Scheduling Strategies for Risk Mitigation

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Abstract: Risk mitigation is essential for risk management because it aims to reduce or eliminate risks. To make the best use of resources, a scheduling strategy for risk mitigation is needed to determine the risks to be mitigated and when to mitigate them. The traditionally used strategy for scheduling risk mitigation, "risk value first strategy", does not consider time elements of risk. Both PMI risk management framework and IEEE standard for software project risk management point out that time elements should be considered in risk mitigation. However, there is a lack of principles and guidelines on how to schedule risk mitigation with due consideration of these time elements. In this paper, we formally define scheduling strategy for risk mitigation, identify new scheduling strategies, and compare their performance by applying stochastic simulation.

1 INTRODUCTION

Taking careful measures to manage the risks involved in projects is a key contributor to the success of these projects (Keil et al., 1998). The positive correlation between effective risk management and project success was emphasized in (Heemstra and Kusters, 1996), (Lister, 1997), (Sherer, 2004). The adoption of risk management practices can help to increase the success rate of project and then enhance the competitiveness of organizations.

Risk mitigation is essential for risk management because it aims to reduce or eliminate risks. To make the best use of resources, a scheduling strategy for risk mitigation is needed to determine the risks to be mitigated and when to mitigate them. The generally used strategy for scheduling risk mitigation is "risk value first strategy". That is, risks are prioritized for response action based on their risk values. For example, we can first use Risk Exposure (RE) (Boehm, 1989) to compute the risk value. RE=P×I, where P is the probability of risk occurrence and I is the impact of the risk if it occurs. Then risks are scheduled for mitigation according to their risk values so that risks with higher risk values will be treated earlier. However this strategy does not consider time elements of risk. Managing time elements of risk is necessary for an effective risk management. Both Project Management Institute (PMI) risk management framework (PMI, 2008) and the IEEE standard for software project risk management (IEEE, 2001) point out that time elements should be considered in risk mitigation.

A simple example shown in Figure 1 illustrates the necessity of considering time elements in risk mitigation. In Figure 1, $R_i(P_i, I_i)$ represents risk R_i with probability P_i and impact I_i . In this example, we suppose that: (1) There are three risks which would occur during design, coding and testing phase of a hypothetical software development project respectively. (2) We can only treat one risk at a time and it takes the same amount of time to mitigate each risk. (3) The mitigation of each risk eliminates the risk at the end of the mitigation.

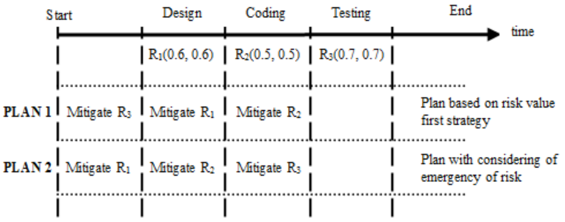

Figure 1: An Example Showing the Necessity of Managing Time Elements.

PLAN 1 applies the risk value first strategy to schedule the risk mitigation. Since R_3 has the highest risk value and R_2 has the lowest risk value, R_3 is treated first and R_2 is treated at last. Then, R_3 will

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never occur (risk mitigation eliminates R_3 before it would occur) while R_1 and R_2 would occur during the time period of their risk mitigation. PLAN 2 considers the emergency of risk that is ignored by PLAN 1. All risks will be eliminated before they would occur according to PLAN 2. Thus, it is better than PLAN 1.

Although the PMI framework and the IEEE standard point out the necessity of managing time elements in risk mitigation, there is a lack of principles and guidelines on how to schedule risk mitigation with due consideration of time elements.

This paper aims to formally define scheduling strategy for risk mitigation, identify new scheduling, and focus on following research questions:

1. Is the traditionally used strategy, risk value first strategy, a good choice for scheduling risk mitigation?
2. Is there a best scheduling strategy for most projects?
3. Is there a worst scheduling strategy for most projects?

According to (Zhou, 2012), stochastic simulation is a better choice than other methods to compare the performance of different scheduling strategies. A stochastic simulation model (SMRMP) (Zhou and Leung, 2012) with due consideration of time elements of risk will be used in our study to obtain meaningful results.

The paper is organized as follows. We briefly review the risk management process and the stochastic simulation model in section 2. In section 3, we formally define scheduling strategy for risk mitigation, identify new scheduling strategies and propose a metric to measure the performance of scheduling strategy. In section 4, we compare the performance of identified scheduling strategies and answer the research questions. At last, we conclude our study and outline the future work in section 5.

2 LITERATURE REVIEW

2.1 Project Risk

Risk is a potential event that would impact the project. It has two basic attributes, risk probability (*P*) and risk impact (*I*). Accordingly, risk is a function of *P* and *I* (Holton, 2004). We use Risk Value (RV) to represent the measurement of risk. So

$$RV = f(P, I) \qquad (1)$$

For a given project, the project risk set and its risks are defined as follows.

Def 1. Given a project $\mathbf{Z}$, it includes a set of identified n risks at time t, $RS(\mathbf{Z}, t) = \{R_1, R_2, \ldots, R_n\}$.

The size of $RS(\mathbf{Z}, t)$, $|RS(\mathbf{Z}, t)|$ may change as time elapses since new risks may be identified and added into $RS(\mathbf{Z}, t)$ and expired risks will be eliminated from $RS(\mathbf{Z}, t)$.

Def 2. For any $R_i \in RS(\mathbf{Z}, t)$, and $1 \le i \le |RS(\mathbf{Z}, t)|$, $R_i(P_i, I_i)$ represents risk R_i with probability P_i and impact I_i.

2.2 Risk Management Process

Risk management aims to identify risks and take actions to reduce or eliminate their probability and/or impact so that the project is kept from being damaged by risks. There are many paradigms, models and standards to guide the risk management practice, such as risk management paradigm developed by Software Engineering Institute (Williams et al., 1999), PMI framework (PMI, 2008), IEEE Std 1540 (IEEE, 2001), AS NZS 4360 (AS/NZS, 2004) and ISO 31000 (ISO, 2009). Although these models and standards address the risk management processes in different manners, they can be mapped to each other to a large extent. Generally, these paradigms, models and standards follow the cyclic process shown in Figure 2.

