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RISK ASSESSMENT OF NEW PRODUCT DEVELOPMENT PROCESS WITH CONCURRENT ENGINEERING BASED ON STOCHASTIC NETWORK MODEL

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Abstract - New Product Development (NPD) is a process of bringing a new product into the market. Often, large enterprises like Samsung, Apple and Huawei are carrying out NPD from time-to-time to maintain their market share. Speed-to-market has slowly dominating NPD and becoming one of the most important aspect in NPD. Concurrent Engineering (CE) provides an alternative approach to integrate concurrent design into NPD to reduce the overall process completion time. However, the combination between CE and NPD is complicated and involved various risks and uncertainties. In order to deal with the complication and risks in CENPD, a risk assessment model of CENPD based on stochastic Graphical Evaluation and Review Technique (GERT) network model is proposed. A novel simulation approach by using Simul8 is also proposed to solve the GERT model as it is too difficult to be mathematically computed. This research aims to identify the tradeoff analysis between project time and cost and provide useful managerial insights in CENPD project planning.

Keywords - Project Management, New Product Development (NPD), Concurrent Engineering (CE), Graphical Evaluation and Review Technique (GERT), Overlapping and Rework

I. INTRODUCTION

To dates, speed-to-market has become one of the most important aspect especially among the companies that develop new product as it can realize a higher market share and exploit more competitive advantages[1]. Concurrent Engineering (CE) has slowly come into places as companies tend to adopt the acceleration procedures upon the NPD planning. The combination between CE and NPD hasresulted in various risks and uncertainties, thus, motivate the need for careful planning.

Unlike any other business process modelling, NPD is viewed as “creative”, “innovative”, and “iterative” where the interaction of information between activities made up the fundamental structure of NPD[2]. A network model that are capable of highlighting the relationship between activities are proven to be excellent to improve the predictability and efficiency of the project. At the early stage of the development for project planning, several basic network techniques were first introduced into the real world like Critical Path Method (CPM)[3], Metra potential Method (MPM)[4]and Line of Balance (LOB)[5]. The merits of using network modelling technique is that it can be interpreted easily. However, NPD is a stochastic process and the above-mentioned modelling techniques are deterministic point estimation and may not be well-suited for NPD. Over the decades, some notable studies thathas been done on network modeling tool by the combination of Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) after the success of Manhattan Project in 1940 and 1943[6], but the technique cannot be used to define NPD as the it lacks of the capability to discuss loops and probability branches. Another approach which is the Design Structure Matrix (DSM) was being massively studied and applied especially in the field of CENPD. DSM does provide a way to account for the complexities of NPD and rework iterations in a matrix structure, but it does not provide an illustration of the network flow and difficult to beinterpreted[7,8].

An extension of PERT which is called as Graphical Evaluation and Review Technique (GERT) developed by Drezner and Pristsker provides an alternative approach to resolve NPD problem[9]. The network allows probability branches and loops to model the iterative NPD problems and are able to provide accurate and efficient result. In addition, the flow chart network type of graphical presentation can be understood and interpreted easily.

Despite enormous studies have been carried out to use GERT to model CENPD process[10,11,12],conventional studies do not discuss the overlapped rework probabilistic model. Moreover, the feedback rework loop was not being taken seriously where feedback rework loop is nothing but only a repetitive of a series of process which is incorrect. In reality, after a rework occurred, the following activities will get affected, fully or partially.

Thus, this paper aims to propose a risk evaluation and management method for CENPD based on the stochastic GERT network model including overlapping and rework design process. This paper will also propose a novel simulation technique that to solve the complicated GERT network. The layout of this paper is as follow: Section 2 will introduce the model, Section 3 will elaborate the simulation and case study referred, Section 4 will outline the experiments results and Section 5 will summarize and made a conclusion to this paper.

