Integrated Qualitative and Quantitative Risk Analysis of Project Portfolios

Lev Virine

Presented at the:
2013 Enterprise Risk Management Symposium
April 22-24, 2013

Integrated Qualitative and Quantitative Risk Analysis of Project Portfolios

Lev Virine*

ABSTRACT

Project portfolio risk management and risk analysis form one of the critical components of enterprise risk management. Organizations measure and analyze risks associated with projects, project portfolios, and programs. Such risks can be related to project schedules and affect, for example, project durations, completion dates, costs, resources, and success rates. The project risks also can be unrelated to particular project schedules and affecting market, capital, insurance, joint ventures, and other parameters. The process of project portfolio risk management begins with risk identification. Risks are included on 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 nonschedule-related risks, are assigned to a particular project and within this project to the particular activity or resource. Further, ECM allows one to model the relationship between project risks by defining risks that cause or trigger other risks. All risks and relationships between them will be presented on the project or portfolio Gantt charts using *event chain diagrams.* After risks are assigned to project and portfolio schedules, Monte Carlo simulation of the project schedule is performed based on a 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 the incremental increase of a 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.

*Lev Virine, Ph.D., P.Eng. is President of Intaver Institute Inc., 303, 6707, Elbow Drive S.W., Calgary, Alberta, Canada, T2V0E5, lvirine@intaver.com.

1. Enterprise Risk Management in Project-Based Organizations

Many organizations, especially those in the construction, aerospace, and pharmaceutical industries, focus their resources primary on projects rather than on operation. A project is a “temporary endeavour undertaken to create a unique, product, service, or result” (Project Management Institute 2013). 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 that 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 includes 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 (ERM) 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 an activity’s duration, and the same or another risk can affect an activity’s cost, resource allocation, project success rate, and other project parameters. By assigning risk to a project activity and recalculating the project schedule it is possible to determine how risk would affect the schedule and portfolio. The risk register in a project portfolio includes schedule-related risks and nonschedule risks. Market, capital, insurance, and joint ventures belong to the category of nonschedule risks. They may be assigned to activities of the project schedule, but they do not affect project schedule directly. Risks related to an activity’s duration and cost affect the project schedule.

2. Quantitative versus Quantitative Analysis of a Project Portfolio

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

- Risk attributes, such as risk description, objectives, owner, and start and end date
- 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 a different activity, it must have a 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, the risk "Supplier did not deliver the components" may affect three different activities of two project schedules within a portfolio. Since components can be different, the probabilities of each risk assignment can be different as well (see Table 1).

Table 1

Risk Assignment Probabilities and Impacts

	Probability	Impact	Impact Value
Activity 1	10	Restart task	
Activity 2	30	Fixed delay	2 days
	20	Fixed cost increase	$4,000
Activity 3	25	Relative delay	20% of activity's duration
	30	Reduce quality	

"quality" is a nonschedule risk impact. Other impacts are schedule related.

The risk assigned to resources may include an increase of the hourly rate or reassigning a resource to different activities. Risk and opportunity can be converted to an issue, and the issue can be converted to lessons learned. Risk and opportunities can be presented on a risk probability versus impact matrix. The risks can be ranked based on a risk score, which is risk probability multiplied by risk impact.

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

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

Therefore the process of portfolio risk analysis should include both qualitative and quantitative analysis. Quantitative analysis can be performed using event chain methodology.

3. Introduction to Event Chain Methodology

Risk events can affect project schedules differently. Events can occur in the middle of an activity, they can be correlated with each other, one event can cause other events, the same event may have different impacts depending upon circumstances, and different mitigation plans can be executed under different conditions. These complex systems of uncertainties must be identified and visualized to improve the accuracy of project schedules.

The accuracy of project scheduling can be improved by constantly refining the original plan using actual project performance measurement (Wysocki and McGary 2003). This can be achieved through analysis of uncertainties during different phases of the project and incorporating new knowledge into the project schedule. In addition, a number of scheduling techniques such as resource leveling and the incorporation of mitigation plans and repeated activities into the project plans are difficult to apply to project schedules with risks and uncertainties. Therefore, the objective is to identify an easy-to-use process, which includes project performance measurement and other analytical techniques.

Event chain methodology (ECM) has been proposed as an attempt to satisfy the following objectives related to project scheduling and forecasting:

1. Simplifying the process of modeling risks and uncertainties in project schedules, in particular, by improving the ability to visualize multiple events that affect project schedules and perform reality checks
2. Performing more accurate quantitative analysis while accounting for such factors as the relationships between different events and the actual moment of events
3. Providing a flexible framework for scheduling that includes project performance measurement, resource leveling, execution of migration plans, correlations between risks, repeated activities, and other types of analysis

4. Existing Techniques as Foundations for ECM

One of the fundamental issues associated with managing project schedules lies in the identification of uncertainties. If the estimates for input uncertainties are inaccurate, this will lead to inaccurate results regardless of the analysis methodology. The accuracy of project planning can be significantly improved by applying advanced techniques for identification risks and uncertainties. The PMBOK® Guide includes references to such techniques as brainstorming, interviewing, SWOT (strengths, weaknesses, opportunities, and threads) analysis, root cause identification, checklist analysis, assumption analysis, and various diagramming techniques. Extensive sets of techniques and tools that can be used by individuals as well as in groups are available to simplify the process of uncertainty modeling (Clemen 1996; Hill 1982).

