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Event Chain Methodology In Details

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Abstract

This paper is a detailed description of event chain methodology: schedule network analysis and an uncertainty modeling technique for project management. Event chain methodology focuses on identifying and managing the events and event chains that affect projects.

Event chain methodology improves the accuracy of project planning simplifying the modeling and analysis of uncertainties in the project schedules. As a result, it helps to mitigate the negative impact of cognitive and motivational biases related to project planning.

Introduction

Virtually all projects are affected by multiple risks and uncertainties. These uncertainties are difficult to identify and analyze which can lead to inaccurate project schedules. Due to such uncertainties, most projects do not proceed exactly as planned. In many cases, they lead to project delays, cost overruns, and even project failures. Therefore, creating accurate project schedules, which reflect potential risks and uncertainties remains one of the main challenges in project management.

Flyvbjerg, Holm and Buhl (2002; 2004; 2005) reviewed technical, psychological and political explanations for inaccurate scheduling and forecasting. They found that strategic misrepresentation under political and organizational pressure expressed by project planners as well as cognitive biases play major role in inaccurate forecasting. In other words project planner either unintentionally due to some psychological biases or intentionally under organizational pressure come up with wrong estimations. These estimations are used in project schedules and lead to inaccurate forecasts.

Among the cognitive biases related to project forecasting are the planning fallacy (Buehler, Griffin, & Ross, 1994) and the optimism bias (Lovallo & Kahneman, 2003). According to one explanation, project managers do not account for risks or other factors that they perceive as lying outside of the specific scope of a project. Project managers also may discount multiple improbable high-impact risks because each one has very small probability of occurring. Tversky and Kahneman (1974) have proposed that limitations in human mental processes cause people to employ various simplifying strategies to ease the burden of mentally processing information when making judgments and decisions. During the planning stage, project managers rely on heuristics or rules of thumb to make their estimates. Under many circumstances, heuristics lead to predictably faulty judgments or cognitive biases (McCray, Purvis, & McCray, 2002). The availability heuristic (Tversky & Kahneman, 1973; Carroll, 1978) is a rule of thumb with which decision makers assess the probability of an event by the ease with which instances or occurrences can be brought to mind. For example, project managers sometimes estimate task duration based on similar tasks that have been previously completed. If they base their judgments on their most or least successful tasks, this can cause inaccurate estimations. The anchoring heuristic refers to the human tendency to remain close to the initial estimate. Anchoring is related to an overconfidence in estimation of probabilities – a tendency to provide overly optimistic estimates of uncertain events. Arbitrary anchors can also affect people's estimates of how well they will perform certain problem solving tasks (Cervone & Peake, 1986).

Problems with estimation are also related to selective perception - the tendency for expectations to affect perception (Plous, 1993). Sometimes selective perception is referred, as "What I see is what I want to see". One of the biases related to selective perception is the confirmation bias. This is the tendency of decision makers to actively seek out and assign more weight to evidence that confirms their hypothesis, and to ignore or underweight evidence that could discount their hypothesis (Watson, 1960; Evans, Barston & Pollard, 1983).

Another problem related to improving the accuracy of project schedules is the complex relationship between different uncertainties. 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.

Finally, the accuracy of project scheduling can be improved by constantly refining the original plan using actual project performance measurement (Wysocki & 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 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 has been proposed as an attempt the satisfy the following objectives related to project scheduling and forecasting by:

1. Mitigating negative the effects of motivational and cognitive biases and improve the accuracy of estimating and forecasting.
2. 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.
3. Performing more accurate quantitative analysis while accounting for such factors as the relationships between different events and the actual moment of events.

4. Providing a flexible framework for scheduling which includes project performance measurement, resource leveling, execution of migration plans, correlations between risks, repeated activities, and other types of analysis.

Existing techniques as foundations for Event chain methodology

The accuracy of project scheduling with risks and uncertainties can be improved by applying a process or workflow tailored for the particular project or set of projects (portfolio) rather than using one particular analytical technique. According to the PMBOK® Guide (Project Management Institute, 2004) such processes can include methods of identification of uncertainties, qualitative and quantitative analysis, risk response planning, and risk monitoring and control. The actual processes may involve various tools and visualization techniques.

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 which 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. 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. They provide three choices for each risk where the project manager can select when the risk can manifest itself during the project: a) at anytime 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 in to one document. Each risk in their risk breakdown structure includes what they call a "frequency" or rank property.

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, 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 & Ryavec, 1962; Cho & 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 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. In this respect, Monte Carlo 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 suffers from the anchoring heuristic: when project managers comes up with a certain base duration, he or she tends to stick closely to it and build a distribution around it regardless (Quattrone et al., 1984)

Another approach to project scheduling with uncertainties was developed by Goldratt (1997). Goldratt applied the theory of constraints to project management. The cornerstone of the theory is 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 critical chain has proved to be a very effective methodology for a wide range of projects (Srinivasan, Best, & Chandrasekaran, 2007; Wilson & Holt, 2007), it is not fully embraced by many project managers because it requires changing of established processes particularly with regards to the management of project buffers and resource constrained chains.

A number of quantitative risk analysis techniques dealing with specific issues related to uncertainty management. Decisions tree (Hulett and Hillson, 2006) helps to calculate expected value of 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 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 & Neustadt, 2003; Booch, Rumbaugh, & Jacobson, 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 & Rapley, 2003; Virine & McVean, 2004). Uncertainties associated with project variables, relationships between uncertain variables and result 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 include 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.

