A Study on Project Risk Analysis Model for Outsourcing Based on Bayesian Networks: Application to Small Company OEM Project of Mold Industry

Youn Sook Kim*, Tomohiro Murata*, Jaesug Ki**

Abstract-As a basic industry, mold industry is critical to the competitiveness of manufacturing industry. Due to its OEM operational traits, it is difficult to manufacture standardized products in mold industry and market demands require short production lead times. Today, small- and medium-sized companies (SMEs) in mold industry are seeking more efficient production processes where automated production facilities are better used to reduce lead times and costs. Globally, mold industry is becoming a specialized field compared to other industries and manufacturing processes of global SMEs require close data sharing and management of correlation among each process. As various processes are being operated simultaneously all over the world with different molding techniques under uncertain conditions in mold industry, project risk management is all the more important. This paper surveyed on Korean small- and medium-sized mold producers that outsource more than 50% of manufacturing processes. Companies can swiftly respond to the problems inside the company but when they outsource or toll manufacturing processes, the "critical path" of each process where there are issues of product quality and delayed delivery can also negatively affect product quality and delivery schedule of the entire process, so the paper suggests a new integrated management model for the activities in each process of outsourcing. The new model is an instrument to evaluate and monitor the progress of an outsourcing project and is used as a predictive tool based on probability to find the dangers and fundamental risk factors of project delay.

Index Terms-Project Risk Management, Project Risk Analysis Model, Bayesian Networks, Small Company OEM Project of Mold Industry

I. Introduction

At a time when the technological development in CAD/CAM programs and the rapid growth of 3D printing technologies raised the need for response strategies for newly emerging technologies in the management environment of mold industry higher than ever, the commercialization of CNC machinery that enables 5-axis machining of manufacturing environment and the introduction of 80,000 RPM machining centers that require no post-processing handlings all made mold industry no longer depend on the skills of a master.

More than 25,000 parts are needed to design one car. With all these parts manufactured in different places of the world at the same time, it will be impossible in current global production landscape to manufacture products of the same quality with the same delivery date while maintaining high quality and unique design of a brand, with existing methods. This is why an integrated production risk management system for production processes must be developed to materialize an integrated risk management in the manufacturing environment for global SMEs.

Most SMEs in mold industry have limited production capacity, which makes it difficult for them to flexibly respond to the orders from customers and that is why they outsource manufacturing processes. Also, many companies outsource manufacturing processes to reduce costs in the face of high wages. During the outsourced manufacturing processes, there are many cases where significant dangers arising from quality defects lead to delays in schedule, raising an urgent need for risk management in this regard.

This paper surveyed on Korean small- and medium-sized mold producers that outsource more than 30% of manufacturing processes. Companies can swiftly respond to the problems inside the company but when companies outsource or toll manufacturing processes, the "critical path" of each process where there are issues of product quality and delayed delivery can also negatively affect product quality and delivery schedule of the entire process, so the paper suggests a new risk evaluation model for outsourcing processes.

II. Proposed Bayesian networks model for project risk evaluation

As for risks, all risks that can be identified at the planning and development stage must be identified. Identification processes must be executed constantly during the project so that additional risks can be registered and monitored at the risk management ledger. Information on the risk management ledger includes a name of risk, a type of risk, risk probability, risk impact, fundamental cause, trigger, related activities and etc.

$$P(RP=Occur)=\sum_{RT1,RT2}P(RP=Occur \mid RT1,RT2)P(RT1)P(RT2)\ldots \quad (1)$$

The size of risk impact is subjective information subject to experience and is put in the form of {Low, Medium, High} at NPT of RI node.

Risk Probability (RP) node and Risk Impact (RI) node become the parent node of Delay Impact (DI). Like DI Node of Table I, NPT of DI node is applied with conditional

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density function and risk impact is converted into the distributed form of delay impact (%) by expansion [11]. The converted risk impact affects more than one schedule network activities.

$$P(RP=Occur)=\sum_{RT1,RT2}P(RP=Occur \mid RT1,RT2)P(RT1)P(RT2)\ldots\ldots \quad (2)$$