II. MODEL DESCRIPTION

2.1. GERT Network Features

GERT which was developed by Drezner and Pristker as an extension to the PERT network structure, is a stochastic activity-on-arc network. Thus, the nodes itself does not carry the reference of time or cost but only the characteristic of network. Figure 1 shows the GERT nodes.

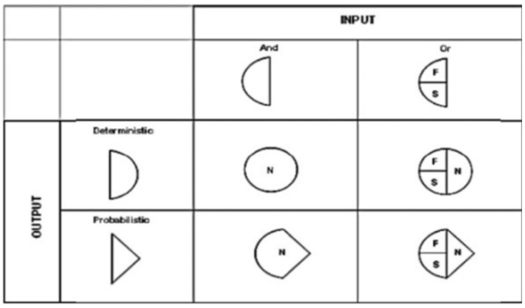

Fig.1. GERT Nodes

AND Node: Realized when all input activities are completed

OR Node: Realized when any one input activity is completed

Deterministic Node: All output activities have a probability of 1

Probabilistic Node: All output activities have a sum of probability of 1

F Number: First node realization required number of

S Number: Subsequent realization required number of activities

2.2. Reworks

At the heart of CENPD lies the rework principle. Reworks is the repetition of task and it is often being associated with the term iterations. In this research, iteration is referred as the number of repetitions. Reworks are the fundamental principle of NPD and are inevitable. In this research, the rework is defined into 3 types which is the Overlapped Rework, First Order Rework and Second Order Rework.

2.2.1. Overlapped Rework

With the addition of Concurrent Engineering (CE) element onto the New Product Development (NPD), there exist an extra risk called the Overlapped Rework risk that resulted from forced overlapping from dependent activities and semi-independent activities[13].Hence, what is the optimal degree of overlapping should the 2 activities be overlapped at?

In this research, Overlapped Rework time in Figure 2 is defined as the rework time of successor activity (activity j in this case) resulted from force overlapping between activity i. Dehghan et al. had stated in his work that the overlapped rework duration depends on several factors which is the overlapping time, strength of the information dependency between the two activities, evolution of information and the experience[14]. Thus, the overlapped rework probability in this research is defined as:

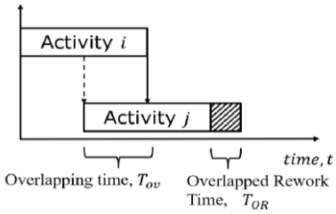

Fig.2. Overlapping

$$P_o = a_{ij}(D_o)^{b_j} \qquad (1)$$

$$D_o = \frac{T_{ov}}{\min\{T_i, T_j\}} \qquad (2)$$

where,

P_o = Overlapped Rework Probability$(0 \leq P_o < 1)$

a_{ij} = Information Dependency between activity i and j$(0 \leq a_{ij} < 1)$

D_o = Degree of Overlapping

b_j = Experience Level $(0 < b_j \leq 2)$

$\min\{T_i, T_j\}$ = Shorter time of either activity i or activity j

T_{ov} = Overlapping Time

The time and cost of overlapped rework are also defined as below:

$$T_{OR} = \frac{a_{ij}}{b_j} \cdot T_{ov} \qquad (4)$$

$$C_{OR} = \frac{T_{OR}}{T_j} \cdot C_j \qquad (5)$$

The GERT representation of overlapping and overlapped rework is shown in Figure 3. The same GERT model will be used for cost.

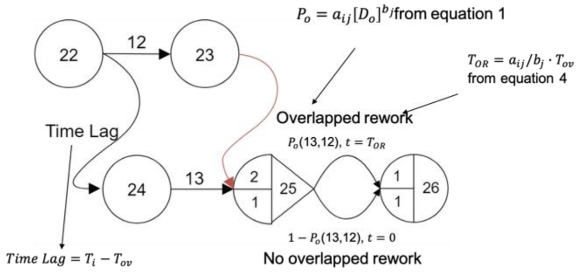

Fig.3. GERT Representation of Overlapping and Overlapped Rework

2.2.2. First Order Rework

First order rework, or commonly known as the feedback rework is a key feature for NPD. As shown in Figure 4, first order rework is the feedback rework of upstream activity i by downstream activity j. It is a process of fixing the error that was committed by the previous activity after the completion of successor activity as shown in Figure 4.