The PMBOK Guide recommends creating risk templates based on historical data. There are no universal, exhaustive risk templates for all industries and all types of projects. Most risk templates, including the example from the PMBOK Guide, are very generic and may not be relevant to specific projects. The project management literature includes many examples of different risk lists, which can be used as templates (Hillson 2002). Kendrick (2003) proposed a more advanced type of template: risk questionnaires, which provide three choices for each risk where the project manager can select when the risk can manifest itself during the project: (a) at any time, (b) about half the time, and c) less than half the time. One of the most comprehensive analyses of risk sources and categories was performed by Scheinin and Hefner (2005). They reviewed risk lists from different sources and attempted to consolidate it into one document. Each risk in their risk breakdown structure includes what they call a “frequency” or rank property.

The PMBOK Guide recommends a number of quantitative analysis techniques, such as Monte Carlo analysis, decision trees, and sensitivity analysis. One of the earliest quantitative methods, PERT (Program Evaluation and Review Technique) was developed to address uncertainty in project schedules. According to classic PERT, the expected task duration is calculated as the weighted average of the most optimistic, the most pessimistic, and the most likely time estimates. The expected duration of any path on the precedence network can be found by summing up the expected durations. The main problem with classic PERT is that it gives accurate results only if there is a single dominant path through a precedence network (MacCrimmon and Ryavec 1962; Cho and Yum 1964).

Monte Carlo analysis is used to approximate the distribution of potential results based on probabilistic inputs (Hulett 1996, 2000; Goodpasture 2004; Schuyler 2001). Each trial is generated by randomly pulling a sample value for each input variable from its defined probability distribution. These input sample values are then used to calculate the results. This procedure is then repeated until the probability distributions are sufficiently well represented to achieve the desired level of accuracy. The main advantage of a Monte Carlo simulation is that it helps to incorporate risks and uncertainties into the process of project scheduling. However, Monte Carlo analysis has the following limitations:

1. Project managers perform certain recovery actions when a project slips. These actions in most cases are not taken into account by Monte Carlo analysis. In this respect, Monte Carlo analysis may give overly pessimistic results (Williams 2004).
2. Defining distributions is not a trivial process. Distributions are a very abstract concept that some project managers find difficult to work with. To define distributions accurately, project managers have to perform a few mental steps that can be easily overlooked. Monte Carlo analysis suffers from the anchoring heuristic: when a project manager comes up with a certain base duration, he or

she tends to stick closely to it and builds a distribution around it regardless (Quattrone et al. 1984; Tversky and Kahneman 1974)

Another approach to project scheduling with uncertainties was developed by Goldratt (1997), who applied the theory of constraints to project management. The cornerstone of the theory is a resource-constrained critical path called a critical chain. Goldratt's approach is based on a deterministic critical path method. To deal with uncertainties, Goldratt suggests using project buffers and encourages early task completion. Although the critical chain approach has proven to be a very effective methodology for a wide range of projects (Srinivasan et al. 2007; Wilson and Holt 2007), it is not fully embraced by many project managers because it requires changing established processes, particularly with regard to the management of project buffers and resource-constrained chains.

A number of quantitative risk analysis techniques deal with specific issues related to uncertainty management. A decision tree (Hulett and Hillson 2006) helps to calculate the expected value of a project as well as identify project alternatives and select better courses of action. Sensitivity analysis is used to determine which variables, such as risks, have the most potential impact on projects (Schuyler 2001). These types of analysis usually become important components in a project-planning process that accounts for risks and uncertainties.

One of the approaches, which may help to improve accuracy of project forecasts, is the visualization of project plans with uncertainties. Traditional visualization techniques include bar charts or Gantt charts and various schedule network diagrams (Project Management Institute 2004). Visual modeling tools are widely used to describe complex models in many industries. Unified modeling language (UML) is actively used in the software design (Arlow and Neustadt 2003; Booch et al. 2005). In particular, this visual modeling language approach was applied to defining relationships between different events. Visual modeling languages are also applied to probabilistic business problems (Virine and Rapley 2003; Virine and McVean 2004). Uncertainties associated with project variables, relationships between uncertain variables and results of analysis, as well as calculation algorithms can be displayed using these diagrams.

Among integrated processes designed to improve the accuracy of project planning with risks and uncertainties are reference class–forecasting technique (Flyvbjerg 2006). This process includes identifying similar past and present projects, establishing probability distributions for selected reference classes, and using them to establish the most likely outcome of a specific project. The American Planning Association officially endorses reference class forecasting. Similar types of methods based on historical analysis are used in different industries. For example, statistical analysis of predefined analog sets is used for evaluation of oil and gas production based on geological uncertainties (Rose 2001). Analysis based on historical data helps to make more accurate forecasts; however, they have the following major shortcomings:

1. Creating sets of references or analog sets is not a trivial process because it involves a relevance analysis of previous projects. Some previous projects may not be fully relevant to the current one.
2. Many projects, especially in the area of research and development, may not have any relevant historical data.