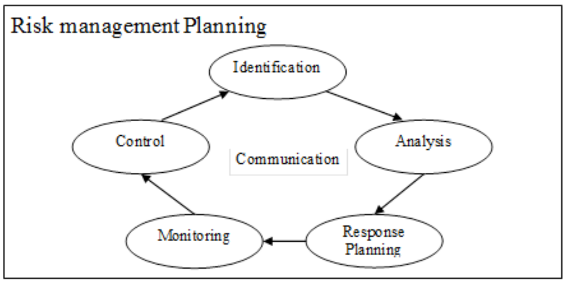


Figure 2: Cyclic Process of Risk Management.

Risk Management Planning defines how to conduct risk management practices throughout the project. It is important to provide adequate resources and time and establish both internal and external context of risk management.

Risk identification aims to identify risks that would affect the project objectives and document their characteristics. Current risk identification methods include examining the major areas of the project, collecting information from personnel, learning from past and applying analytical tools (PMI, 2008), (Kwan, 2009), (SEI, 2006). Among these proposed approaches, the taxonomy developed by (Carr et al., 1993) is more popular than others.

The risk analysis aims to understand the identified risks and provide data to assist in managing them. Generally, risk analysis includes: (1) estimate the probability, impact, and the expected timing of the risk (IEEE, 2001); (2) analyze risks and prioritize them. Recently, risk analysis is expanded with the consideration of risk dependency (Kwan and Leung, 2011).

There are four different options that can be used to treat a risk. They are avoid, transfer, mitigate and accept (PMI, 2008), (AS/NZS, 2004). Risk response planning aims to identifying possible options to reduce or eliminate risks, assessing these options and making a plan to implement risk mitigation activities. To make the best use of resources, a scheduling strategy is used to determine the risks to be mitigated and when to mitigate them. The generally used strategy for scheduling risk mitigation is "risk value first strategy".

Risk monitoring and control aims to tracking the change of all identified risks and identifying new risks, monitoring residual risks, and evaluating risk response effectiveness and performance of risk management (PMI, 2008).

2.3 Time Element in Risk Management

In risk management, time elements exist at both the project level and risk level. Time elements of risk management (project-level) are different times that directly associate with the process of risk management. Time elements of risk (risk-level) are different times that directly associate with the risk from its first identification to its expiration.

All well accepted risk management paradigms, frameworks and standards clearly define the lifecycle of risk management. In practice, for each project, we can clearly define the time duration for all five risk management processes and the time for periodical risk review. However, there is no explicit model for many time elements of individual risk.

"IEEE Standard for Software Life Cycle Processes - Risk Management" (IEEE, 2001) points out that practitioners should estimate the expected timing of the risk and document it. Then, practitioners need to schedule the treatment of each risk accordingly. PMI risk management model (PMI, 2008) also points out that the risk mitigation should be scheduled with due consideration of the expected occurrence time of the risk. However, both the PMI framework and the IEEE standard lack principles and guidelines on how to schedule risk mitigation with due consideration of many key times of risk. Consequently, these time elements are rarely used in practice. This may lead to improper risk mitigation activities and an ineffective risk management.

Very few studies have explicitly modeled the time elements of risk. Leung proposed variants of risk, presented a model of risk lifecycle, and gave the relationship between the risk variants by explicit consideration of the occurrence time of risk (Leung, 2010).

Zhou and Leung identified two key time periods of individual risk for an effective risk management (Zhou and Leung, 2011). These two time periods are time period of risk occurrence and risk mitigation. The time period of occurrence is the duration that a risk would occur. The time period of mitigation is the duration for executing planned mitigation activity of a risk.

Zhou and Leung also proposed a stochastic simulation model of risk management process with due consideration of time elements of risks (Zhou and Leung, 2012). This simulation model can be used for many risk management issues, such as understanding of risk management process, predicting risk management outcome, and making informed risk management decision. This model will be presented in next section.

2.4 A Stochastic Simulation Model

Figure 3 shows the "Simulation Model of Risk Management Process" (SMRMP) proposed in (Zhou and Leung, 2012).

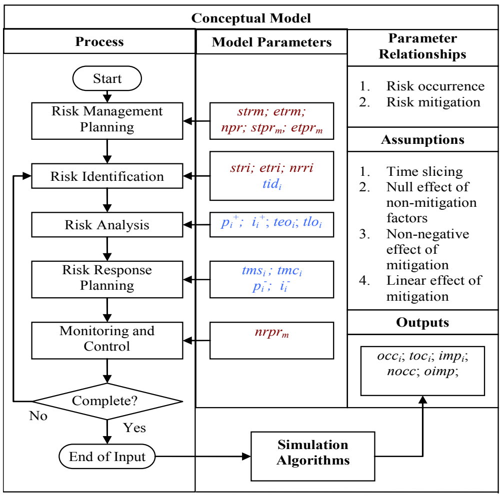


Figure 3: Conceptual Model for Risk Management Process.

Based on a two levels approach, the inputs and outputs of the model have been identified (Zhou and

Leung, 2012). The first level is the risk level which focuses on a single risk. The second level is the project level which considers all risks of the whole project. Some natural relationships between the parameters are identified. Algorithms are also developed to compute output of the simulation from the input parameters. Besides that, the model has four assumptions. This model was evaluated to be valid (Zhou and Leung, 2012) by applying the paradigm proposed by Sargent (Sargent, 2010).

Table 1 and 2 summarize the input parameters and outputs of SMRMP respectively.

Table 1: Parameters of SMRMP (Zhou and Leung, 2012).