As according to Osborne, who studies the semiconductor projects in intel, found that reworked activities typically exhibits a little further improvement curve for each activity as a step function. In other words, it takes a relatively shorter time and lesser cost to complete the work again as the worker is believed to have gained a certain level of understanding, IE_i to the activity or only certain part of the activity should be reworked, RR_i[15].

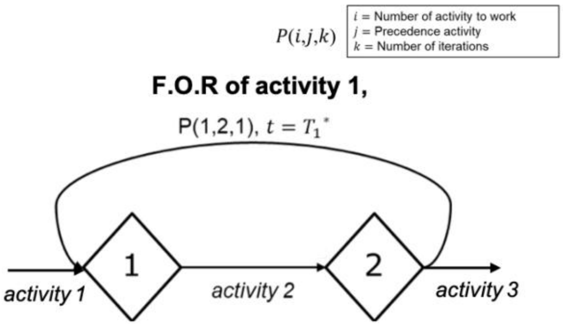

Fig.4.GERT Representation of First Order Rework

The time and cost of First Order Rework are defined as follow:

$$T_{FR,i} = T_i \cdot RR_i \cdot IE_i \quad (6)$$

$$C_{FR,i} = \frac{T_{FR,i}}{T_i} \cdot C_i \quad (7)$$

2.2.3. Second Order Rework

Second order rework is the feedforward rework of downstream activityj by the initiation of a First Order Rework from the upstream activityi. In traditional GERT explanation, when an upstream activity 1 is reworked due to error,activity 2 is being restarted (in the original time) again. This is impractical because in reality, activity 2 may or may not be reworked even if activity 1 reworked. Thus, Second Order Rework is being introduced after the second iteration $(k > 1)$ and shown in Figure 5.

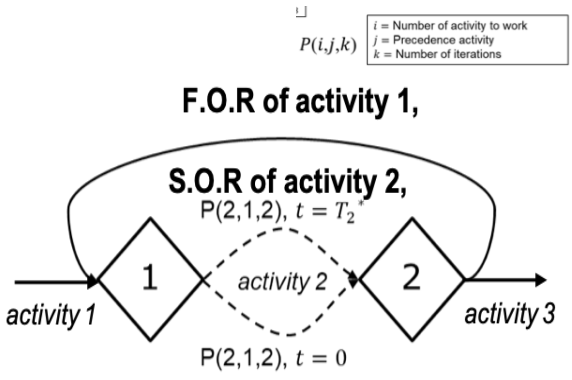

Fig.5. Second Order Rework

Same as First Order Rework, it will take a relatively shorter time and lesser cost to complete the work. The time and cost of Second Order Rework are defined as follow:

$$T_{SR,j} = T_j \cdot RR_j \cdot IE_j \quad (8)$$

$$C_{SR,j} = \frac{T_{SR,j}}{T_j} \cdot C_j \quad (9)$$

2.3. Loop Risk Index

First Order Rework of NPD is often viewed as the main source of uncertainty as it might cause the chain reaction of Second Order Rework and make the system difficult to be controlled. The most effective way to manage the project is to focus more on the source of uncertainty.

