AGENT-BASED MODELING AND SIMULATION OF RESOURCE ALLOCATION IN ENGINEERING CHANGE MANAGEMENT

Bochao Wang and Young B. Moon
Departement of Mechanical and Aerospace Engineering, Syracuse University, Syracuse, NY 13244, U.S.A.

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Abstract: An engineering change (EC) refers to a modification of products and components including purchased parts or even supplies after product design is finished and released to the market. While any company involved in product development would have to deal with engineering changes, the area of engineering change management hasn't received much attention from the research community. It is partly because of its complexity and lack of appropriate research tools. In this paper, we present preliminary research results of modeling the engineering change management (ECM) process using an agent-based modeling and simulation technique. The aim of the research reported in this paper is to study optimal strategies of resource allocation for a company when it is dealing with two kinds of ECs: "necessary ECs" and "initialized ECs." We discuss results from these simulation models to illustrate some insights of ECM, and present several research directions from these results.

1 INTRODUCTION

Any company involved in product development would have to deal with engineering changes. An engineering change (EC) refers to a modification of products and components including purchased parts or even supplies after product design is finished and released to the market (Lee 2006), (Clark & Fujimoto, 1991), (Huang, Yee & Mak, 2003), (Terwiesch & Loch, 1999), (Chen 2002, DEC et al. 1998). ECs may be initiated by customers, suppliers, or the company itself.

While EC management is a complex task, the increasing market competition forces the companies to take a more pro-active role in handling the engineering changes. In a sense, any engineering change is a disruption to a normal operation. And it may impact several functions across a company. However, an effective and efficient management of engineering changes can bring significant benefits to company's competitiveness (Rukta, 2006) by satisfying its customers better and further improving its products.

Despite of its importance, the area of engineering change management hasn't received much attention from the research community. Notable exceptions are the works of Nadia (Nadia, 2006) and Terwisch (Terwiesch, 1999). Nadia studied engineering change orders (ECOs) thoroughly and even identified key contributors to long ECO lead times with improvement strategies advices. Terwiesch compared the behavior of two methods of managing an engineering change request (ECR) process.

The aim of the research reported in this paper is to study optimal strategies of resource allocation for a company when it is dealing with two kinds of ECs: *necessary ECs* and *initialized ECs*. Necessary ECs refer to those ECs dealing with must-to-do changes to address problems such as technical problem, manufacturing process or design fault. Initialized ECs may arise from introducing new technology to match competitors, to take the lead, to simplify or improve manufacturing processes, or to accommodate customers' proposal. So the latter is not mandatory but may bring potential benefits to the company.

2 THE RESEARCH METHODOLOGY

2.1 ABMS

ABMS (Agent-based Modeling and Simulation) is a computational model for simulating the actions and interactions of autonomous individuals in a network,

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with a view to assessing their effects on the system as a whole. It is a relatively new approach to modeling complex systems (Macal, 2005) in order to support decision-making (Nilsson, 2006) and obtain deeper understanding of intrinsic regularity in a system.

We adopted ABMS so that we can model ECM activities (Garcia, 2005) affected by various factors such as consumer bahavior, competitive or cooperative relationship (Lam, 2007) among companies, and different adaptive strategies by manufacturers. These factors are quite difficult to be modelled using other conventional simulation modeling techniques.

2.2 Methodology

2.2.1 The Basic Model

The basic model was built to address a question: what is the impact on customers' satisfaction level when limited resources are allocated differently between necessary EC and initialized EC. Some simple properties and rules are given to agents, and we expect aggregate macro-scale behaviours or trends emerging from the self-adaptive and interactions between agents.

2.2.2 Hypothesis

We came up with six hypotheses concerning EC factors, then built models to see whether these can be supported or not under certain circumstance. In future, we plan to use real data to see its validation.

<u>ECM Hypotheses</u>

H1. The effectiveness of a company's ECM is positively correlated with the firm's market share.
H2. The degree of co-operation between manufacturers and suppliers is positively correlated with the performance of the firm.
H3. Changing the ratio between initialized ECs between necessary ECs may lead to a different result in a short period time.
H4. Initialized ECs are not important in gaining market share.
H5. The level of EC frequency is positively correlated with customers' satisfaction.
H6. ECM results are different for different types of industry.