No	Notation	Value	Level	Description
1	***strm***	0^{*1}	project-level	start time of risk management
2	***etrm***	L^{*1}	project-level	end time of risk management
3	***stri***	>0	project-level	start time of the risk identification
4	***etri***	$> stri > 0$	project-level	end time of the risk identification
5	***nrri***	≥0	project-level	number of risks identified in risk identification
6	***npr***	>0	project-level	number of periodical reviews
7	$\boldsymbol{stpr_m}$	>0	project-level	start time of the mth periodical review
8	$\boldsymbol{etpr_m}$	$>stpr_m$	project-level	end time of the mth periodical review
9	$\boldsymbol{nrpr_m}$	≥0	project-level	number of risks identified in the mth periodical review
10	$\boldsymbol{tid_i}$	>0	risk-level	the time that R_i is identified
11	$\boldsymbol{teo_i}$	>0	risk-level	earliest time of occurrence of R_i
12	$\boldsymbol{tlo_i}$	$>teo_i>0$	risk-level	latest time of occurrence of R_i
13	$\boldsymbol{p_i^+}$	$\in (0, 1)$	risk-level	probability of R_i when it is first identified
14	$\boldsymbol{i_i^+}$	$\in (0, 1]$	risk-level	impact of R_i when it is first identified
15	$\boldsymbol{tms_i}$	$\geq tid_i>0$	risk-level	mitigation start time of R_i
16	$\boldsymbol{tmc_i}$	$\in (tms_i, tlo_i]$	risk-level	mitigation close time of R_i
17	$\boldsymbol{p_i^-}$	$\in [0, 1)$	risk-level	expected probability of R_i after the mitigation
18	$\boldsymbol{i_i^-}$	$\in [0,1]$	risk-level	expected impact of R_i after the mitigation

*1 suppose the risk management starts at time 0 and ends at time L

Table 2: Outputs of SMRMP (Zhou and Leung, 2012).

No	Notation	Value	Level	Description
1	$\boldsymbol{occ_i}$	Yes/No	risk-level	represent whether R_i occurs or not
2	$\boldsymbol{toc_i}$	$\in (teo_i, tlo_i]$	risk-level	occurrence time of R_i if it occurs
3	$\boldsymbol{imp_i}$	>0	risk-level	impact of R_i if it occurs at toc_i
4	***nocc***	≥0	project-level	number of all occurred risks
5	***oimp***	≥0	project-level	overall impact of all risks

The model assumptions are listed as follows.

1. Time slicing. For a given project ***Z***, the time period of its risk management is equally divided into L time intervals with a set of L+1 time points, $TP(Z) = \{0, 1, 2, ..., L\}$. All management activities start at one of these time points and take integral multiple of intervals.
2. Null effect of non-mitigation factors. The factors not related to risk mitigation, such as change of external and internal risk management environments, will not change the probability and impact of a risk.
3. Non-negative effect of mitigation. Risk mitigation will not increase the probability and impact of a risk. It is reasonable since risk mitigation should not increase the risk and is often effective in reducing the risk.
4. Linear effect of mitigation. The probability and impact of a risk will linearly decrease during its mitigation period from $\boldsymbol{p_i^+}$ to $\boldsymbol{p_i^-}$ and from $\boldsymbol{i_i^+}$ to $\boldsymbol{i_i^-}$ respectively.

Model users should go through the whole process of risk management to determine the values of model parameters based on the parameter relationships and model assumptions. After inputting all model parameters, users can run the simulation for each risk, and get outputs which can help to predict the expected impact on projects.

Since the probability and impact of a risk may change with time, EOR and EAI are introduced to measure the expected occurrence rate and expected impact during (teo_i, tlo_i] (Zhou and Leung, 2012). Since a risk cannot be repeated in real-life projects, IIR is introduced to facilitate the computation of EOR and EAI (Zhou and Leung, 2012).

Def 3. Independent and Identical Risks (IIR): If R_1 and R_2 are independent risks and have the exactly same values in all risk-level parameters, then they are independent and identical risks (IIR).

Def 4. Suppose there are N IIRs, if M risks occurred among all N risks when N is sufficiently large, then EOR=M/N.

Def 5. Expected Actual Impact (EAI): Suppose there are N IIRs, if M risks occurred among all N risks when N is sufficiently large, then EAI=$\sum_M imp_i / N$, where $\sum_M imp_i$ is the total impact of M occurred risks.

3 SCHEDULING STRATEGY FOR RISK MITIGATION

3.1 Definition of Scheduling Strategy

To facilitate the definition of scheduling strategy for risk mitigation, we first define the set of risks need to be treated at time *t* and the resource assigned for risk mitigation.

Def 6. Given a risk set *TRS(**Z**, t)* and *TRS(**Z**, t)*⊆ *RS(**Z**, t)*, ∀R_j ∈ *TRS(**Z**, t)*, R_j is a risk which does not have a mitigation plan and waiting for treatment, and ∀R_k ∈ *RS(**Z**, t)- TRS(**Z**, t)*, R_k is a risk which is acceptable and need not to be treated or has been scheduled for mitigation.

We abstract the human resource for risk mitigation as a set of processors which have different capabilities to mitigate risk.

Def 7. For a given project ***Z***, a set of *k* processors at time t, $ProS(\mathbf{Z},\ t) = \{processor_i \mid 0 < i \le k\}$, are available for risk mitigation. ∀*processor*$_i$∈ *ProS(**Z**,t)*, *CAP(processor*$_i$*)*=c_i, where *CAP(processor*$_i$*)* is the capability of *processor*$_i$ for risk treatment and c_i is a real number greater than 0.

The capability of a processor can be considered as 1 if it represents the capability of a team member that has normal capability for risk mitigation. Then the capabilities of all processors can be estimated according to capabilities of different team members.

For R$_i$ assigned to *processor*$_j$ (0<j≤*k*),

$$tmc_i - tms_i = Effort_i \big/ c_j \tag{2}$$

where *Effort*$_i$ is the estimated effort for the treatment of R$_i$.

Note that the processor is assumed to process one risk at a time. However, it is possible that a team member may treat two (or more) different risks at the same time in practice. In this case, this team member can be abstracted as two (or more) processors with capability equal to the capability of the team member. From this point of view, we can consider each processor can process one risk at a time.

For convenient sake, in this study, we assume all processors in *ProS(**Z**, t)* have the same capability equal to 1, and each processor processes one risk at a time. Then the effort of mitigating a risk can be estimated according to the capability of the processor and the time needed to mitigate the risk. Note that the time unit should be consistent with the time unit adopted in the simulation model.

The mitigation scheduling of a project ***Z*** aims to allocate a set of *m* risks (|*TRS(**Z**, t)*|=*m*) to a set of *k* processors (|*ProS(**Z**, t)*|=*k*), to minimize the expected impact on ***Z***. Suppose there is only one processor (*k*=1), then there are *m*! different sequences to allocate risks to this single processor. We can choose the schedule with the minimal expected impact among all *m*! different sequences. However, this approach is unreasonable in practice because the time for finding the best option from *m*! options is non-polynomial. The situation become more complicated when there are more processors (*k*>1). Thus there is a need to develop scheduling strategies to determine the sequence for treating the risks in *TRS(**Z**, t)*.