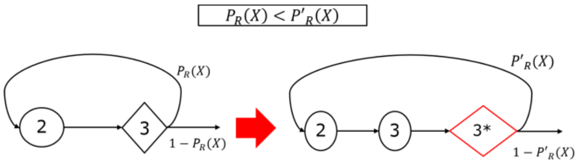

Fig.6. Review Point

By introducing the Review Point as shown in Figure 6, as a safety measure to the project, of which are composed of highly experienced worker, it is assume that it can reduce the First Order Rework probability. However, extra review point means extra cost to the project, if the cost reduction from the reduction of First Order Rework Probability cannot compensate with the extra cost of Review Point, it will only burden the project cost. Thus, Loop Risk Index (LRI) is introduced to identify the highest risk First Order Rework to decide the suitable Review Point Position.

$$LRI_i = Severity_i \times Occurance_i \times Iteration\ timing_i \quad (10)$$

where,

$Severity_i =$ The change ratio in performance in average and standard deviation with and without rework loop i

$Occurance_i =$ The actual occurrence probability from N simulations

$Iteration\ timing_i =$ The percentage of work completed when the rework loop i first occurred

LRI is a rank measure to measure the risk of First Order Rework Loop based on Risk Priority Number (RPN). It was first being modified by Leon et al, as Loop Criticality Index (LCI)[11]. After several discussions, we believe that 3 aspects should be weighted equally rather than weighted more on severity and occurrence in LCI.

2.4. Activity Uncertainty

On the basis of NPD, it is assumed that the activities time and cost are not as simple as the point estimation of average, but it often comes with a distribution. The most common type of distribution like beta distribution was commonly used in various study to represent the cost and time distribution of an activity for example like the PERT. As most of the time in an activity, even the project itself could end early that the expected time, it may be delay by excuses like human problems or machine failure. Hence, there lies an uncertainty within the project time and cost.

Therefore, this research will follow the case study of using triangular distribution to represent time and cost of each activities. One thing to be noted that time and cost are independent of each other as the information transfer time and cost are included in the respective distribution. Even so, they still share a correlation of 0.9 as cost still depend somewhat on time.

III. SIMULATION AND CASE STUDY

3.1. Simulation

The simulation software that will be using in this research is the Simul8 Professional 2005 version. Due to the resource limitation, we are unable to carried out the simulation in later version. Simul8 is a commercialized manufacturing software based on a drag-and-drop basis. It is a simple software, yet the Professional Version provides feature like Visual Logic which enable the user to program the model the way we want. In other words, it is a simple software that can be used to model complicated model. The simulation was taken for $N = 1000$ as it guarantees a certain level of accuracy and confidence. Figure 7 shows the simulation procedure.

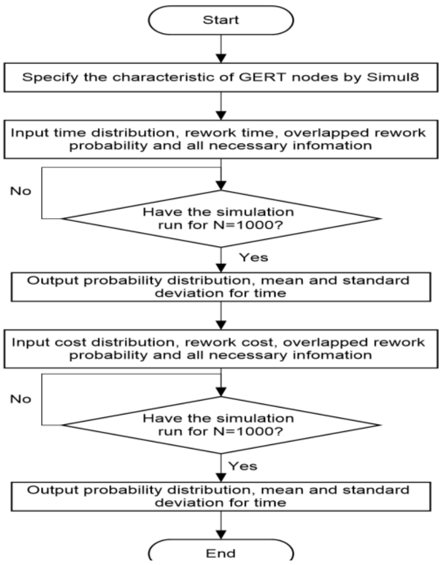

Fig.7. Simulation Flow Chart

3.2. Case Study

The case study used in this research is an Uninhabited Combat Aerial Vehicle (UCAV) preliminary design process at an aerospace company from a study presented by Browning[8]. The GERT model will be converted as the modelling technique used in the case study is Design Structure Matrix (DSM).The rightmost relationship of the sub-diagonal data was drawn in GERT as it is believed to have the highest relation to each other. The GERT model is shown in Appendix A.

The overlapping pair of activities was chosen from Delphi Method of 30 recipients as suggested by Eppinger that it is often very difficult to obtain the exact value of the sensitivity and evolution.Thus, the level of dependency can also be described by some experienced worker[16].