Overview of event chain methodology

Event chain methodology is a practical schedule network analysis technique as well as a method of modeling and visualizing of uncertainties. Event chain methodology comes from the notion that regardless of how well project schedules are developed, some events may occur that will alter it. Identifying and managing these events or event chains (when one event causes another event) is the focus of event chain methodology. 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 events chain methodology 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 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 affect on the main project

parameters. Reality checks may be used to validate whether the probability 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.

Basic Principles of Event Chain Methodology

Event chain methodology 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 deals with the analysis of the schedule with event chains, and the sixth principle defines project performance measurement techniques with events or event chains. Event chain methodology is not a completely new technique as it is based on existing quantitative methods such Monte Carlo simulation and Bayesian theorem.

Some of the terminology used in event chain methodology comes from the field of quantum mechanics. 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).

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 notion of state means that 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 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. 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* (Figure 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 affect the activities, it will dramatically affect the property of the activity, for example cancel the activity.

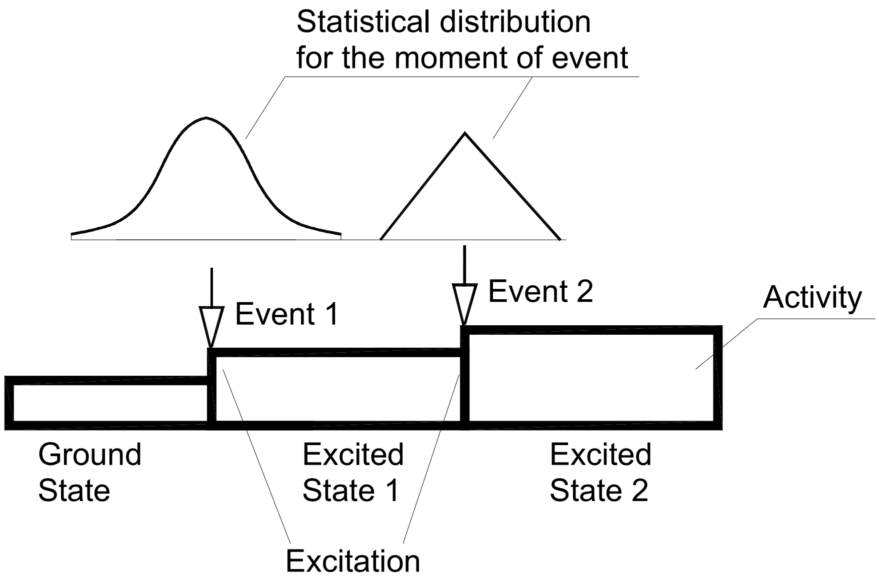


Figure 1. Events cause activity to move to transform from ground states to excited states

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 of all activities 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 (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. It 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. 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. Among them are:

- *Impact of the event* is the property of the state rather than event itself. It means that 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 its ground state of the activity, this event can cause a 50% 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% delay of the activity because management has performed certain actions when event first occurred.

- *Probability of occurrence* is also a property of subscription. For example, there is a 50% chance that the event will occur. Similarly to impact, 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 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 1). Very often, the overall impact of the event depends on when an event occurs. For example, the moment of the event can affect total duration of activity if it is restarted or cancelled. Below is an example how one event (restart activity) with a probability of 50% can affect one activity (Table 1). Monte Carlo simulation was used to perform the analysis. Original activity duration is 5 days:

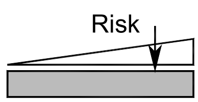
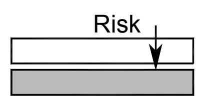
	Risk most likely occurs at the end of the activity (triangular distribution for moment of risk)	Equal probability of the risk occurrence during the course of activity	Risk occurs only ay the end of activity
			
Mean activity duration with the event occurred	5.9 days	6.3 days	7.5 days
90th percentile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

Table 1: Moment of risk significantly affect activity duration

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.

Impacts of an event affecting activities, a group of activities, or lags can be:

- Delay activity, split activity, or start activity later; delays can be defined as fixed (fixed period of time) and relative (in percent of activity duration); delay also can be negative
- Restart activity
- Stop activity and restart it later if required
- End activity
- Cancel activity or cancel activity with all successors, which is similar to end activity except activity will be marked as canceled to future calculation of activity's success rate
- Fixed or relative increase or reduction of the cost

- Redeploy resources associated with activity; for example a resource can be moved to another activity
- Execute events affecting another activity, group of activities, change resource, or update a calendar. For example, this event can start another activity such as mitigation plan, change the excited state of another activity, or update event subscriptions for the excited state of another activity

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.

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.

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.

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 (Figure 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.

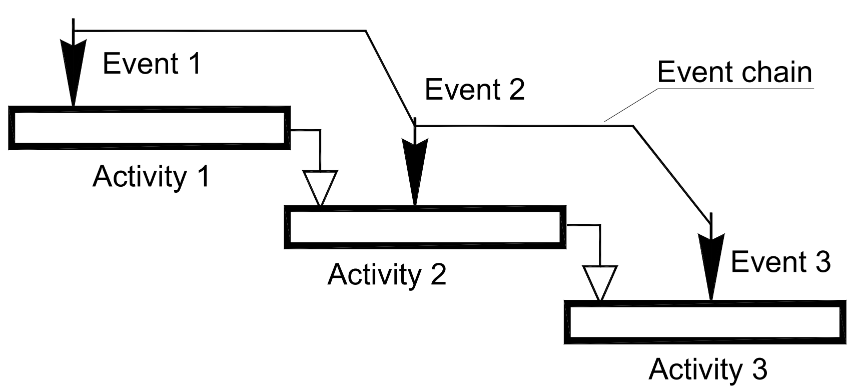


Figure 2. Example of event chain

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

1. The event "Requirement change" 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 *sender*. 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 below illustrates the difference between event chain and independent events (Figure 2 and Table 2). Monte Carlo simulations were used to perform the analysis. The project includes three activities of 5 days each. Each activity is affected by the event "restart activity" with a probability of 50%.