Based on *TRS(**Z**, t)* and *ProS(**Z**, t)*, we define scheduling strategy for risk mitigation as follows.

Def 8. Scheduling strategy for risk mitigation is an algorithm that takes *TRS(**Z**, t)* and *ProS(**Z**, t)* as input and generates a scheduled risk mitigation plan as its output. For each R_i ∈ *TRS(**Z**, t)*, it decides whether R_i is to be mitigated, and then chooses *processor*$_j$ ∈ *ProS(**Z**, t)* to mitigate R_i during a selected time period.

Since risk mitigation aims to prevent the project from impacted by the risks, the performance of a scheduling strategy ***S*** can be measured by the expected impact of all risks in *TRS(**Z**, t)*, *EAI(S|TRS(Z,t))*, after ***S*** has been applied to *TRS(**Z**, t)*. *EAI(S|TRS(Z,t))* is defined as

Def 9. Let *EAI(S|TRS(Z,t))* be the expected impact of all risks in *TRS(**Z**, t)* after a scheduling strategy ***S*** has been applied to *TRS(**Z**, t)*.

$$EAI\left(S \mid TRS(Z,t)\right) = \sum_{R_i \in TRS(Z,t)} EAI(R_i) \tag{3}$$

where *EAI(R$_i$)* is EAI of R$_i$. *EAI(S|TRS(Z,t))* ranges in (0, | *TRS(**Z**, t)*|) because EAI ranges in (0, 1).

A higher value of *EAI(S|TRS(Z,t))* means a higher expected impact on the project and indicates a lower performance of ***S***. Thus we define the performance of a scheduling strategy as follows.

Def10. Let *Perf(S)* represents the performance of a scheduling strategy ***S*** applied to the risk set *TRS(**Z**, t)*. For two scheduling strategies $\boldsymbol{S_i}$ and $\boldsymbol{S_j}$,

Perf(S$_i$)>Perf(S$_j$) when *EAI(S$_i$|TRS(Z,t))<EAI(S$_j$|TRS(Z,t))*;
Perf(S$_i$)=Perf(S$_j$) when *EAI(S$_i$|TRS(Z,t))=EAI(S$_j$|TRS(Z,t))*;
Perf(S$_i$)<Perf(S$_j$) when *EAI(S$_i$|TRS(Z,t))>EAI(S$_j$|TRS(Z,t))*.

3.2 New Scheduling Strategies

Traditionally, risk value first strategy (V strategy) is used in practice. However, it does not consider the time elements of risk. Besides the V strategy, we propose several new strategies.

1. Emergency first strategy (E strategy).

Emergency first strategy first orders all risks according to their T_{eo}, then risks with an earlier T_{eo} will be treated earlier. For example, suppose teo_i=30 and teo_j=50 are earliest occurrence time of R_i and R_j respectively, then R_i will be mitigated first.

The principle behind this strategy is that we should mitigate the risk before it would occur. The best case of applying this strategy is all risks are mitigated before they would occur. No risk will occur if all mitigations are successful in eliminating the risks. The example shown in Figure 1 is a good example of applying this strategy.

2. Lowest effort first strategy (L strategy).

Lowest effort first strategy first orders all risks according to the efforts needed for mitigating the risk, then risks requiring a lower effort will be treated earlier. For example, suppose 40 Man-hour and 80 Man-hour are needed effort to mitigate R_i and R_j respectively, then R_i will be mitigated first.

The principle behind this strategy is that we can mitigate more risks within the same time period because mitigating a risk with lower effort will use less time. Consequently, we may prevent more risks from occurring and this leads to a low overall impact of the project.

3. Combined strategies.

We consider applying combination of V, E and L strategies at the same time by constructing some combined strategies. For example, we can combine the risk value first strategy and emergency first strategy together. The resulting strategy first prioritizes all risks based on their risk value and T_{eo} respectively, producing two risk lists. For risk R_i, a score is calculated by combining its priority values from these two risk lists. Using the calculated scores, all risks can be finally prioritized and then scheduled so that a risk with a higher priority will be treated earlier.

As there are three basic strategies, V strategy, E strategy and L strategy, we can create four combined strategies, VE strategy (combined V with E), VL strategy (combined V with L), EL strategy (combined E with L) and VEL strategy (combined all three basic strategies). We assign weights, w_1, w_2 and w_3, to the priority according to the three basic strategies. In this study, we apply equal weights to these three strategies as there are no prior studies showing that one basic strategy is better than another. The combined strategy is equivalent to VE Strategy when $w_1 = w_2$ and w_3=0, VL Strategy when $w_1 = w_3$ and w_2=0, EL Strategy when $w_2 = w_3$ and w_1=0 and VEL Strategy when $w_1 = w_2 = w_3$. We can create more combined strategies by using unequal weights in the future.

Table 3 shows examples of applying different strategies to schedule risk mitigation. The number shown under basic strategies is the priority that the risk is scheduled (a lower value indicates a higher priority). For example, R_1 is scheduled first, and then followed by R_2, R_3 and R_4 when applying V strategy. The score value under combined strategies is calculated by adding the priority of corresponding basic strategies. For example, for VE strategy, the score of the 5th column is the result of adding the priority in V strategy (the 2nd column) and that in E strategy (the 3rd column). Then all risks are prioritized based on their scores. Note that if two or more risks have the same score, then they can be prioritized in any order. Since we have to choose one order to mitigate the risks, in our study, the risk with a smaller index will get a higher priority when several risks have the same score. For example, R_2 and R_3 have the same score of 4 under VL strategy. Then R_2 is assigned a higher priority than R_3 and will be mitigated earlier than R_3.

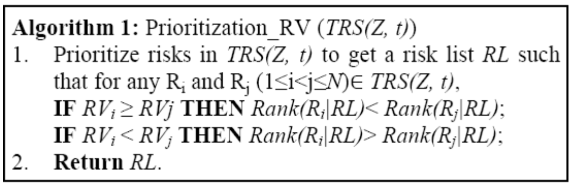
Table 3: Examples of Mitigation Strategies.