3 MODEL DESCRIPTION

3.1 Agents and Behaviour Rules

Agents represent autonomous decision-making entities that interact with each other and/or with their environment based on a set of rules. In a reasonable environment, every agent would get its necessary information, make adjustments on its behaviour following the rule through iterative learning, and pursue a certain goal or objective. Specific agents used in our models are described next.

3.1.1 Manufacturer Agent

Manufacturers make similar products in a same industry. Besides arranging daily regular production, they receive ECRs driven by customers as well as themselves. Then they evaluate and make decisions on whether an EC is a *necessary EC* or an *initialized EC*. They implement and track ECs. Also they obtain feedback from the market to adjust their strategy.

Different types of manufacturers have different rules to govern their behaviour. In our models, there is one control manufacturer who keeps its strategy constant. It depends only on feedback of market share and adjusts the ratio of resources used for necessary ECs vs. Initialized ECs in order to determine how to get maximum profits. Another type of manufacturer uses a feed forward strategy to act. The third kind of manufacturer is an intelligent manufacturer that memorizes prior decisions and results and learns to perform best.

3.1.2 Consumer Agent

Consumers may propose ECRs, and consumer satisfaction is based on price, other consumers' opinions, product quality and the level of continuous improvement in product. These rational consumers take best offers with highest personal satisfaction (Kano, 1984). The interactions between different kinds of agents and among similar kinds agents lead to an aggregate macro scale behaviours or emerging trends.

3.1.3 Supplier Agent

Suppliers keep in close touch with a manufacturer, and many ECs may need supplier's help to reduce EC cost and lead time, or improve efficiency. However, these will cost extra communication and research expenses. A manufacturer may choose to cooperate with other suppliers or not, considering their potential profits as in the prisoners' dilemma scenario.

3.2 EC comparison

A summary of characteristics of two kinds of EC (necessary EC and initialized EC) is given in Fig. 1.

	Necessary EC	Initialized EC	Implication
Urgency	Urgent ASAP	Evaluated and discussed Decision making Even need to be tested Planning in advance	Deal with Initialized EC shouldn't be hurry and beyond engineering management
Cost	Mostly low	Relative high	Extra evaluation and negotiation, usually new tech involved
Risk	Pretty Low	Somewhat high	New tech, research related No foreseeable profit
Customer Satisfaction	Satisfied	Excitement	Kano model analysis

Figure 1: Comparison of two kinds of ECs used in models.

3.3 Model Procedure

Figure 2 shows a general procedure used in the models.

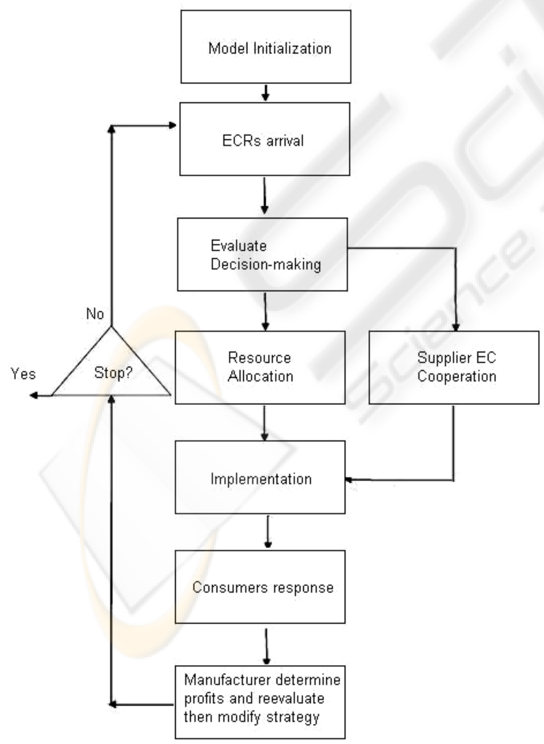

Figure 2: General model procedure.

First, we initialize the population of manufacturers and consumers. Also, we determine the manufacturers' initial resource allocation value with adaptiveness that limits the range of allocation adjustment.

Every consumer has some probability to buy a certain kind of product regardless of its vendor, and the probability varies depending on people and products. We also inject some influencing consumers whose opinions have more weights on other consumers.