Risks can be divided into two categories; positive risks (opportunities) and negative risks (threats). More than one response strategies (plan) can be developed to an identified risk [8, 9, 10]. Strategies for negative risks include avoidance, mitigation, imputation, acceptance, and strategies for positive risks include utilization, reinforcement, sharing and acceptance [9]. This paper does not cover imputation, sharing, and acceptance in risk evaluation as they do not directly affect project risks and focuses on response strategies for negative risks. Response strategies for negative risks can be represented by Bayesian networks. Avoidance strategy is to reduce risk probability before a risk occurs and RP node and AVD node become the parent node of RP_AVD node after the execution of avoidance strategy. Like RP_AVD node in NPT of RP_ AVD node is applied with conditional probability, calculating risk probability. Mitigation strategy is to reduce risk impact when a risk occurs and after the execution of mitigation strategy, MTG node and DI node become the parent node of DI_MTG node. Like DI_MTG node of NPT of DI_MTG is applied with conditional density function and after the execution of mitigation strategy, DI is calculated in distributed form. The converted risk impact affects more than one schedule network activities. [11].

Suggested risk management model is a model that evaluates the risk of going beyond production capacity (R) and the quality risk at outsourced manufacturing processes (R') to establish risk management strategies for outsourcing. Outsourcing manufacturing processes are to avoid the risk of going beyond production capacity and aims to complete the production of high-quality molds without any delay in a delivery schedule by proceeding orders with subcontractors without any interruption. As for outsourced production, AVD is a strategy to avoid the risk of going beyond production capacity. After the execution of avoidance strategy, AVD node and RP node become the parent node of RP_AVD node. NPT of RP_AVD in Table I is applied with conditional probability, calculating risk probability. Quality risks at an outsourced manufacturing process become the parent node of risk probability node at outsourced manufacturing processes and are calculated as shown in Table I. Response strategies for risks at an outsourced manufacturing process can be represented by Bayesian networks as shown in Figure1. Trigger node (RT1, RT2) becomes the parent node of risk probability (RP) node. Like RP Node of Table I, NPT of RP node is applied with conditional probability and risk probability is calculated by expansion[12].

Quality risks at outsourced manufacturing processes are deemed hard to avoid and only mitigation strategy is deemed applicable. In order to schematize a Bayesian network, each node's casual relationships must be understood first. And then make each factors and indictors which have impact on planned schedule and cost a node and connect cause and effect with mold manufacturing process based Bayesian network and a outsourcing risk model for key mold specification and excess capacity level can be schematized as shown in Fig.1.

Table I NPT For AVD,RP_AVD,RI

RI(Risk Impact)	
Low	0.2
Medium	0.6
High	0.2

RP	AVD	RP_AVD	
		Occur	Not Occur
Occur	Avoid	0.05	0.95
	Not Avoid	0.99	0.01
Not Occur	Avoid	0.00	1.0
	Not Avoid	0.00	1.0

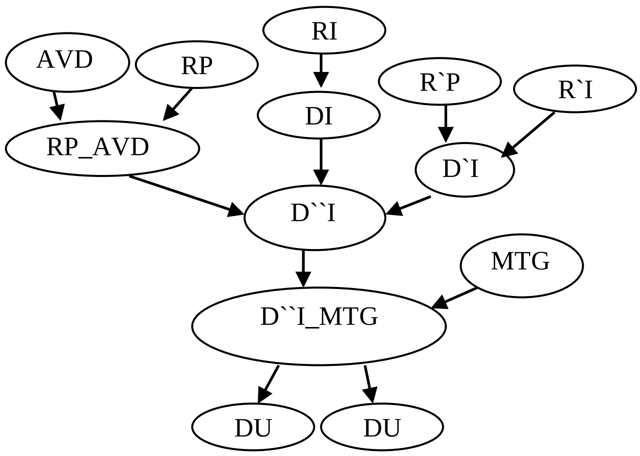

Fig 1 Outsourcing Risk Assessment Mold in Bayesian Nets

Relaxation strategy for excess production capacity is hard to exist. Therefore, in this case of risk assessment model is premised that is excluded. But there could be existed risks for quality degradation in the case of outsourcing. We need Relaxation strategy for the risks

When a risk exceeding the manufacturing capacity occurs, it is necessary to avoid the danger caused through outsourcing. In order to reflect this, the nodes of the avoidance strategy (AVD) and the production capacity excess risk probability (RP) node can be modeled to the parent node of the risk probability (RP_AVD) node after execution of the avoidance strategy. The conditional probability is applied to the NPT of the risk probability node as TableII and the probability of occurrence of risk is calculated.