	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

Table 2. Event chain leads to higher project duration compared to the series of independent events with the same probability.

Below are four different strategies for dealing with risks (Project Management Institute, 2004) defined using event chain methodology'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 (Figure 3).

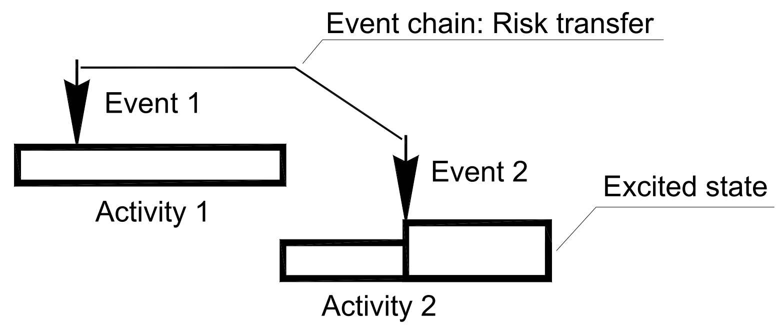


Figure 3. Event chain: risk transfer

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 (Figure 4).

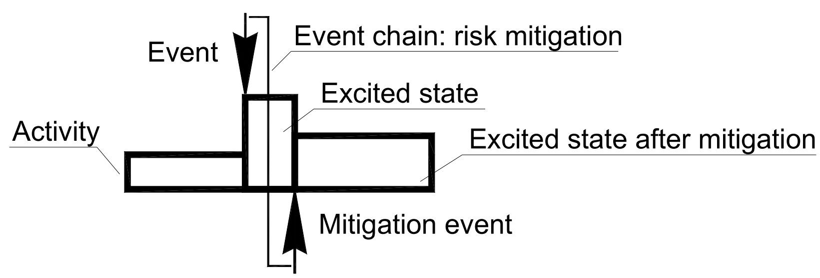


Figure 4. Event chain: Risk mitigation

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

Principle 3: Event chain diagrams and state tables

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

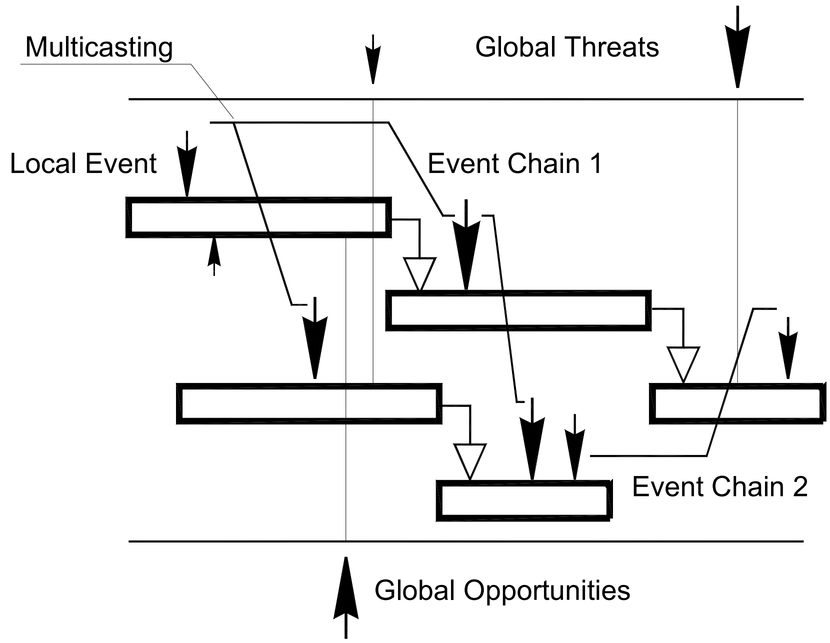


Figure 5. Example of event chain diagram

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. A sender event with multiple connecting lines to receivers represents multicasting.
5. 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.

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 1). 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 1).
6. Multiple diagrams may be required to represent different event chains for the same schedule.
7. Different colors can be use 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 with 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. 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.

Example of state table for a software development activity is shown on Table 3. The ground state of the activity is subscribed to two events: "architectural changes" and "development tools issue". If either of these events occur, they transform 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.

	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			

Table 3: Example of the state table for software development activity

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 an 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, as this will cause a double-count of the project's risk.

Monte Carlo simulation process for Event chain methodology has a number of specific features. Before the sampling process starts all event chains should be identified. Particularly, all sender and receiver events should be identified through an analysis of state tables for each activity. Also, if events are assigned to resources, they need to be reassigned to activities based on resource usage for each particular activity. For example, if manager is equally involved in two activities, a risk "Manager is not familiar with technology" with a probability 6% will be transferred to both activities with probability of 3% for each activity. Events assigned to summary activities will be assigned to each activity in the group. Events assigned to lags are treated the same way as activities.