The constants are taken as follow: $a_{12,13} = 1.0$, $b_{13} = 2.0$, $a_{10,11} = 0.8$ and $b_{11} = 1.5$. This model will be taking into account of the decreasing effect in rework probability at 0.5. For example, if the first iteration will have a First Order Rework probability of 0.5, the same rework's probability will be reduced to 0.25 on the next iteration and so on. 3 experiments were being carried out and it will be discussed in Chapter 4.

IV. RESULT AND DISCUSSION

4.1. Tradeoff Analysis of Project Time and Cost against different Degree of Overlapping

This experiment aims to evaluate the tradeoff between degree of overlapping with project time and cost of CENPD process and determine the suitable degree of overlapping based on the constants and formulation defined. The overlapping pair of activities is chosen as activity 12 and activity 13 and the result is shown in Figure 8.

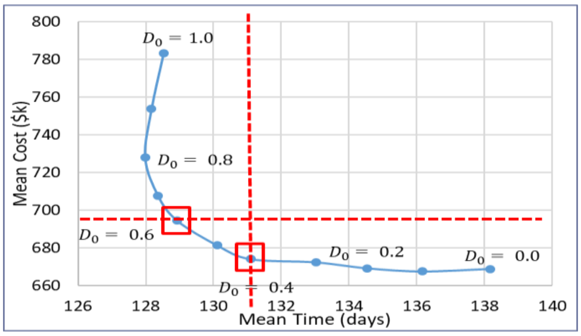

Fig.8. Tradeoff Analysis of Time and Cost against Different Degree of Overlapping

$D_o = 0.0$ indicates there is no overlapping and $D_o = 1.0$ indicates that the activities are parallel or full overlapping. It can be seen from Figure 8 that there exists a tradeoff where more time can be saved by overlapping as the project completion time is decreasing at a higher degree of overlapping. However, more cost will be exerted as the degree of overlapping increases. The main reason of the increment of cost is due to the overlapped rework effect.

The cost will get sensitive and difficult to control beyond the line $D_o > 0.4$, while the time will only begin to increase after $D_o < 0.6$. Nevertheless, the final decision on the degree of overlapping will fall onto the project manager. In this case, $D_o = 0.4$ is the best point of minimum expected cost (if cost is the top priority) and $D_o = 0.4$ is the best point of minimum expected project time (if time is the top priority).

The simulation can also provide the project manager some very useful information like the probability distributions. These information can help the project manager to negotiate with client or setting up the target according to the probability distributions by evaluating the risk. For example, by looking into the point, $D_o = 0.4$, Figure 9 and Figure 10 can be obtained.

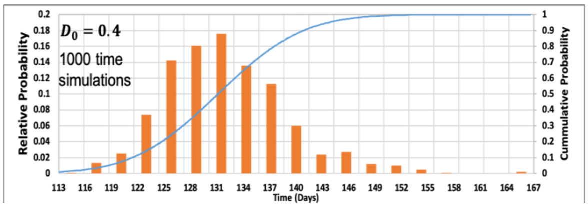

Fig.9. Probability Distribution of Expected Project Completion Time at Degree of Overlapping, $D_o = 0.4$

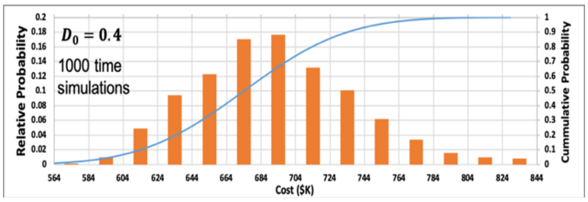

Fig.10. Probability Distribution of Expected Project Completion Cost at Degree of Overlapping, $D_o = 0.4$

4.2. Sensitivity Analysis of Project Time and Cost on Increasing Number of Overlapping.

As some studies tend to optimize the overlapping as much as possible[7,12]. Hence, this test aims to evaluate the effect of project risk and cost when the number of overlapping increased. Another set of overlapping activities will be introduced which is activity 10 and activity 11 as shown in Appendix B. The same steps of experiment 1 was carried out and the optimal degree of overlapping is set to be at only $D_O = 0.8$ for simplicity.