ECM is a practical schedule network analysis technique as well as a method of modeling and visualizing of uncertainties. ECM comes from the idea that regardless of how well project schedules are developed, some events may occur that will alter the schedule. Identifying and managing these events or event chains (when one event causes another event) is the focus of ECM. The methodology focuses on events rather than a continuous process for changing project environments because with continuous problems within a project it is possible to detect and fix them before they have a significant effect upon the project.

Project scheduling and analysis using ECM includes the following steps:

1. Create a project schedule model using *best-case scenario estimates* of duration, cost, and other parameters. In other words, project managers should use estimates that they are comfortable with, which in many cases will be optimistic. Because of a number of cognitive and motivational factors, including the planning fallacy or the optimism, overconfidence, and confirmation biases, project managers tend to create optimistic estimates even when they are trying not to do so. In most cases, it is impossible to prevent project managers from defining overly optimistic schedules.
2. Define a list of events and event chains with their probabilities and impacts on activities, resources, lags, and calendars. This list of events can be represented in the form of a risk breakdown structure. These events should be identified

separately (separate time, separate meeting, different experts, different planning department) from the schedule model. It helps to avoid the confirmation bias or a situation where expectations about the project (cost, duration, etc.) affect the event identification.

3. Perform a quantitative analysis using Monte Carlo simulations. The results of Monte Carlo analysis are statistical distributions of the main project parameters (cost, duration, and finish time) as well as similar parameters associated with particular activities. Based on such statistical distributions, it is possible to determine the chance that the project or activity will be completed on a certain date and within a certain cost. The results of Monte Carlo analysis can be expressed on a project schedule as percentiles of start and finish times for activities.
4. Perform a sensitivity analysis as part of the quantitative analysis. Sensitivity analysis helps identify the crucial activities and critical events and event chains. Crucial activities and critical events and event chains have the most effect on the main project parameters. Reality checks may be used to validate whether the probabilities of the events are defined properly.
5. Repeat the analysis on a regular basis during the course of a project based on actual project data and include the actual occurrence of certain risks. The probability and impact of risks can be reassessed based on actual project performance measurement. It helps to provide up-to-date forecasts of project duration, cost, or other parameters.

5. Basic Principles of ECM

ECM is based on six major principles. The first principle deals with single events, the second principle focuses on multiple related events or event chains, the third principle defines rules for visualization of the events or event chains, the fourth and fifth principles deal with the analysis of the schedule with event chains, and the sixth principle defines project performance measurement techniques with events or event chains. ECM is not a completely new technique as it is based on existing quantitative methods such Monte Carlo simulation and the Bayesian theorem.

Some of the terminology used in ECM comes from the field of quantum mechanics (Nielsen and Chuang 2000). In particular, quantum mechanics introduces the notions of excitation and entanglement, as well as grounded and excited states (Shankar 1994; Manoukian 2006). The notion of event subscription and multicasting is used in object-oriented software development as one of the types of interactions between objects (Fowler 2002; Martin 2002).

5.1. Principle 1: Moment of Event and Excitation States

An activity in most real-life processes is not a continuous and uniform procedure. Activities are affected by external events that transform them from one *state* to another. The idea of a state means that an activity will be performed differently as a response to the event. This process of changing the state of an activity is called *excitation*. In quantum mechanics, the idea of excitation is used to describe an elevation in energy level above an arbitrary baseline energy state. In ECM, excitation indicates that something has changed the manner in which an activity is performed. For example, an activity may require different resources, take a longer time, or must be performed under different conditions. As a result, this may alter the activity's cost and duration.

The original or planned state of the activity is called a *ground state*. Other states, associated with different events, are called *excited states* (Fig. 1). For example, in the middle of an activity requirements change. As a result, a planned activity must be restarted. Similarly to quantum mechanics, if significant event affects the activities, it will dramatically affect the property of the activity, for example, cancel the activity.

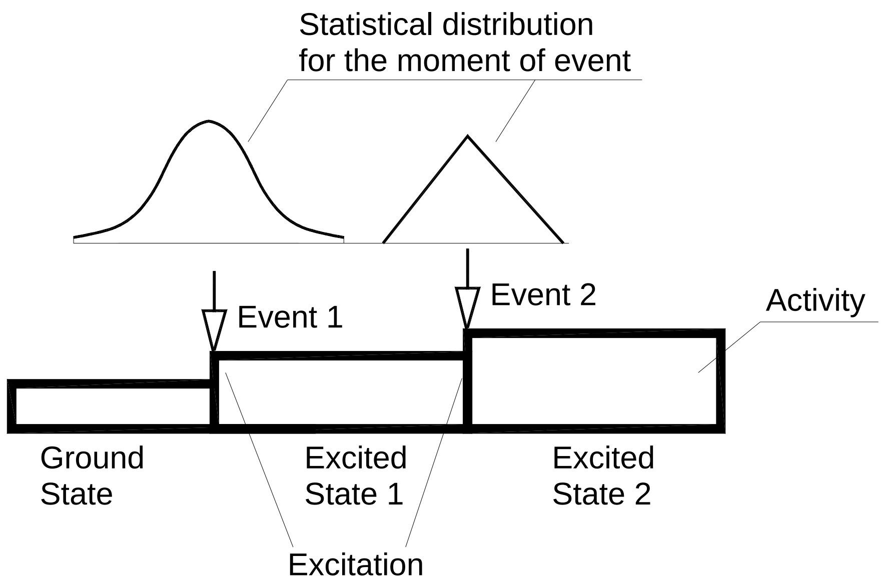


Figure 1: Events Cause an Activity to Move to Transform from Ground States to Excited States

Events can affect one or many activities, material or work resources, lags, and calendars. Such *event assignment* is an important property of the event. An example of an event that can be assigned to a resource is an illness of a project team member. This event may delay all activities that this resource is assigned to. Similarly resources, lags, and calendars may have different grounded and excited states. For example, the event "Bad weather condition" can transform a calendar from a ground state (five working days per week) to an excited state: nonworking days for the next 10 days.