Each trial of the Monte Carlo simulation includes the following steps specific to Event chain methodology:

1. Moments of events are calculated based of statistical distribution for moment of event on each state.
2. Determines if sender events have actually occurred at this particular trial based on probability of the sender.
3. Determines if probabilities of receiver events are updated based on sender event. For example, if a sender event unconditionally causes a receiver event, probability of a receiver event will equal 100%.
4. Determines if receiver events have actually occurred; if a receiver event is a sender event at the same time, the process of determining probabilities of receiver events will continue.
5. The process will repeat for all ground and excited states for all activities and lags.
6. If an event that causes the cancellation of an activity occurs, this activity will be identified as canceled and the activity's duration and cost will be adjusted.
7. If an event that causes the start of another activity occurs, such as execution of mitigation plan, the project schedule will be updated for the particular trial. Number of trials where the particular activity is started will be counted.
8. The cumulative impact of the all events on the activity's duration and cost will be augmented by accounting for fluctuations of duration and cost.

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 project will be completed before deadline, probabilistic cashflow and other types of analysis are performed in the same manner as with a classic Monte Carlo analysis of the project schedules. Probability of activity existence is calculated based to two types inputs: probabilistic and conditional branching and number of trials where an activity is executed as a result of a "Start activity" event.

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 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 event chains based on cost and duration may differ. Because the same event may affect different activities and have different impact of these activities, the goal is to measure a cumulative impact of the event on the project schedule. Critical event chains based on duration are calculated using the following approach. For each event and event chain *on each trial* the cumulative impact of event on project duration (D_{cum}) is calculated based on the formula:

$$D_{cum} = \sum_{i=1}^{n} (D_i^{'} - D_i)*k_i$$

where $\boldsymbol{n}$ is number of activities in which this event or event chain occurs, D_i is the original duration of activity $\boldsymbol{i}$ and $D_i^{'}$ is the duration of activity $\boldsymbol{i}$ with this particular event taken into an account, k_i is the Spearman rank order correlation coefficient between total project duration and duration of activity $\boldsymbol{i}$. If events are assigned to calendars, $D_i^{'}$ is the duration of activity with the calendar used as a result of the event.

Cumulative impact of event on cost (C_{cum}) is calculated based on formula:

$$C_{cum} = \sum_{i=1}^{n} (C_i^{'} - C_i)$$

where C_i is the original cost of activity and $C_i^{'}$ is the activity cost taking into account the this particular event.

Spearman rank order correlation coefficient is calculated based on the cumulative effect of the event on cost and duration (C_{cum} and D_{cum}) and total project cost and duration.

One of the useful measures of the impact of the event is *event cost* or additional expected cost, which would be added to project as a result of the event. Event cost is not a mitigation cost. Event cost can be used as decision criteria for selection of risk mitigation strategies. Mean event cost C_{event} is normalized cumulative effect of the event on cost and calculated according to the following formula:

$$C_{event} = (C_{project}' - C_{project}) * k_{event} / \sum_{i=1}^{n} k_i$$

where $C_{project}'$ is the mean total project cost with risks and uncertainties, $C_{project}$ is the mean total project cost without taking into account events, but with accounting for fluctuations defined by statistical distributions, k_{event} is the correlation coefficient between total project cost and cumulative impact of the event on cost on the particular activity, k_i is correlation coefficient between total cost and cumulative impact of the event on the activity ***i***. Event cost can be calculated based on any percentile associated with statistical distribution of project cost.

Critical events or critical event chains can be visualized using a sensitivity chart, as shown on Figure 6. This chart represents events affecting cost in the schedule shown on Figure 2. Event 1 occurs in Task 1 (probability 47%) and Task 3 (probability 41%). Event 3 occurs in Task 3 (probability 50%) and Event 2 occurs in Task 2 (probability 10%). 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. Total project cost with risks as a result of analysis equals $30,120. 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, sum of event costs equals difference between original cost and cost with risks and uncertainties ($10,120).

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

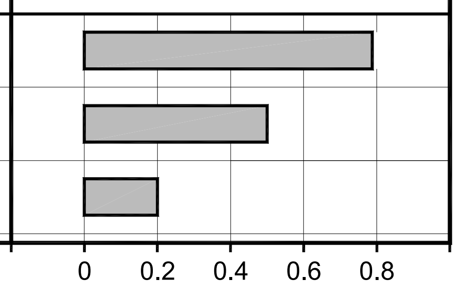


Figure 6. Critical events and event chains

Critical events and events chains can be used to perform a reality check. If the probability and outcome of events are properly defined, the most important risks based on subjective expert judgment should be critical risks as a result of quantitative analysis.

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 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.

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 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 10 times. After a half year, bad weather has occurred 8 times. For the remaining half year, the event could still occur 5 times. This approach is related to psychological effect called "gambler's fallacy" or 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 (auniform distribution of the moment of event). 50% of work is completed within 5 days. If the probabilistic moment of event happens to be between the start of the activity and 5 days, this event will be ignored (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 the completion.
3. Probabilities of event can be calculated based on original probability and historical data related to accuracy of previous assessment of the probability. In this case probability of event can be calculated using Bayesian Theorem:

$$P(E|H) = P(H|E)*P(E) / (P(H|E)*P(E) + P(H|E')*P(E'))$$

   Where:

   P(E|H) – probability of event

   P(E) – original probability of event (e.g. 30%).

   P(E') – probability of normal flow of the activity (event did not occur) (e.g. 70%)

   P(H|E) – accuracy of event assessment based on historical data (i.e. the probability the event was properly identified) (e.g. 90%)

   P(H|E') – accuracy of normal flow of activity assessment (e.g. 80%)

   In this example, the probability of the event calculated taking into account the accuracy of the assessment of historical data equals 32.5%. Probability of the event has slightly increased because the previous assessment of probability was not 100% accurate. This approach to probability calculations is effective if there is an established process or tools to record the actual occurrence of events.