Risk	Basic Strategy			Combined Strategy							
	V	E	L	VE		VL		EL		VEL	
	Pri	Pri	Pri	Sco	Pri	Sco	Pri	Sco	Pri	Sco	Pri
R_1	1	2	4	3	1	5	3	6	3	7	2
R_2	2	3	2	5	3	4	1	5	2	7	3
R_3	3	1	1	4	2	4	2	2	1	5	1
R_4	4	4	3	8	4	7	4	7	4	11	4

We next formally define above scheduling strategies. Suppose $TRS(Z,t) = \{R_1, R_2, ..., R_N\}$. Let *Rank(R_i|RL)* be the rank of R_i in the prioritized risk list (*RL*) of *n* risks, with rank of 1 indicating the first risk of *RL* and rank of *n* indicating the last risk of *RL*. That is a lower rank value indicates a higher priority.

Recall that RV_i, teo_i and $Effort_i$ ($1 \le i \le N$) represent the risk value, earliest time of occurrence and estimated mitigation effort of R_i respectively. Algorithm 1, 2 and 3 shows three different ways to prioritize *TRS(Z, t)*.

Algorithm 1 produces a risk list such that a risk with a higher risk value will have a higher priority.



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Algorithm 1: Prioritization_RV (TRS(Z, t))
1.  Prioritize risks in TRS(Z, t) to get a risk list RL such
    that for any $R_i$ and $R_j$ ($1 \le i < j \le N$) $\in$ TRS(Z, t),
    IF $RV_i \ge RVj$ THEN $Rank(R_i|RL) < Rank(R_j|RL)$;
    IF $RV_i < RV_j$ THEN $Rank(R_i|RL) > Rank(R_j|RL)$;
2.  Return RL.
```

As mentioned earlier, two risks with the same score will be prioritized according to their risk indexes.

Thus, in Algorithm 1, R_i has a higher priority than R_j when $RV_i = RV_j$ and $1 \leq i < j \leq N$. Similarly, in Algorithm 2, 3, and 9, if two risks have the same T_{eo}, estimated mitigation effort, and computed score respectively, then they will be prioritized according to their risk indexes too.

Algorithm 2 produces a risk list such that a risk with an earlier T_{eo} will have a higher priority.

```
Algorithm 2: Prioritization_TEO (TRS(Z, t))
1. Prioritize risks in TRS(Z, t) to get a risk list RL such
   that for any $R_i$ and $R_j$ ($1 \leq i<j \leq N$) $\in$ TRS(Z, t),
   IF $teo_i \leq teo_j$ THEN $Rank(R_i|RL) < Rank(R_j|RL)$;
   IF $teo_i > teo_j$ THEN $Rank(R_i|RL) > Rank(R_j|RL)$;
2. Return RL.
```

Algorithm 3 produces a risk list such that a risk with a smaller mitigation effort will have a higher priority.

```
Algorithm 3: Prioritization_EFFORT (TRS(Z, t))
1. Prioritize risks in TRS(Z, t) to get a risk list RL such
   that for any $R_i$ and $R_j$ ($1 \leq i<j \leq N$) $\in$ TRS(Z, t),
   IF $Effort_i \leq Effort_j$ THEN $Rank(R_i|RL) < Rank(R_j|RL)$;
   IF $Effort_i > Effort_j$ THEN $Rank(R_i|RL) > Rank(R_j|RL)$;
2. Return RL.
```

V strategy is defined as Algorithm 4.

```
Algorithm 4: V strategy (TRS(Z, t), ProS(Z, t))
1. RL = Prioritization_RV (TRS(Z, t)).
2. Allocation(RL, ProS(Z, t)).
```

Allocation(*RL*, *ProS(**Z**, t)*) is shown as Algorithm 5, which allocates the prioritized risks to the processors in *ProS(**Z**, t)* such that the risk with a higher priority will be allocated first.

```
Algorithm 5: Allocation(RL, ProS(Z, t))
1. Get the first risk $R_i$ in the prioritized risk list RL.
2. Find a set of processors, $ProS_i \subseteq ProS(Z, t)$, which can
   process $R_i$.
3. IF $ProS_i$ is not empty,
   THEN select a $processor_j$ which is the first one that
   completes its currently assigned work in $ProS_i$, and
   assign $R_i$ to $processor_j$.
4. Remove $R_i$ from RL.
5. IF RL is not empty, THEN go to step 1.
```

Note that a processor is not able to process risk R_i if it cannot complete the mitigation of R_i before its latest time of occurrence. For example, suppose a processor completes its currently assigned work at t=50. If tlo_i=40, then the processor is not able to process R_i since the mitigation after the latest time of occurrence does not make sense. Another example is that suppose tlo_i=60 and the time length for mitigating R_i is 20. In this case, if the mitigation is started at t=50, the processor cannot complete the mitigation before tlo_i (actually it completes the mitigation at t=50+20=70).

There may exist more than one processor that can process risk R_i at the same time. Then, we should select the first processor that completes its work because the risk in *RL* should be treated as early as possible. For example, assume some risks have been assigned to $processor_1$ and $processor_2$, $processor_1$ will complete its currently assigned works at t=20 and $processor_2$ will complete its currently assigned works at t=40. Suppose teo_i, tlo_i and $Effort_i$ are 40, 60 and 10 respectively. Then, both $processor_1$ and $processor_2$ can process R_i because they can complete the mitigation of R_i (at t=30 and t=50 respectively) before tlo_i =60. In this case, we should select $processor_1$ to mitigate R_i because it completes its currently assigned work earlier (at t=20) and consequently the mitigation of R_i can be started earlier if it is assigned to $processor_1$.

Also, there may not exist any processors that can process risk R_i if they are all busy. In this case, R_i is removed from RL directly.

E strategy and L strategy are defined as Algorithm 6 and 7 respectively.

```
Algorithm 6: E strategy (TRS(Z, t), ProS(Z, t))
1. RL = Prioritization_TEO (TRS(Z, t)).
2. Allocation(RL, ProS(Z, t)).
```

```
Algorithm 7: L strategy (TRS(Z, t), ProS(Z, t))
1. RL = Prioritization_EFFORT (TRS(Z, t)).
2. Allocation(RL, ProS(Z, t)).
```

Algorithm 8 defines VE strategy.