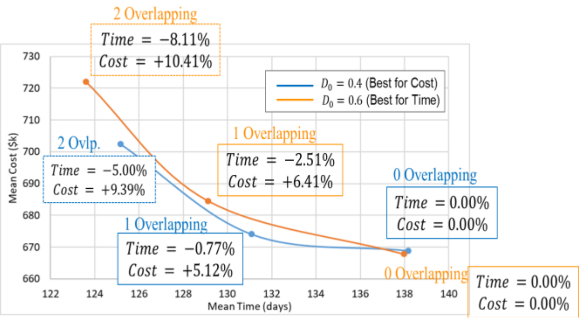

Fig.11. Sensitivity Analysis of Project Time and Cost against Different Number of Overlapping

Figure 11 shows the sensitivity analysis of project time and cost against different number of overlapping. The results from experiments 1 showed 2 possible degree of overlapping depending on either time or cost should be prioritized. Thus, $D_O = 0.4$and $D_O = 0.6$as shown in Figure 11.Second pair of overlapping is said to be fixed at only $D_O = 0.8$ for simplicity.

It can be concluded from Figure 10 that more numbers of overlapping can reduce the project time at different degree of overlapping. However, more overlapping will induce a higher cost due to the overlapped rework. Hence, more overlapping pair is risking the project cost. However, the final decision may still depend onto the project target and the condition.

4.3. Effects Analysis of adding Suitable Review Point on Project Time and Cost at $D_O = 0.4$ (1 Overlapping)

In order to further manage the project risk, Review Point will be added into the model and this experiment aims to evaluate the effect of suitable review point position and the control range of the following Review Point. This experiment will be removing the decreasing effect on First Order Rework Probability to properly evaluate the First Order Rework. This experiment will be carried out at the same example where there is only one overlapping pair at $D_O = 0.4$. The review point at this stage will not add extra time and cost to the project. The time and cost of review point can be used to compare directly to the reduction of expected project time and cost to decide if there is a need to add Review Point.

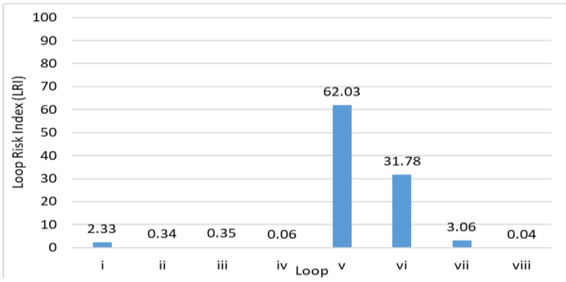

Fig.12. Loop Risk Index

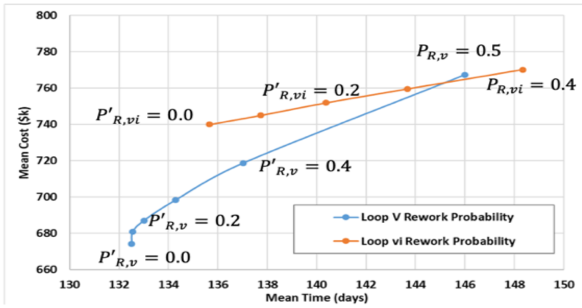

Fig.13. Sensitivity Analysis of Loop v and Loop vi against Different Probability

Figure 12 shows the result of LRI from equation 10 and Loop v is ranked the highest risk First Order Rework loop and Loop vi is ranked the second highest risk First Order Rework loop to the project time and cost. Two rework loop is selected as the possible review position and a sensitivity analysis is carried out to further evaluate them.