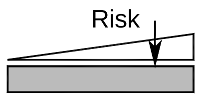
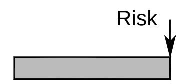
Each state of activity in particular may *subscribe* to certain events. This means that an event can affect the activity only if the activity is subscribed to this event. For example, an assembly activity has started outdoors. In the ground state the activity is subscribed to the external event "Bad 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.

An event subscription has a number of properties, among which are the following:

- *Impact of the event* is the property of the state rather than event itself. It means that the impact can be different if an activity is in a different state. For example, an activity is subscribed to the external event "Change of requirements." In the ground state of the activity, this event can cause a 50 percent delay of the activity. However, if the event has occurred, the activity is transformed to an excited state. In an excited state if "Change of requirement" is occurs again, it will cause only a 25 percent delay of the activity because management has performed certain actions when the event first occurred.
- *Probability of occurrence* is also a property of subscription. For example, there is a 50 percent chance that the event will occur. Similarly to impact, the probability of occurrence can be different for different states.
- *Excited state:* the state the activities are transformed to after an event occurs
- *Moment of event:* the actual moment when the event occurs during the course of an activity. The moment of an event can be absolute (a 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 (Fig. 1). Very often the overall impact of the event depends on when an event occurs. For example, the moment of the event can affect the total duration of activity if it is restarted or cancelled. Table 2 presents an example how one event (restart activity) with a probability of 50 percent can affect one activity. Monte Carlo simulation was used to perform the analysis; the original activity duration is five days.

Table2

Moment of Risk Significantly Affects Activity Duration

	Risk most likely occurs at the end of the activity (triangular distribution for moment of risk)	Equal probability of the risk occurrence during the course of the activity	Risk occurs only at the end of the activity
			
Mean activity duration with the event occurring	5.9 days	6.3 days	7.5 days
90th percentile	7.9 days	9.14 days	10 days

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 the activity to the ground state.

The impacts of events are characterized by additional parameters. For example, a parameter associated with the impact “Fixed delay of activity” is the actual duration of the delay.

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 an event will be proportionally reduced. The impact of events associated with a calendar changes both working and nonworking times.

One event can have multiple impacts at the same time. For example, a “Bad weather” event can cause an increase of cost and duration at the same time. Event can be *local*, affecting a particular activity, group of activities, lags, resources, and calendars, or *global*, affecting all activities in the project.

5.2. Principle 2: 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 (Fig. 2). Here is an example of an event chain ripple effect:

1. Requirement changes cause a delay of an activity
2. To accelerate the activity, the project manager diverts resources 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.

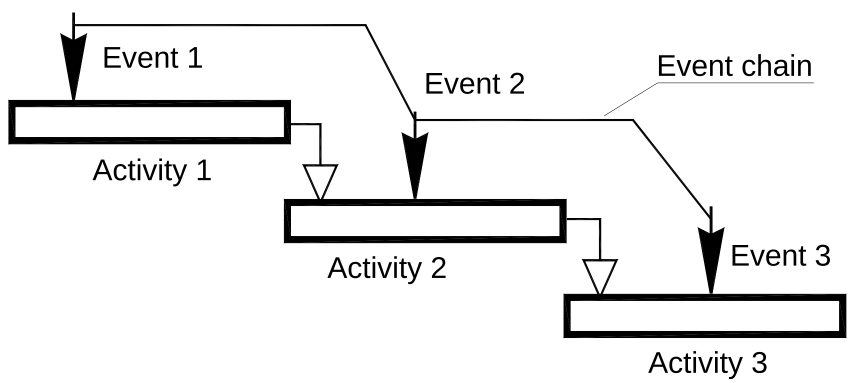


Figure 2: Example of an Event Chain

Event chains are defined using event impacts called, for example, "execute event affecting another activity group of activities, change resources, or update calendar." Here is how the aforementioned example can be defined using ECM:

1. The event "Requirement change" will transform the activity to an excited state that 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 *sender or trigger*. The sender 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.

The actual effect of an event chain on a project schedule can be determined as a result of quantitative analysis. The example here illustrates the difference between event chain and independent events (Fig. 2 and Table 3). Monte Carlo simulations were used to perform the analysis. The project includes three activities of five days each. Each activity is affected by the event "restart activity" with a probability of 50 percent.