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 on Figure 7. The chance changes constantly as a result of various events and event chains. In most cases, this chance is reducing 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.

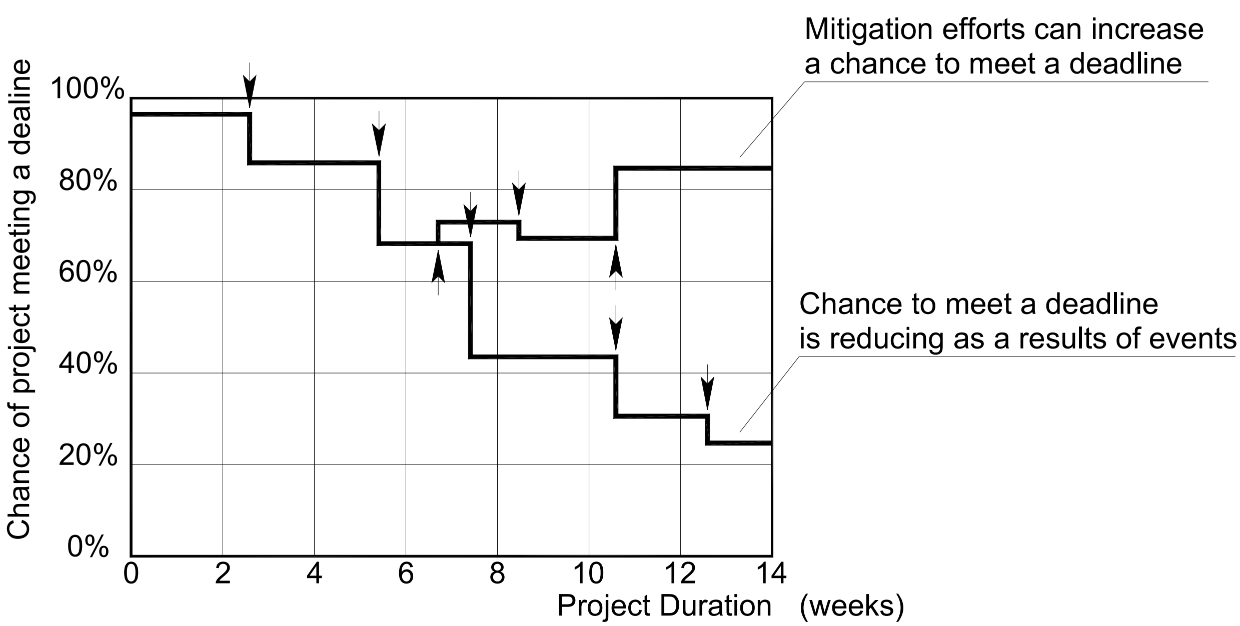


Figure 7. Monitoring chance of project completion on a certain date

In the critical chain method, the constant change in the size of the project buffer is monitored to ensure that project is on track. In event chain methodology, the chance of the project meeting a certain deadline during different phases of the project serves a similar purpose: it is an important indicator of project health. Monitoring the chance of the project meeting a certain deadline does not require a project buffer. It is always possible to attribute particular changes in the chance of meeting a deadline to actual and forecasted events and event chains, and as a result, mitigate their negative impact.

Event chain methodology Phenomena

Event chain methodology significantly simplifies the definition and analysis of complex problems associated with project scheduling, such as event correlations or resource leveling. The algorithms intended to solve these problems are called Event chain methodology phenomena. They are based on basic principles of event chain methodology.

Repeated activities

Sometimes events can cause the start of an activity that has already been completed. This is a very common scenario for real life projects: sometimes a previous activity must be repeated based on the results of a succeeding activity (Figure 8). Modeling of these scenarios using Event chain methodology is simple. The original project schedule does not need to be updated, as all that is required is to define the event and assign it to an activity that points to the previous activity. In addition, a limit to the number of times an activity can be repeated must be defined.

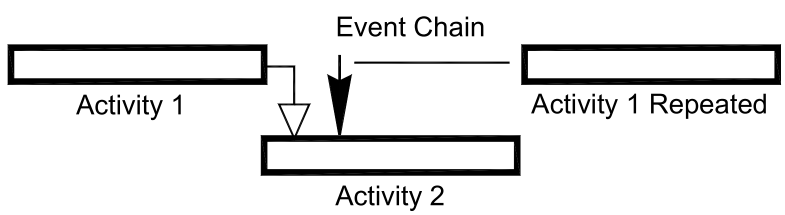


Figure 8. Repeated activity

Event chains and risk mitigation

If an event or event chain occurs during the course of a project, it may require mitigation efforts. In some cases, mitigation plans can be generated. Mitigation plans are an activity or group of activities (small schedule) that augment the project schedule if a certain event occurs. Mitigation plans can be defined as a part of original project schedule and only executed under certain conditions. However, in these cases, the project schedule may become very convoluted due to multiple conditional branches, which significantly complicates the analysis. Event chain methodology offers a solution: assign the mitigation plan to an event or event chain. These small schedules are executed when an event or event chain occurs.

The same mitigation plan can be used for different events. For example, event “Change requirements” and “Delay with component delivery” may execute the same mitigation plan (group of activities) “Update original design”. If both events occur together, this mitigation plan will only be executed once.