Figure 13 shows the First Order Rework probability of Loop v and Loop vi respectively. As the original probability of Loop v and Loop vi was $P_{R,v} = 0.5$and $P_{R,vi} = 0.4$respectively. Hence, the 2 points in Figure 13 was very close to each other. Since the Simul8 simulation was carried out in a stochastic nature, the 2 points hardly collide at the same point (It could be if this is a deterministic simulation). Both the Loop v and Loop vi show a decreasing trend over the project time and cost with a decreasingprobability. It should noted that Loop v can acquire a lower project time and cost due to the higher ranking in LRI.

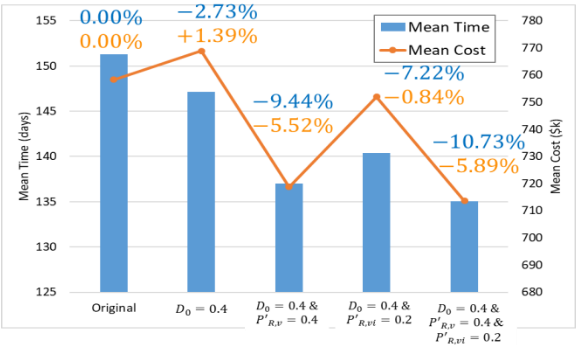

Fig.14. The Project Time and Cost after Different Scenario

With the inclusion of degree of overlapping $D_0 = 0.4$, Review Point at First Order Rework loop v probability controlled at $P'_{R,v} = 0.4$ and First Order Rework loop vi controlled at $P'_{R,vi} = 0.2$, the project time and cost can be reduced to 10.73% and 5.89% respectively.

V. CONCLUSION

One important aspect should be noted in project management is that the project manager holds the call to make the final decision. As different situation will require different approach and there will be never a best solution for all cases. This research presented a more practical cases to use stochastic GERT to model the CENPD process including overlapping rework probabilistic model, First Order Rework, Second Order Rework, iterations, uncertainty in time and cost, decreasing effect on the First Order Rework Probability, Improvement Effect and Rework Ratio. Following are the main achievement of this research.

1. GERT model to model the overlapped rework, First Order Rework and Second Order rework. A probabilistic model of Overlapped Rework is also presented in this paper.
2. The tradeoff between degree of overlapping and the number of overlapping onto the project time and cost are evaluated. The First Order Rework analysis by using LRI is carried out and correspond action was done by introducing Review Point.
3. Novel simulation approach by using Simul8 Professional 2005 version was proposed.