Table 3

Event Chain Leads to Higher Project Duration Compared to the Series of Independent Events with the Same Probability

	Independent Events in Each Activity	Event Chain
Mean duration	18.9 days	19.0 days
90th percentile (high estimate of duration)	22.9 days	24.7 days

Below are four different strategies for dealing with risks (Project Management Institute 2009) defined using ECM's event chain principle:

1. *Risk acceptance*: Excited state of the activity is considered to be acceptable
2. *Risk transfer*: Represents an event chain; the impact of the original event is an execution of the event in another activity (Fig. 3)

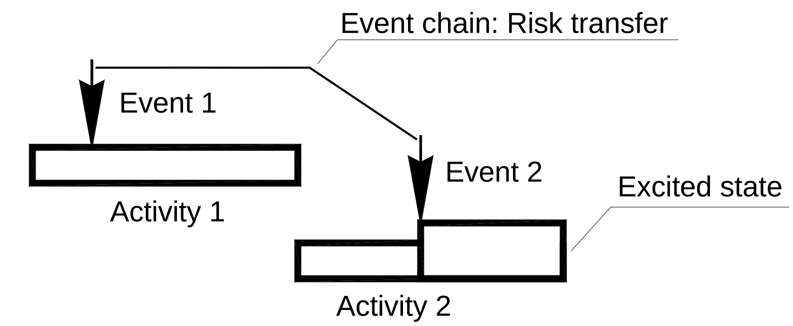


Figure 3: Event Chain: Risk Transfer

3. *Risk mitigation*: Represents an event chain; the original event transforms an activity from a ground state to an excited state, which is subscribed to a mitigation event; the mitigation event that occurs in excited state will try to transform activities to a ground state or a lower excited state (Fig. 4)

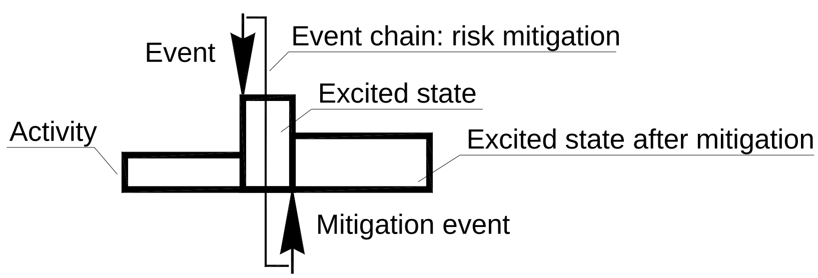


Figure 4: Event Chain: Risk Mitigation

4. *Risk avoidance*: The original project plan is built in such a way that none of the states of the activities are subscribed to this event

5.3. Principle 3: Event Chain Diagrams and State Tables

Complex relationships between events can be visualized using event chain diagrams (Fig. 5). Event chain diagrams are presented on a Gantt chart according to the specification, which is a set of rules that can be understood by anybody using this diagram.

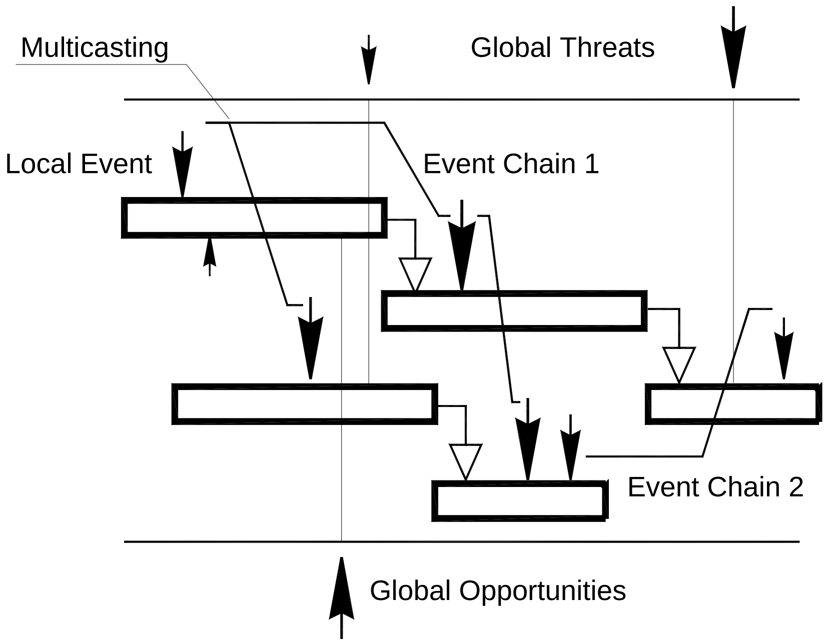


Figure 5: Example of an Event Chain Diagram

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. A sender event with multiple connecting lines to receivers represents multicasting
5. Events affecting all activities (global events) are shown outside the Gantt chart. Threats are shown at the top of the diagram. Opportunities are shown at the bottom of the diagram.

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 the 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 Fig. 1); the height of the state’s rectangle represents the relative impact of the event
5. Statistical distributions for the moment of an event can be shown together with the event arrow (see Fig. 1)
6. Multiple diagrams may be required to represent different event chains for the same schedule
7. Different colors can be used to represent different events (arrows) and connecting lines associated with different chains.