Each mitigation plan has an entry point (mitigation event depicted by event arrow) and exit points as shown on Figure 9. As a result, the original project schedule and the project schedule with simulation results (with risks and uncertainties) are different. Mitigation plan exit points are a property of event subscription.

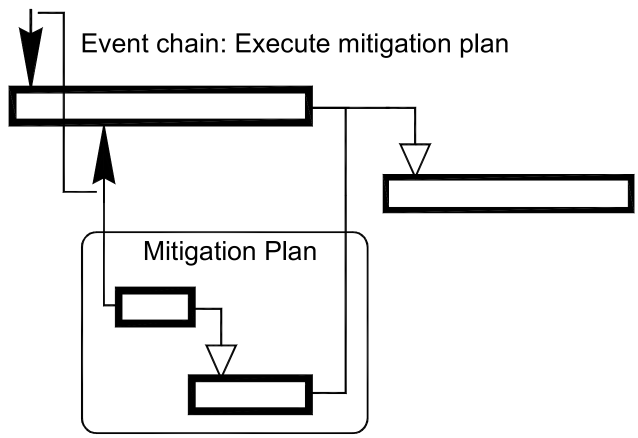


Figure 9. Event is causing execution of the mitigation plan

Delays in event chains

Events can cause other events to occur either immediately or with a delay. The delay is a property of the event subscription. The delay can be deterministic, but in most cases, it is probabilistic. If the time of the original event and the delay are known, it is possible to determine when the new event will happen and in some cases, the activity that will be associated with it. For example, original event "Relocation of the business" can cause event "Missing data" some time after the original event.

Resource leveling

In standard resource leveling the algorithm uses a number of criteria to determine how to act on overallocated activities and which activity should be delayed or split first. In Event chain methodology this process is simplified through the mechanism of event subscription. Resource leveling is performed on each trial in the Monte Carlo simulation.

Here is an example of a project schedule that includes three overlapping activities with one resource (see Figure 10). If overallocation occurs, it triggers an event "Resource overallocation". This event will be multicast to all activities where this resource is present. However, not all activities can be subscribed to this event. For example, activity 3 may not have a subscription to the event "Resource overallocation". Impact of the event is defined as a property of the event subscription. Excited state of activity 1 is subscribed to a "split" impact. Excited state of activity 2 is subscribed to a "Start later" impact. As a result, the choice should be made either to split Activity 1 or start Activity 2 later. The particular choice of the event impact should be made using different criteria: activity priority, predecessor relationship, slack, dates, etc. These criteria are a property of the event "Resource overallocation". In the example, shown on Figure 10, the impact of the event is a split of Activity 1.

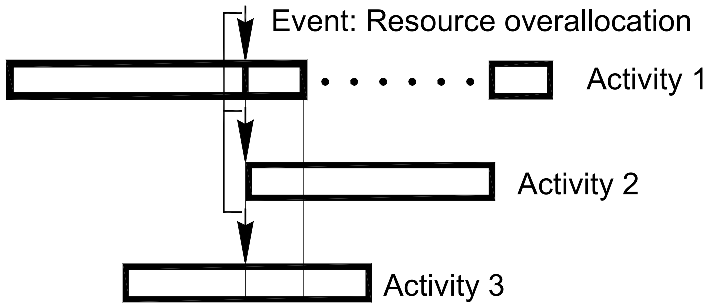


Figure 10. Resource leveling using Event chain methodology

Event correlations and entanglement

Some events can be correlated to each other. For example if the event "Poor quality component A" occurs, the event "Poor quality of the component B" may also occur, for example, if they are manufactured by the same vendor. One event does not cause another event, which means that both events do not constitute an event chain. However, there is a definite correlation between these two events. These correlations can be defined as additional property of event subscription by assigning correlation coefficients. During Monte Carlo simulation these correlation coefficients will be used in the sampling process.

The entanglement phenomena event chain methodology is similar to correlations. In quantum mechanics, entanglement is an effect in which the quantum states of two or more objects have to be described with reference to each other, even though the individual objects may be spatially separated (Schrödinger, 1935; Everett, 1957; Nielsen & Chuang, 2000). In Event chain methodology, entanglement is an effect according to which states of apparently independent activities are changing at about the same time without a common underlying event. For example, after a number of layoffs in the organization, the morale is adversely affected. It affects the performance of all projects and activities including activities, which are not directly related to each other. These apparently independent activities are transferred to an excited state. After a period of time however, performance normalizes and activities tend to return a grounded state (Figure 11). This occurs not because of certain events such as management actions, but because of a number of psychological effects. In particular, after a certain period of time, people tend to forget negative events, as long as they don't lead major consequences to the individual.

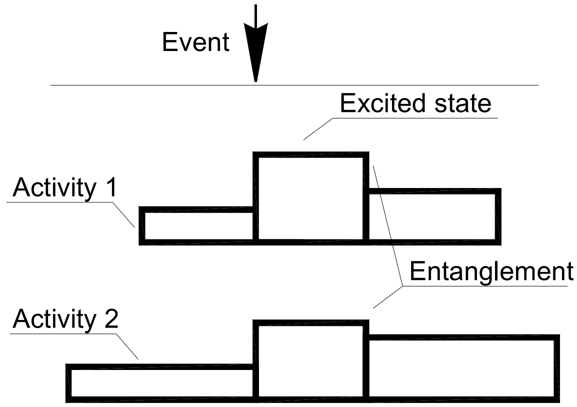


Figure 11. Entanglement effect

Entanglement is a very common response to changes in organizational culture, corporate vision, relationship with partners and subcontractors, and other similar events. People's psychological response to these events is similar, which is the primary reason for the entanglement. To define entanglement in the project schedules, state tables for multiple activities should include a spontaneous shifting of states at approximately the same time without necessarily associating them to a particular event.