Table Ⅱ NPT for RP_AVD, RI, DI

RP	AVD	RP_AVD	
		Occur	Not Occur
Occur	Avoid	0.01	0.99
	Not Avoid	1	0
Not Occur	Avoid	0	1
	Not Avoid	0	1

RI(Risk Impact)	
Low	0
Medium	0
High	1

RP_AVD	RI	DI(Delay Impact, %)
Occur	High	TNormal(0.99,0.01,0.1)
Not Occur	High	0

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Relaxation strategy for excess production capacity is hard to exist. Therefore, in this case of risk assessment model is premised that is excluded. But there could be existed risks for quality degradation in the case of outsourcing. We need Relaxation strategy for the risks.Therefore, Relaxation strategy has to be modeled as MTG that reduces the risks of quality degradation in the case of outsourcing, not relaxation strategy for excess production capacity.

The whole saccules of Delay Impact(D"I) caused by risks for quality degradation in the case of outsourcing are influenced by the own saccules of the outsourcing. Therefore, DI and D'I are the same as the Parent Node. D'I is influenced by the percentage of the occurrence probability of risks for quality degradation (R'P) and Risk impact(R'I) of quality degradation. Therefore, R'I and R'P become Parent node of D'I. For this reasons, D'I and D"I can be an applied probability distribution function such as following Table Ⅲ and TableⅣ.

Table Ⅲ NPT for R`P, R`I, D'I

R`I	
Low	0.2
Medium	0.6
High	0.2

R`P	R`I	D`I
Occur	Low	TNormal (0.1, 0.01, 0, 1),
	Medium	TNormal (0.3, 0.01, 0, 1),
	High	TNormal (0.5, 0.01, 0, 1),
Not occur	0	

Table Ⅳ NPT for DI, RI', D"I

DI	R`I	D``I
0	Low	TNormal (0.1, 0.01 ,0, 1)
	Medium	TNormal (0.3, 0.01, 0, 1)
	High	TNormal (0.5, 0.01, 0, 1)

Schedule delay rates(D"I_MTG) after relaxation strategy for quality degradation risks is influenced by relaxation strategy for quality degradation risk (MTG) and D"I. Therefore, D"I and MTG becomes Parent node of D"I_MTG. Schedule delay rate of the entire mold (D"I_MTG) is applied probability distribution function such as below Table Ⅴ. Schedule delay rates(%) is figured out after performing relaxation strategy for quality degradation

Table Ⅴ NPT for R'P, MTG, D"I_MTG

R'P	MTG	D''I_MTG
Occur	Mitigate	D"I * 0.3(70% Decrease)
	Not Mitigate	D"I * 1.0(Not Changed)
Not Occur	0	

III. Mold manufacturer Case study

For verifying the outsourcing project risk assessment model based on Bayesian nets proposed in this paper, we applied the case project of "A" company for modeling and assessing our proposed risk assessment model using AgenaRisk[2]. We modeled and analyzed the outsourcing project schedule risk based on the data presented in Table Ⅳ ~Ⅴ. In this example, avoid strategy is assumed that the probability of overcapacity risk should be reduced to 100% and also mitigation strategy assumed the probability of quality risk should be reduced to 70%. Figure 1 and Figure 2 are the results of modeling the schedule network diagram using Bayesian net tool.

Diagram based on the Bayesian network that integrates the CPM schedule network and the risk and risk response strategies based on the data in Tables Ⅵ and Ⅶ. Fig.1 shows the integrated schedule network diagram based on Bayesian network[2]. After run risk assessment using Bayesian network analysis tool of AgenaRisk, Table Ⅵ shows the results.

The results of Table Ⅷ can be derived by carrying out the risk evaluation. The table lists the risk and response strategies, the expected time, the 90% confidence interval, and the magnitude of the delay effect.