The central purpose of event chain diagrams is not to show all possible individual events. Rather, event chain diagrams can be used to understand the relationship between events. Therefore, it is recommended the event chain diagrams be used only for the most significant events during the event identification and analysis stage. Event chain diagrams can be used as part of the risk identification process, particularly during brainstorming meetings. Members of project teams can draw arrows between associated activities on the Gantt chart. Event chain diagrams can be used together with other diagramming tools.

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. A 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.

Table 4 shows an example of a state table for a software development activity. The ground state of the activity is subscribed to two events: “architectural changes” and “development tools issue.” If either of these events occurs, it transforms the activity to a new excited state called “refactoring.” “Refactoring” is subscribed to another event: “minor requirement change.” Two previous events are not subscribed to the refactoring state and therefore cannot reoccur while the activity is in this state.

Table 4

Example of the State Table for Software Development Activity

	Event 1: Architectural Changes	Event 2: Development Tools Issue	Event 3: Minor Requirements Change
Ground state	*Probability*: 20% *Moment of event*: any time *Excited state*: refactoring *Impact*: delay 2 weeks	*Probability*: 10% *Moment of event*: any time *Excited state*: refactoring *Impact*: delay 1 week	
Excited state: refactoring			*Probability*: 10% *Moment of event*: beginning of the state *Excited state*: minor code change *Impact*: delay 2 days
Excited state: minor code change			

5.4. Principle 4: 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 input data for analysis.

In most real-life projects, even if all the possible risks are defined, there are always some uncertainties or *fluctuations* in duration and cost. To take these fluctuations 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, because this will cause a double count of the project's risk.

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. Success rates are calculated based on the number of simulations where the event “Cancel activity” or “Cancel group of activities” occurred. Probabilistic and conditional branching, calculating the chance that the project will be completed before the deadline, probabilistic cash flow, and other types of analysis are performed in the same manner as with a classic Monte Carlo analysis of the project schedules. The probability of an activity’s existence is calculated based on two types of inputs: probabilistic and conditional branching and the number of trials where an activity is executed as a result of a “Start activity” event.

5.5. Principle 5: 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 to 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, as shown in Figure 6, which represents events affecting cost in the schedule shown in Figure 2. Event 1 occurs in Task 1 (probability 47 percent) and Task 3 (probability 41 percent). Event 3 occurs in Task 3 (probability 50 percent), and Event 2 occurs in Task 2 (probability 10 percent). All events are independent. The impact of all these events is “restart task.” All activities have the same variable cost $6,667; therefore, the total project cost without risks and uncertainties equals $20,000. The total project cost with risks as a result of analysis equals $30,120. The cost of Event 1 will be $5,300, Event 2 will be $3,440, and Event 3 will be $1,380. Because this schedule model does not include fluctuations for the activity cost, the sum of event costs equals the difference between the original cost and the cost with risks and uncertainties ($10,120).

	Tast 1	Task 2	Task 3	K	Event Cost
Event 1	47%		41%	0.77	5,300
Event 3			50%	0.50	3.440
Event 2		10%		0.20	1,380

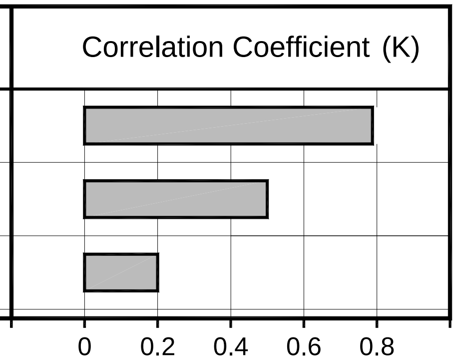


Figure 6: Critical Events and Event Chains

5.6. Principle 6: 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 ECM. 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.

But what should one do if the activity is partially completed and certain events are assigned to the activity? If the event has already occurred, will it occur again? Or vice versa, if nothing has occurred yet, will it happen?

There are four distinct approaches to this problem:

1. Probabilities of a *random* event in a 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 a “bad weather” event during a course of one-year construction project can occur 10 times. After a half year, bad weather has occurred eight times. For the remaining half year, the event could still occur five times. This approach is related to the psychological effect called the “gambler’s fallacy,” or the belief that a successful outcome is due after a run of bad luck (Tversky and Kahneman 1971).
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. For example, activity “software user interface development” takes 10 days. Event “change of requirements” can occur any

time during a course of activity and can cause a delay (a uniform distribution of the moment of event). Fifty percent of the work is completed within five days. If the probabilistic moment of the event happens to be between the start of the activity and five days, this event will be ignored (and not cause any delay). In this case, the probability that the event will occur will be reduced and eventually become zero, when the activity approaches completion.

3. Probabilities of events can be calculated based on original probability and historical data related to the accuracy of previous assessments of the probability. In this case the probability of an event can be calculated using the 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. For example, the event “change of requirements” has occurred. It may occur again depending on many factors, such as how well these requirements are defined and interpreted and the particular business situation. To implement this approach excited state activities should be explicitly subscribed or not subscribed to certain events. For example, a new excited state after the event “change of requirements” may not be subscribed to this event again, and as a result this event will not affect the activity a second time.