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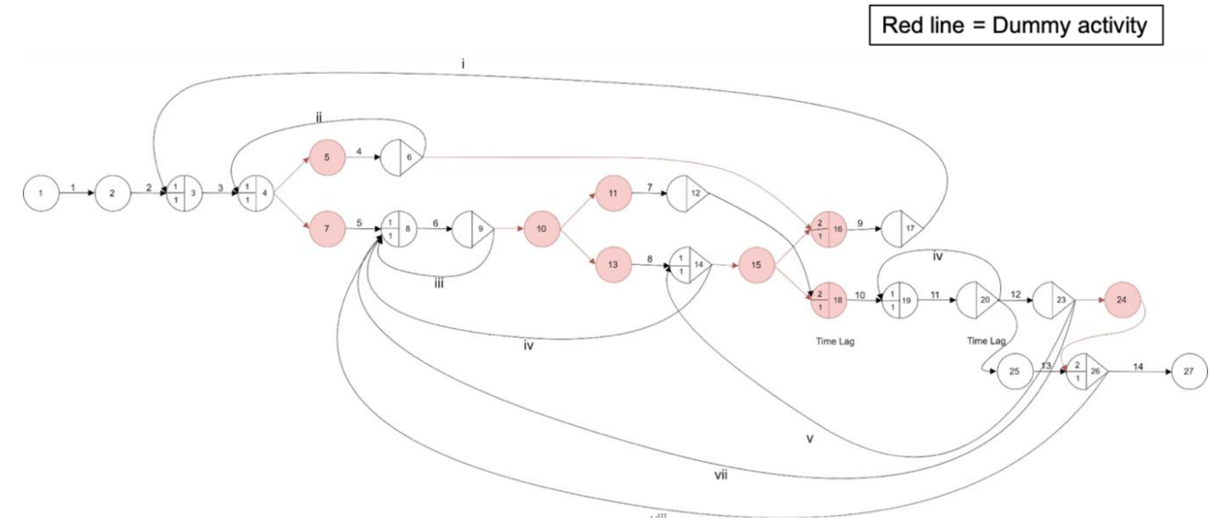
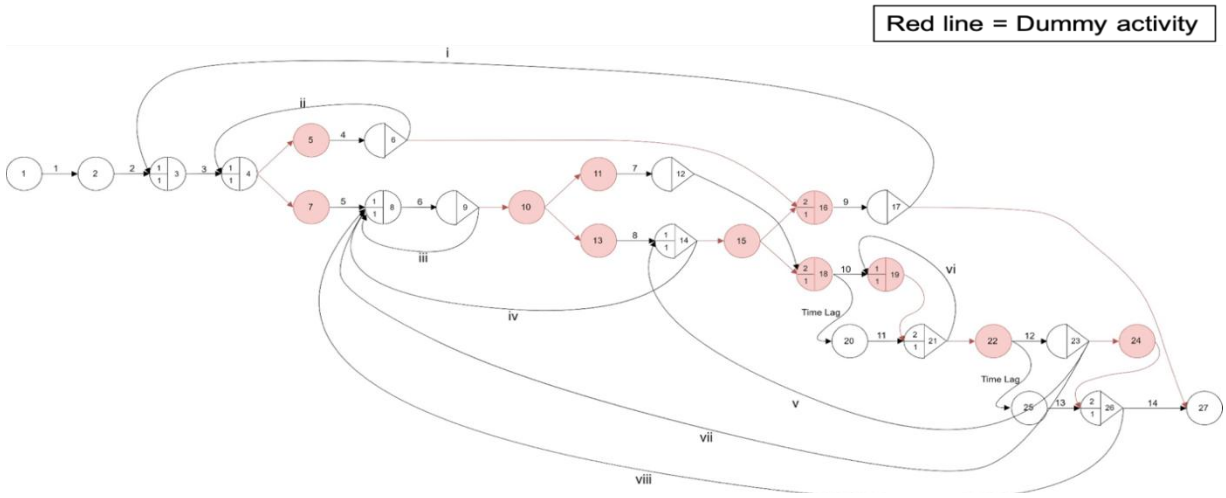
APPENDIX A



APPENDIX B



APPENDIX C

	Duration			Cost			
Activity	BCV	MLV	WCV	BCV	MLV	WCV	IC
1	1.90	2.00	3.00	8.60	9.00	13.50	0.35
2	4.75	5.00	8.75	5.30	5.63	9.84	0.20
3	2.66	2.80	4.20	3.00	3.15	4.73	0.60
4	9.00	10.00	12.50	6.80	7.50	9.38	0.33
5	14.30	15.00	26.30	128.00	135.00	236.00	0.40
6	9.00	10.00	11.00	10.00	11.30	12.40	1.00
7	7.20	8.00	10.00	11.00	12.00	15.00	0.35
8	4.75	5.00	8.75	8.90	9.38	16.40	1.00
9	18.00	20.00	22.00	20.00	22.50	24.80	0.25
10	9.50	10.00	17.50	21.00	22.50	39.40	0.50
11	14.30	15.00	26.30	21.00	22.50	39.40	0.75
12	13.50	15.00	18.80	41.00	45.00	56.30	0.30
13	30.00	32.50	36.00	214.00	232.00	257.00	0.28
14	4.50	5.00	6.25	20.00	22.50	28.10	0.70

★★★