```
Algorithm 8: VE strategy (TRS(Z, t), ProS(Z, t))
1. $RL_1$ = Prioritization_RV (TRS(Z, t)).
2. $RL_2$ = Prioritization_TEO (TRS(Z, t)).
3. RL= CombinedRL($RL_1$, $RL_2$).
4. Allocation(RL, ProS(Z, t)).
```

CombinedRL(RL_1, RL_2,…, RL_l) is shown as Algorithm 9, which produces a risk list such that the

```
Algorithm 9: CombinedRL($RL_1$, $RL_2$,…, $RL_l$)
// $RL_1$, $RL_2$,…, $RL_l$ are prioritized risk lists of TRS(Z, t)
1. Prioritize risks in TRS(Z, t) to get a risk list RL such
   that for any $R_i$ and $R_j$ ($1 \leq i<j \leq N$) $\in$ TRS(Z, t),
   IF $Rank(R_i|RL_1) + Rank(R_i|RL_2) + \ldots + Rank(R_i|RL_l) \leq$
   $Rank(R_j|RL_1) + Rank(R_j|RL_2) + \ldots + Rank(R_j|RL_l)$
   THEN $Rank(R_i|RL) < Rank(R_j|RL)$;
   IF $Rank(R_i|RL_1) + Rank(R_i|RL_2) + \ldots + Rank(R_i|RL_l) >$
   $Rank(R_j|RL_1) + Rank(R_j|RL_2) + \ldots + Rank(R_j|RL_l)$
   THEN $Rank(R_i|RL) > Rank(R_j|RL)$;
2. Return RL.
```

risk with a lower score (which is computed by its rank from input risk lists, RL_1, RL_2,…, RL_l) will have a higher priority.

VL, EL and VEL strategies can be implemented similarly to Algorithm 8.

4 PERFORMANCE OF SCHEDULING STRATEGIES

Next, we compare the performance of different strategies by running simulations based on SMRMP. Let *imp(R)* denotes the impact of a given risk *R* in one simulation. $\sum_{i=1}^{N} imp(R)_i / N$ is the average impact of *R* in N simulations, where $imp(R)_i$ is the impact of *R* in the i^th^ simulation (1<i≤N). According to (Zhou and Leung, 2012), if N is sufficiently large, then $\sum_{i=1}^{N} imp(R)_i / N$ follows a normal distribution with mean EAI(R). That is $\sum_{i=1}^{N} imp(R)_i / N$ can be used to approximate EAI(*R*) when N is sufficiently large. Let *imp(**S**|TRS(**Z**,t))* denotes the total impact of all risks of *TRS(**Z**,t)* in one simulation with strategy ***S***. Then, $\sum_{i=1}^{N} imp(S \mid TRS(Z,t))_i / N$ can be used to approximate *EAI(S|TRS(Z,t))* when N is sufficiently large. $imp(\boldsymbol{S}|TRS(\boldsymbol{Z},t))_i$ is the total impact of all risks of *TRS(**Z**,t)* in the i^th^ simulation (1<i≤N). For example, after applying V strategy to *TRS(**Z**,t)* and running simulation for 1000 times, the average *imp(V|TRS(**Z**,t))* from these simulations can be used to measure the performance of V strategy.

Def11. Let average overall impact, AVEOI(***S***) denotes the average *imp(**S**|TRS(**Z**,t))* of running a large number (N) of simulations on *TRS(**Z**,t)* with strategy ***S***. AVEOI(***S***) is computed as

$$AVEOI(S) = \sum_{i=1}^{N} imp(S \mid TRS(Z,t))_i \Big/ N \qquad (4)$$

If all risks of project ***Z*** need to be scheduled for mitigation, then *imp(**S**|TRS(**Z**,t))* can be replaced by ***oimp*** of SMRMP because ***oimp*** is the total impact of the project.

Since AVEOI(***S***) is an approximation of *EAI(S|TRS(Z,t))*, it can be used to measure the performance of ***S***. That is a lower AVEOI(***S***) indicates ***S*** has a higher performance and a higher AVEOI(***S***) indicates ***S*** has a lower performance.

We are also interested in the difference in performance of two strategies when they are applied to the same project.

Def12. Suppose S_i and S_j are two scheduling strategies that are applied to project ***Z***, with AVEOI($\boldsymbol{S_i}$) ≥ AVEOI($\boldsymbol{S_j}$). PIP (Percentage of Improved Performance) is defined as

$$PIP\left(S_i,S_j\right) = (AVEOI(S_i) - AVEOI(S_j)) \Big/ AVEOI(S_i) \qquad (5)$$

PIP(S_i,S_j) measures the relative improvement of impact of $\boldsymbol{S_j}$ over that of $\boldsymbol{S_i}$. PIP(S_i,S_j) ranges in [0, 1]. PIP(S_i,S_j) equals 0 when AVEOI($\boldsymbol{S_i}$) = AVEOI($\boldsymbol{S_j}$), indicating that $\boldsymbol{S_i}$ and $\boldsymbol{S_j}$ have the same performance. It equals 1 when AVEOI($\boldsymbol{S_j}$) = 0. The higher the value of PIP(S_i,S_j), the larger the improvement of $\boldsymbol{S_j}$ over $\boldsymbol{S_i}$.

4.1 Cases for Simulation

In this section, we identify the cases used for comparing performance of different scheduling strategies. Risk mitigation can be viewed as using a set of processors to mitigate a given set of risks. The processor takes risks as input and mitigates them. So, the risk set is the input to the risk mitigation. For output, we are most interested in the effectiveness of risk mitigation. Next, we identify different cases from these two aspects of input and output of risk mitigation.

The input to risk mitigation is a set of risks *TRS(**Z**, t)*. The external context of these risks is a project ***Z*** of a certain project type (Cadle and Yeates, 2008), size and application domain. The basic internal attributes of risk are probability and impact. First, we explore the external context and internal attributes of risk to identify key parameters for simulation.

After identifying the response option of mitigating a risk, the next issue is to determine when and which processor should work on mitigating the risk. Thus, the scheduling problem can be formulated as how to order the mitigation of a set of risks given a set of processors. Consequently, the type of project, (i.e. software development project, system enhancement project and so on), and the domain of the project (i.e. banking, medical, telecommunication and so on) are not important in the context of our study.

A large project having a large number of risks and a large mitigation team is similar with a small project having a small number of risks and a small mitigation team when scheduling risk mitigation. For example, suppose a large project has 100 risks and 100 processors, and another project have 20 risks and 20 processors. In both cases, each risk can be allocated to a unique processor and all risks can be treated at the same time. Therefore, compared with the ratio of the number of risks to the number of processors, the project size is less important for scheduling risk mitigation because it may indicate the number of risks only and cannot represent the size of mitigation team.

Def13. RRP (Ratio of Risks to Processors) is defined as

$$RRP = \left|TRS(Z,t)\right| / \left|ProS(Z,t)\right| \tag{6}$$

where *TRS(**Z**, t)* and *ProS(**Z**, t)* are the set of risks waiting for mitigation and the set of processors respectively.