The chance that the project will meet a specific deadline can be monitored and presented on the chart shown in Figure 7. The chance changes constantly as a result of various events and event chains. In most cases, this chance is declining over time. However, risk response efforts, such as risk mitigations, can increase the chance of successfully meeting a project deadline. The chance of the project meeting the deadline is constantly updated as a result of the quantitative analysis based on the original assessment of the project uncertainties and the actual project performance data.

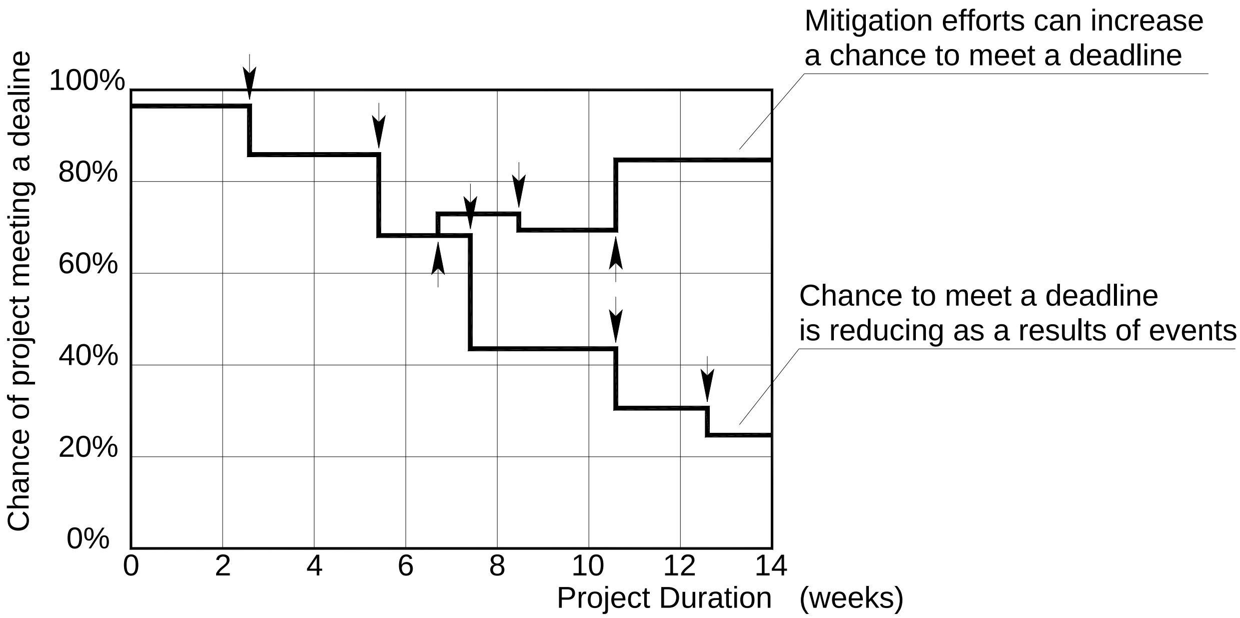


Figure 7: Monitoring Chance of Project Completion on a Certain Date

6. 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 the U.S. 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 into their ERM processes.

ECM is designed to mitigate the negative impact of cognitive and motivational biases related to the estimation of project uncertainties:

- The task duration, start and finish time, cost, and other project input parameters are influenced by motivational factors such as total project duration to a much greater extent than events and event chains. This occurs because events cannot be easily translated into duration, finish time, and so on. Therefore, ECM can help to overcome negative effects of selective perception, in particular confirmation bias and, to a certain extent, the planning fallacy and overconfidence.

- ECM relies on the estimation of duration based on best-case scenario estimates and does not necessarily require low, base, and high estimations or statistical distributions and, therefore, mitigates the negative effect of anchoring.
- The probability of events can be easily calculated based on historical data, which can mitigate the effect of the availability heuristic (Tversky and Kahneman. 1973). Compound events can be easy broken into smaller events. The probability of events can be calculated using a relative frequency approach where the probability equals the number an event occurs divided by the total number of possible outcomes. In classic Monte Carlo simulations, the statistical distribution of input parameters can also be obtained from the historical data; however, the procedure is more complicated and is often not used in practice.

ECM allows taking into account factors that are not analyzed by other schedule network analysis techniques: moment of event, chains of events, delays in events, execution of mitigation plans, and others. A complex relationship between different events can be visualized using event chain diagrams and state tables, simplifying event and event chain identification.

Finally, ECM includes techniques designed to incorporate new information about actual project performance into an original project schedule and therefore constantly improve the accuracy of the schedule during the course of a project. ECM offers a practical solution for resource leveling, managing mitigation plans, correlations between events, and other activities.

ECM is a practical approach to scheduling software projects that contain multiple uncertainties. A process that utilizes this methodology can be easily used in different projects, regardless of size and complexity. Scheduling using ECM is an easy-to-use process, which can be can be performed using off-the-shelf software tools. Although ECM is a relative new approach, it is actively used in many organizations, including large corporations and government agencies.

References

Arlow, J., and I. Neustadt. 2003. *Enterprise Patterns and MDA: Building Better Software with Archetype Patterns and UML*. New York: Addison-Wesley Professional.

Booch, G., J. Rumbaugh, and I. Jacobson. 2005. *The Unified Modeling Language User Guide*. 2nd edition. New York: Addison-Wesley Professional.