Implementation considerations

The foundation of Event chain methodology is the definition of possible events, states of the activities, group of activities, resources, lags, and calendars including subscription to different events. For most real-life project, this constitutes a very significant amount of information. Abundance of information may lead to potential omissions and subsequently to an inaccurate analysis.

Below are some simplification techniques, which can be used for defining events and subscriptions:

1. The easiest way to define events is the *event breakdown structure* or hierarchical system of events. The term event breakdown is used here instead of risk breakdown structure to incorporate notion of events with positive impact (opportunities). The main advantage of an event breakdown structure is that properties of the events assigned at the higher level will be automatically propagated to the lower level of the hierarchy.
2. *Event templates* are event breakdown structures most commonly used for particular types of project and organizations are useful tool to simplify defining events. Such event templates may include some rare, but serious and sometimes catastrophic events that may affect project schedule. Defining such events for each new project is a tedious process, which can potentially cause a large number of omissions. The simplest way to define a local event is to assign a predefined event from the event template to particular activities, resources, and calendars.
3. Events should be defined at the highest level of the work breakdown structure as possible as events assigned to summary activities will be propagated to each activity in the group unless otherwise specified.
4. After events are assigned to activities, state tables (see table 2) can be defined. In many cases all event properties in the ground state and all excited states will be the same. In other words, all states are subscribed to the same events. In this case, state tables will have only one row. A positive answer to the question: "Can something new happen after a certain event occurs?" indicates that multiple rows in the state table are required.
5. *Impact alternatives* is a way to define the different impact for a particular event on an activity. For example, the event "Quality issue with the component" may cause a 10 day delay with 20% probability, a 20 day delay with 10% probability, and the restart of an activity with 20% probability. Impact alternatives cannot occur at the same time.

6. *Event register* is a useful tool to manage events. In essence, the event register is the database, which includes all information about opportunities. Event registers are especially useful when the same events affect multiple project types. For example, through the mechanism of the event register, changes in probability of event can be reflected in all activities and all projects to which this event is assigned.

Conclusions

Event chain methodology 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 much greater extent than events and event chains. This occurs because events cannot be easily translated into duration, finish time, etc. Therefore, Event chain methodology can help to overcome negative affects of selective perception, in particular the confirmation bias and, within a certain extent, the planning fallacy and overconfidence.
- Event chain methodology relies on the estimation of duration based on best-case scenario estimates and does not necessarily require low, base, and high estimations or statistical distribution 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. Compound events can be easy broken into smaller events. The probability of events can be calculated using relative frequency approach where 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.

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.

Finally, 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 offers practical solution for resource leveling, managing mitigation plans, correlations between events and other activities.

Event chain methodology 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 Event chain methodology is an easy to use process, which can be can be performed using off-the-shelf software tools. Although Event chain methodology is a relative new approach, it is actively used in many organizations, including large corporations and government agencies.

Appendix: Glossary of Event chain methodology Terms

Assignment of the event (event assignment) – property of the event indicated what activity or group of activities, resource, calendar, or lag this event affects

Critical events (critical event chains) – events or event chains that have the most potential to affect the projects. Critical events and event chains are determined based of calculation of correlation between cumulative effect of the event or event chain on activity cost and duration and total project cost or duration.

Entanglement – an effect according to which states of apparently independent activities are changing at about the same time without a common underlying event.

Event chain – set of single events linked to each other

Event chain diagram – visualization of project schedule based on Gantt chart with global and local events, event chains, and optionally with states of activities

Event cost - measure of the impact of the event. Event cost additional expected cost, which would be added to project as a result of the event.

Event template – set of predefined event, which can be used to identify events affecting project schedule.

Excitation – process in which activity is transformed from one state to another as a result of event

Excited state – new state of the activity, which is caused by an event

Fluctuation – uncertainty related to activity's parameters such as duration and cost, which are not caused by the identified event. Fluctuation is expressed as statistical distribution of activity's parameters

Global event – events affecting all activity, lags, resources, or calendars

Ground state – original state of the activity before any events affect it

Impact alternatives – different mutually exclusive potential impacts of one event

Local event – events affecting particular activity, group or activities, lags, resources, or calendars

Moment of event – actual moment when event is occurred during a course of the activity; moment of event in most cases is probabilistic

Multicasting – process according to which one sender event cause multiple receiver events

Receiver event – event, which is caused by another event (sender)

Sender event - original event of the event chain, which is causing other events

State of activity – a certain way in which activity is performed

State table – a table, which represents activity's states and associated events. State table includes properties of the event subscription

Subscription to the event – set of events, which may affect particular activity in a certain state

References

Arlow J. & Neustadt I. (2003). Enterprise Patterns and MDA: Building Better Software with Archetype Patterns and UML. Addison –Wesley Professional

Booch G., Rumbaugh J., & Jacobson I. (2005). The Unified Modeling Language User Guide, Addison –Wesley Professional; 2nd edition

Buehler, R., Griffin, D., & Ross, M. (1994). Exploring the "planning fallacy": Why people underestimate their task completion times. Journal of Personality and Social Psychology, 67, 366-381

Carroll, J.S. (1978). The effect of imagining an event on expectations for the event: An interpretation in terms of availability heuristic. Journal of Experimental Psychology, 17, 88-96

Cervone, D., & Peake, P.K. (1986). Anchoring, efficacy, and action: The influence of judgmental heuristics of self-efficacy judgments. Journal of Personality and Social Psychology*, 50*, 492-501

Cho J.G., Yum B.J. (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*,* Brooks/Cole Publishing Company, 2nd ed., Pacific Grove, CA

Everett, H. (1957). 'Relative State' Formulation of Quantum Mechanics. Reviews of Modern Physics, 29: 454-462

Evans, J. St. B. T., Barston, J.L., & Pollard, P. (1983). On the conflict between logic and belief in syllogistic reasoning. Memory and Cognition, 11, 295-306.