RRP is more meaningful than the number of risks for scheduling risk mitigation because it integrates both the number of risks and number of processors. RRP is a better parameter for the simulation when compared to the number of risks.

It is meaningful that we use different RRP values obtained from different contexts to represent different cases. We obtain RRP values from different combinations of project sizes and mitigation team (processor) sizes. We assume the number of risks is related to the project size so that larger projects will have more risks. In this study, we consider two categories of project size, large project and small project, and consider three categories of team size, large team, medium team and small team. We will consider more categories of project size and team size in future study. Note that we will not consider following two combinations: (1) small project and a large mitigation team, leading to a very small RRP and (2) large project and a small mitigation team, leading to a very large RRP, because effective risk mitigation is hard to be achieved in this case. Thus we consider four most common cases: 1. small project (with a small number of risks) and a small mitigation team, 2. small project and a medium mitigation team, 3. large project (with a large number of risks) and a medium mitigation team and 4. large project and a large mitigation team. We choose following values for RRP for the simulations.

1. | *TRS(**Z**, t)*|=20, | *ProS(**Z**, t)*|=2, with RRP=10
2. | *TRS(**Z**, t)*|=20, | *ProS(**Z**, t)*|=4 with RRP=5
3. | *TRS(**Z**, t)*|=60, | *ProS(**Z**, t)*|=4, with RRP=15
4. | *TRS(**Z**, t)*|=60, | *ProS(**Z**, t)*|=15, with RRP=4

Larger projects usually require a longer development lifecycle. So, projects of different sizes would have different time periods of risk management. However, the time unit used in SMRMP is a relative time scale. Hence, different time periods can be normalized into 100 time units. Consequently, we can consider that ***strm*** =0 and ***etrm*** =100.

For the internal attributes of risk, we consider the distribution (DoP) of the probability and the distribution (DoI) of impact of risks. To be meaningful, we consider four different distributions which represent majority of risks having large RV, medium RV, small RV and randomly distributed RV respectively.

(1) Both *P* and *I* follow the distribution shown in Figure 4-I. It implies that most risks have medium *P* and *I*. (2) Both *P* and *I* follow the distribution shown in Figure 4-II. It implies that most risks have high *P* and *I*. (3) Both *P* and *I* follow the distribution shown in Figure 4-III. It implies that most risks have low *P* and *I*. (4) Both *P* and *I* follow the distribution shown in Figure 4-IV.

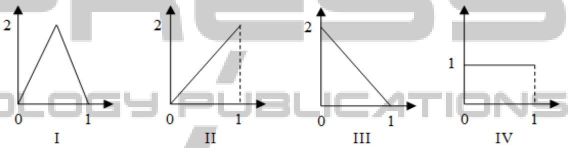

Figure 4: Different Distributions of *P* and *I*.

Note that the distribution of probability and the distribution of impact need not be the same. In our study, the probability and impact of a risk are independent even if they follow the same distribution. In future study, we will consider more cases with different distributions of probability and distributions of impact. The other attributes of risk, such as the time period of occurrence and efforts to mitigate a risk are randomly generated (details will be provided in section 4.2).

To model the effectiveness of risk mitigation, we consider two cases: (1) Full reduction. Each processor can eliminate the assigned risks. (2) Random reduction. Each processor randomly reduces the probability and impact of assigned risks. That is each processor reduces the probability and impact of R_i from p_i^+ and i_i^+ to $p_i^- = r_1 \times p_i^+$ and $i_i^- = r_2 \times i_i^+$ respectively, where r_1 and r_2 are random numbers in [0, 1].

Note that we will not consider the case of Zero reduction that a processor does not reduce the probability and impact of assigned risks because this case is same as no mitigation. Naturally all scheduling strategies give the same performance for this case.

In summary, with due consideration of different inputs (external context and internal attributes of *TRS(**Z**, t)*), and outputs (effectiveness of mitigation) of processor, we obtain totally 4×4×2=32 different cases.

4.2 Parameters of SMRMP

To simulate different cases, we first identify the values of parameters of SMRMP. Based on settings discussed in last section, we select values or probability distributions for the parameters of SMRMP (see Table 1). For each case, we set the parameters of SMRMP as follows.

1. Parameters of SMRMP at project-level.

(1) ***strm*** =0 and ***etrm*** =100. (2) we consider that all risks are identified in the first risk identification and no new risks are identified in periodical reviews. The reason is in comparing performance of different scheduling strategies, it is not important to consider the effect of the periodical reviews, since we can apply scheduling strategies to the risk set *TRS(**Z**, t)* at any time. At the beginning of the project, we can select a scheduling strategy based on risks identified in risk identification to generate a schedule for risk mitigation. Then we can repeat the strategy selection at the end of each periodical review if new risks have been identified. Consequently, we just assume all risks are identified at the beginning of risk management. For convenient sake, we set the start time of risk identification to 0 (***stri***=0) and the end time of risk identification to 1(***etri***=1) respectively.

2. Parameters of SMRMP at risk-level.

(1) $\boldsymbol{tid_i}$ of any risk R_i is 1 since ***etri***=1. (2) $\boldsymbol{p_i^+}$ and $\boldsymbol{i_i^+}$ of risk R_i are generated according to the distribution of the case. (3) $\boldsymbol{p_i^-}$ and $\boldsymbol{i_i^-}$ of risk R_i are generated according to mitigation effectiveness of the case. (4) the time period of occurrence of all risks is randomly generated within the lifecycle of risk management, because risks can occur at any phase of the project. Suppose we identify risk R_i before it would occur, then [$\boldsymbol{teo_i}$, $\boldsymbol{tlo_i}$] should be in the range [1, 100] since $\boldsymbol{tid_i}$ =1 and ***etrm*** =100. (5) the effort of mitigating a risk is randomly generated within the available time for its mitigation. Since the effort for mitigating a randomly generated risk is unpredictable, we consider that a randomly generated mitigation effort is a good choice. According to the effort, the scheduling strategy is applied to determine whether R_i can be mitigated by a specific processor and the time to mitigate it. Thus, the time period of risk mitigation will be determined according to the selected scheduling strategy.