Cho, J. G., and B. J. Yum. 1964. An Uncertainty Importance Measure of Activities in PERT Networks. International Journal of Production Research 12: 460–470.

Clemen, R. T. 1996. *Making Hard Decisions.* 2nd edition. Pacific Grove, CA: Brooks/Cole Publishing.

Flyvbjerg, B., 2006. From Nobel Prize to Project Management: Getting Risks Right. *Project Management Journal* (August): 5–15.

Fowler, M. 2002. *Patterns of Enterprise Application Architecture.* New York: Addison-Wesley Professional.

Goldratt, E. 1997. *Critical Chain.* Great Barrington, MA: North River Press.

Goodpasture, J. 2004. *Quantitative Methods in Project Management.* Boca Raton, FL: J. Ross Publishing.

Hill, G. W. 1982. Group versus Individual Performance: Are N + 1 Heads Better than One? *Psychological Bulletin* 91: 517–539.

Hillson, D. 2002. Use a Risk Breakdown Structure (RBS) to Understand Your Risks. In Proceedings of the Project Management Institute Annual Seminars & Symposium, October 3–10, 2002, San Antonio, TX.

Hulett, D. T. 1996. Schedule Risk Analysis Simplified. *PM Network* (July): 23–30.

Hulett, D. T. 2000. Project Schedule Risk Analysis: Monte Carlo Simulation or PERT?”*PM Network* (February): 43.

Hulett, D.T., and D. Hillson. 2006. Branching Out: Decision Trees Offer a Realistic Approach to Risk Analysis. *PM Network* (May): 36–40.

Kendrick, T. 2003. *Identifying and Managing Project Risk: Essential Tools for Failure-Proofing Your Project.* New York: AMACOM.

MacCrimmon, K. R., and C. A. Ryavec. 1962. An Analytical Study of the PERT Assumptions. Research Memorandum RM-3408-PR. RAND Corporation, Santa Monica, CA, 1962.

Manoukian, E. B. 2006. *Quantum Theory: A Wide Spectrum.* New York: Springer.

Martin, R. C. 2002. *Agile Software Development: Principles, Patterns, and Practices.* New York: Prentice Hall.

Nielsen, M. A., and I. L. Chuang. 2000. *Quantum Computation and Quantum Information.* Cambridge: Cambridge University PressProject Management Institute. 2013. *A Guide to the Project Management Body of Knowledge (PMBOK® Guide).* 5th edition. Newtown Square, PA: Project Management Institute.

Quattrone, G. A., C. P. Lawrence, D. L. Warren, K. Souze-Silva, S. E. Finkel, and D. E. Andrus. 1984. Explorations in Anchoring: The Effects of Prior Range, Anchor Extremity, and Suggestive Hints. Unpublished manuscript. Stanford University, Stanford, CA.

Rose, P. 2001. *Risk Analysis and Management of Petroleum Exploration Ventures.* AAPG Methods in Exploration Series 12. Tulsa, OK: American Association of Petroleum Geologists.

Scheinin, W., and R. Hefner. 2005. A Comprehensive Survey of Risk Sources and Categories. In *Proceedings of Space Systems Engineering and Risk Management Symposiums*, Los Angeles, CA, 337–350.

Schuyler, J. 2001. *Risk and Decision Analysis in Projects.* 2nd edition. Newton Square, PA: Project Management Institute.

Shankar, R. 1994. *Principles of Quantum Mechanics.* 2nd edition. New York: Springer.

Srinivasan, M., W. Best, and S. Chandrasekaran. 2007. Warner Robins Air Logistics Center Streamlines Aircraft Repair and Overhaul. *Interfaces* 37(1): 7–21.

Tversky, A., and D. Kahneman. 1971. Belief in the Law of Small Numbers. *Psychological Bulletin* 76: 105–110Tversky, A., and Kahneman. 1973. Availability: A Heuristic for Judging Frequency and Probability. *Cognitive Physiology* 5: 207–232Tversky, A., and D. Kahneman. 1974. Judgment under Uncertainty: Heuristics and Biases. *Science* 185: 1124–1130Virine, L., and L. Rapley. 2003. Visualization of Probabilistic Business Models. In Proceedings of 2003 Winter Simulation Conference, New Orleans, LA.

Virine, L., and J. McVean. 2004. Visual Modeling of Business Problems: Workflow and Patterns. In Proceedings of 2004 Winter Simulation Conference, Washington, DCWilliams, T. 2004. Why Monte Carlo Simulations of Project Networks Can Mislead. *Project Management Journal* (September): 53–61.

Wilson, P., and S. Holt. 2007. Lean and Six Sigma—A Continuous Improvement Framework: Applying Lean, Six Sigma, and the Theory of Constraints to Improve

Project Management Performance. In Proceedings of the 2007 PMI College of Scheduling Conference, April 15–18, Vancouver, BC.

Wysocki, R. K., and R. McGary. 2003. *Effective Project Management: Traditional, Adaptive, Extreme.* 3rd edition. Toronto: John Wiley & Sons Canada.

Author's Biography

Dr. Lev Virine. P.Eng., 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. His 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. He is the author of more than 50 papers and two books on project risk management and analysis. He received his doctoral degree in engineering and computer science from Moscow State University.