An initial risk is determined based on different industries' attributes, but it can be changed during simulation.

We take ECM tool quality and components standardization into consideration in ECM attributes. There exists one variable called "competition degree" that means how fast potential manufacturers may grow and enter into this market for competition, and of course along with potential bankruptcy.

Output displays show the status of manufacturer resource allocation of initialized ECs, market share ratio comparison, profit comparison, number of consumers who prefer initialized ECs. An agent map shows consumer inclination switch by color change.

4 RESULTS

4.1 Preliminary Observations

The model results show that the initial ratio of allocation plays a significant role. If one manufacturer cannot obtain accurate information of consumers' preference or inclination unlike its competitor, the performance in terms of market share is very poor. Early bird catches the worm.

However, if other conditions are similar or the same, a manufacturer a backward strategy may catch up with others and even dominate the market. A feed forward strategy works to some extent, but the efficiency rely on initial difference between forecasted data with real data. Intelligent agent always performs best, since it obtains the advantage of the pervious two strategies, makes distinctive approach from learning experience. The strategy to stay unchanged usually results in the worst performance.

ECM tool and standardization play important roles in EC process. A higher implementation level of these can help to increase profits and market share of the manufacturer. However, the model results show that the significance of such ECM tool and standardization are not so great. Since an initial strategy determines whether a manufacturer receives the right information of trend from consumers, the adaptability (Weiss, 1996) is the key for catching up with a market leader and for keeping its market share as well as its loyal consumers.

Other influencing factors such as advertisement, consumers' forum, etc., seem to make the manufacturer easier to dominate the market if their products attract most of the consumers in the beginning. However, it does not mean that this situation cannot be altered, even though the change seems to be pretty hard. The difficulty for one manufacturer to snatch the dominator position is positively correlated with the value of influence-probability.

Competition become much more fierce when potential manufacturers' market shares grow at a faster speed and are aggressive such as certain suppliers who want to expand to become a manufacturer. Eliminating manufacturers who occupy very limited market share with low profit through competition happens easily.

4.2 Conclusions on the Hypotheses

In this Section, the six hypotheses that we posed in Section 2 are assessed based on the simulation results.

H1. An effective ECM brings low cost and high efficiency to a company, which leads to higher profits and market share.

H2. Our model focused on the relationship between supplier & manufacturer using the game theory of prisoner's dilemma to see the consequence. A higher level of cooperation helps both of them, but especially the manufacturer.

H3. The ratio between initialized ECs and necessary ECs tells what a manufacturer emphasizes. However, the impact is observable only after some time.

H4. Initiated EC may or may not be a major contributor toward gaining market share, depending on the circumstances such lead time. If a lead time for EC implementation is relatively short, the initialized EC makes little impact. However, if competition is intense enough, the pressure from the market and competitors may force manufacturer to make initialized ECs more frequently, thus giving consumers more satisfaction.

H5. Up to a certain point, increasing EC frequency helps to attract more loyal consumers. However, very frequent ECs introduce more disruptions to the manufacturing system leading to worse performance in market share gain.

H6. We considered EC risk, EC lead time and EC complexity to differentiate different industries. A high risk causes two extreme phenomena. Manufacturers may gamble to pursue profits even though they are sometimes temporary profit. Or they may stay with a conservative strategy to keep foreseeable market share. While at low EC risk, the competition is being encouraged.

5 CONCLUSIONS

The model results confirm that it is useful to classify ECs into initialized ECs and necessary ECs. Also, the competitive nature of a market influences how a firm should emphasize necessary EC vs. initialized EC. The greater the competitions are, the greater the need to emphasize initialized ECs exists. The situation will necesseciate the adoption of new technologies that promote customer satisfaction to excitement rather than just satisfaction.

Another interesting result is that intelligent manufacturer who combines forecasting and feedback strategy and learns from past experience performs best in most cases. Still, adaptive feed forward and feedback strategy works even better in some cases. A possible explanation for this phenomenon is that even though intelligent manufacturer learns from past, some changes happen without any foreseeable notices. As a result, the adaptive ones outplay intelligent ones since they simply rely on difference between expectation and reality.

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