4.3 Results of Simulation

We generate 1000 projects for each case and apply all 7 scheduling strategies to each project. Therefore there are 7000 combinations of projects and scheduling strategies for each case. We run 1000 simulations for each combination to compare the performance of different scheduling strategies.

We run simulations on all 32 cases. Table 4 summarizes the chance of different strategies to be the best/worst strategy among 32 cases. For example, the chance for V strategy to be the best strategy in 32 different cases ranges in [0.1%, 66%]. V strategy has 21% chance to be the best strategy on average (that is, it is the best strategy for 21% of all 32000 sample projects).

Table 4: Summary of Strategies to be the Best/Worst.

	(%)	**V**	**E**	**L**	**VE**	**VL**	**EL**	**VEL**
chance to be the best	Range	0.1-66	0-5	0-17	0.3-36	4-65	0-13	2-34
	Ave	21	0.8	4	14	32	4	24
cases to be the best		8	0	0	3	18	0	3
chance to be the worst	Range	0-17	45-99	0-45	0-14	0-16	0-4	0-43
	Ave	5	68	15	4	1	6	0.8
cases to be the worst		0	32	0	0	0	0	0

Table 5 shows average AVEOI of 7 identified strategies from all 32 cases. From Table 5, we find that *Perf(VL)> Perf(VEL)> Perf(V)> Perf(VE)> Perf(L)> Perf(EL)> Perf(E)* for all sample projects.

Table 5: Average AVEOI of All Cases.

	V	**E**	**L**	**VE**	**VL**	**EL**	**VEL**
AVEOI	5.8815	7.0276	6.1485	5.9916	5.5475	6.1607	5.6132

Table 6 shows the average PIP between the best strategy and the worst strategy and other 7 identified strategies. From Table 6, we find that: On average, always applying the best strategy can improve the performance by 10% over the traditional V strategy, by 31% over the worst strategy, and by at least 8% over other strategies.

Table 6: Average AVEOI of All Cases.

B-W	**B-V**	**B-E**	**B-L**	**B-VE**	**B-VL**	**B-EL**	**B-VEL**
0.31	0.10	0.28	0.19	0.13	0.08	0.19	0.09

4.4 Answers to the Research Questions

Next we answer the research questions listed at the beginning of the paper.

1. Is the traditionally used strategy, risk value first strategy (V), a good choice for scheduling risk mitigation?

From the Table 4, we find that V strategy is the best strategy for only 21% of all 32000 sample projects, and has a lower chance to be the best strategy than

VL and VEL strategy. It also has a higher chance to be the worst strategy than three other strategies (VE, VL and VEL). From Table 6, we find that the best strategy can improve the performance by 10% over V strategy on average. That is, applying the best strategy for each project will improve the performance of always applying the V strategy by 10%. Moreover, V strategy has a lower performance than VL and VEL strategy on average. *Thus, V strategy is not a good choice for scheduling risk mitigation.*

2. Is there a best scheduling strategy for most projects?

From simulation results, we find that none of the 7 strategies can be a "dominate strategy" for projects of a certain case. The dominate strategy of a case is the strategy that is the best strategy for most projects (i.e. more than 70% projects) of the case. From Table 4, we find that VL strategy has the highest chance to be the best strategy for all sample projects and in 18 cases out of 32 cases. It is the best strategy for 32% projects of all 32000 sample projects. It has only 1% chance to be the worst strategy. This performance is similar to that of VEL strategy (0.8%) and is lower than that of the other 5 strategies. However, VL strategy is the best strategy for less than half of projects (only 32% projects) from all cases. *In summary, there is no strategy that can be the best strategy for most projects of all cases or for most projects of a certain case.*

3. Is there a worst scheduling strategy for most projects?

From Table 4, we find that E strategy has the highest chance to be the worst strategy in all 32 cases. It has at least 45% chance and 68% chance on average to be the worst strategy for all cases. Moreover, it has a lower performance than all other strategies. So, it is the least preferred strategy for scheduling risk mitigation. However, it can be the best strategy for some projects. Among 32000 sample projects, it is the best strategy for 0.8% projects.

5 CONCLUSIONS

In this paper, we formally define the scheduling strategy for risk mitigation, identify some new scheduling strategies with due consideration of key time elements if risk, and compare their performance by applying a stochastic simulation model.

From the simulation results, we find that, for all tested cases: (1) The traditionally strategy, V strategy, is not a good choice for scheduling risk mitigation. The best strategy can improve the performance of V strategy by 10% on average. That means we should not always use V strategy. (2) There is no strategy that can be the best strategy for most projects or for most projects of a certain case. This indicates we should not always apply the same strategy to all projects or to the projects of a certain case. (3) For scheduling risk mitigation, E Strategy is the least preferred strategy among 7 identified strategies. According to above findings, we do not recommend the user to always apply the same strategy to all projects. We suggest the user find the best strategy for each project by running simulation.

Our study has some limitations: (1) The "*Null effect of non-mitigation factors*" assumption and "*Linear effect of mitigation*" assumption are a bit strong for real projects. (2) Compared to the variety of real-life projects, we only run simulation for 32 different cases covering a total of 32000 projects.

In the future, we shall: (1) Expand our study by running more simulation with due consideration of effects of non-mitigation factors. (2) Expand our study with some non-linear risk reduction models, such as polynomial models. (3) Identify new mitigation scheduling strategies. In the future, we will try to identify better strategies. (4) Apply the proposed methods to real-life projects including some large-scale applications to confirm its value.

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