project.

Event chain methodology is a practical approach to scheduling software projects with tisks uncertainties. A process that utilizes this methodology can be easily used in different projects, regardless of size and complexity. Scheduling using Event chain methodology is an easy to use process, which can be can be performed using off-the-shelf software tools. Event chain methodology is adopted by many organizations, including large corporations and government agencies in more than 40 countries.

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AUTHOR'S BIO

Dr. Lev Virine. Ph.D. has more than 25 years of experience as a structural engineer, software developer, and project manager. In the past 15 years he has been involved in a number of major projects performed by Fortune 500 companies and government agencies to establish effective decision analysis and risk management processes as well as to conduct risk analyses of complex projects. Lev's current research interests include the application of decision analysis and risk management to project management. He writes and speaks to conferences around the world on project decision analysis, including the psychology of judgment and decision-making, modeling of business processes, and risk management. Lev is an author of more than 50 papers and two books of project risk management and analysis. Lev received his doctoral degree in engineering and computer science from Moscow State University.