Table Ⅵ Activity, Expected Time, Dependency, Early/Late Time and Total Float

DI	Activity name	Expected time	Dependency	Early Time		Lste Time		Toal Float
				ES	EF	LS	Lf	0
1	Start	0		0	0	0	0	0
2	Planning	2	1FS	0	2	0	2	0
3	Outsourcing	30	2FS	2	32	0	32	0
4	Ocean Freight	8	3FF	32	40	32	40	0
5	Management	38	1SS, 4FF	0	40	0	40	0
	Finish	0		40	40	40	40	0

Table Ⅶ Identified Risks, Probability, Impact and Related Activity

Risk ID	Risk Name	Probability	Impact(Delay)	Related Activity
R1	Overcapacity	0.5	High (About 99%Delay)	2
R2	Low Quality	0.3	Medium (About20%Delay)	2, 3
R3	Delay of Freight	0.1	Medium (About5% Delay)	3

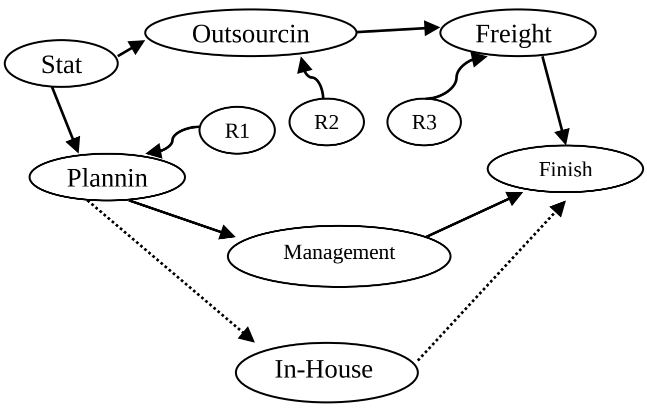

Fig 2 Integrated Schedule Network in Bayesian Nets

Fig.2 is an example of an integrated schedule network. The risk and strategy column contains the identified risks and the corresponding strategies, so you can compare the magnitude of the impacts by risk and response strategy.

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The delay impact column contains the difference between the expected time when the risk is not applied and the expected time when each risk and the corresponding strategy are applied. By using Bayesian net based unified schedule network, we can quantitatively evaluate the impact of the overall risk on the outsourcing project, as well as assess the magnitude of the individual risk impact. It can also quantitatively assess the magnitude of the impact of a risk response strategy on project objectives.

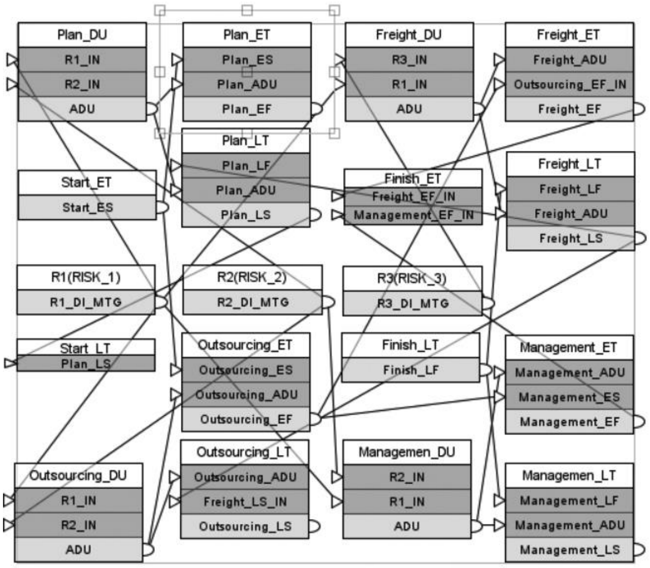

Fig 3 Integrated Schedule Network with Agena Risk

Table Ⅷ Results Table of Risk Assessment for Storage Tank Project

Risk/Strategy	Expected Time	Confidence Interval (90%)	Delay Impact
Without Risk	80.671	[75.911, 86.121]	-
Only R1	107.860	[77.162, 141.160]	27.189
Only R2	95.987	[77.802, 123.080]	15.316
Only R3	95.987	[77.802, 123.080]	15.316
All Risks	89.938	[76.864, 119.320]	9.267

IV. Results

This paper categorized outsourcing as a unit process and expanded the existing risk response strategies to using Bayesian network, we proposed an integrated outsourcing schedule network model and executed a certain risk assessment. And then finally, the possibility and the feasibility of the proposed method are presented through practical application. In this paper, we propose a risk assessment method only for a total outsourcing risk. However, there is a trade-off between schedule and cost and partial outsourcing, so research on how to evaluate risk by integrating future costs and schedule is required.

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