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

Goodpasture J. (2004). Quantitative Methods in Project Management, J.Ross Publishing, Boca Raton, FL

Flyvbjerg, B., (2006). From Nobel Prize to project management: getting risks right. *Project Management Journal*, August 2006, pp 5-15.

Flyvbjerg, B., Holm, M. K. S. & Buhl, S. L. (2002). Underestimating costs in public works projects: Error or Lie? Journal of the American Planning Association, vol. 68, no. 3, pp. 279-295

Flyvbjerg, B., Holm, M. K. S. & Buhl, S. L. (2004). What causes cost overrun in transport infrastructure projects? Transport Reviews, 24(1), pp. 3-18

Flyvbjerg, B., Holm, M. K. S. & Buhl, S. L. (2005). How inaccurate are demand forecasts in public works projects? *Journal of the American Planning Association*, vol. 78, no. 2, pp. 131-146

Fowler M. (2002). Patterns of Enterprise Application Architecture, Addison-Wesley Professional

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 1996, 23-30

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

Hulett D.T. and Hillson D. (2006). Branching out: decision trees offer a realistic approach to risk analysis, *PM Network*, May 2006, pp 36-40.

Kendrick T. (2003). Identifying and Managing Project Risk: Essential Tools For Failure-Proofing Your Project, AMACOM, a division of American Management Association, New York

Lovallo, D. & Kahneman, D. (2003). Delusions of success: how optimism undermines executives' decisions, Harvard Business Review, July Issue, pp. 56-63

Manoukian E.B. (2006). Quantum Theory: A Wide Spectrum. New York: Springer

Martin R.C. (2002). Agile Software Development, Principles, Patterns, and Practices. Prentice Hall

MacCrimmon, K. R. & Ryavec, C. A., (1962). An Analytical Study of the PERT Assumptions, Research Memorandum RM-3408-PR, The Rand Corporation, Santa Monica, CA December 1962.

McCray G.E., Purvis R.L., & McCray C.G. (2002). Project Management Under Uncertainties: The Impact of Heuristics and Biases. *Project Management Journal*. Vol. 33, No. 1. 49-57

Nielsen, M.A. & Chuang, I.L. (2000). Quantum Computation and Quantum Information. Cambridge: Cambridge University Press

Plous, S. (1993). The Psychology of Judgment and Decision Making, McGraw-Hill

Project Management Institute. (2004). A Guide to the Project Management Body of Knowledge (PMBOK® Guide), Third Edition, Newtown Square, PA: Project Management Institute

Quattrone, G. A., Lawrence, C.P., Warren, D.L., Souze-Silva, K., Finkel, S.E., & Andrus, D.E. (1984) Explorations in anchoring: The effects of prior range, anchor extremity, and suggestive hints. Unpublished manuscript. Stanford University, Stanford.

Rose, P. (2001). Risk Analysis and Management of Petroleum Exploration Ventures, AAPG Methods in Exploration Series, No. 12, The American Association of Petroleum Geologists, Tusla, OK

Schuyler, J. (2001). Risk and Decision Analysis in Projects, 2nd Edition, Project Management Institute, Newton Square, PA

Scheinin, W. & Hefner R. (2005). A Comprehensive Survey of Risk Sources and Categories, In Proceedings of Space Systems Engineering and Risk Management Symposiums. Los Angeles, CA: pp. 337-350

Schrödinger, E. (1935) Discussion of Probability Relations Between Separated Systems, Proceedings of the Cambridge Philosophical Society 31 (1935): 555-563; 32 (1936): 446-451

Shankar, R. (1994) Principles of Quantum Mechanics, Second Edition, New York: Springer.

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

Tversky, A. and Kahneman, D. (1971). Belief in the law of small numbers. Psychological Bulletin, 76, 105-110

Tversky A., & Kahneman, D. (1973). Availability: A heuristic for judging frequency and probability. Cognitive Physiology, 5, 207-232

Tversky A., & Kahneman, D. (1974). Judgment Under Uncertainty: Heuristics and biases. *Science*, 185, 1124-1130

Virine L. & Rapley L. (2003). Visualization of Probabilistic Business Models, In Proceedings of 2003 Winter Simulation Conference, New Orleans, LA

Virine L. & McVean J. (2004). Visual Modeling of Business Problems: Workflow and Patterns, In Proceedings of 2004 Winter Simulation Conference, Washington DC

Wysocki R. K. & McGary R. (2003). Effective Project Management: Traditional, Adaptive, Extreme, 3rd Edition, John Wiley & Sons Canada, Ltd

Watson, P.C. (1960). On the failure to eliminate hypotheses in a conceptual task. Quarterly Journal of Experimental Psychology, 12, 129-140

Williams, T. (2004). Why Monte Carlo simulations of project networks can mislead. Project Management Journal, September 2004, 53-61

Wilson P. & Holt S. (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.