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Abstract

In this study, we develop a computational model and a multi-agent simulation system for the analysis and design of product development organizations. The computational model represents the product development organizations as a collection of autonomous/semiautonomous computational agents interacting with each other. It is used to model the dynamic, complex, and distributed nature of organizations. To operationalize the model, a multi-agent simulation system is developed where the detailed information requirements and decision-making procedures of human decision-makers are translated into objected oriented programming modules. This is used to measure the effect of alternative organizational structures and coordination mechanisms on organizational performances. Several hypotheses are developed to test the relationship between organization design parameters and organization performances.

Introduction

In this study, we develop (1) a computational model and (2) a multi-agent simulation system for the analysis and design of product development organizations. The development of the computational model is based on distributed artificial intelligence and organization decision theories. It is used to model the dynamic, complex, and distributed nature of organizations, and to design efficient organizations and their information processing strategies. For product development organizations, the computational model represents the product development organizations as a collection of autonomous or semiautonomous computational agents interacting with each other. The computational model consists of five generic elements: (1) agent, (2) task, (3) coordination mechanism, (4) control structure, and (5) environment. The model is named ATCCE (Agent, Task, Coordination Mechanism, Control Structure, and Environment) to reflect its five generic elements.

Overview of the Computational Model

Agent is the most fundamental building block of the computational model. The basic assumption behind the computational agent is that it is boundedly rational. "Boundedly rational" means it engages in basically consistent, value-satisficing calculations or adaptations within certain time or memory constraints. Each agent is also heterogeneous in that they have different kinds of knowledge and different degrees of cognitive capability. Agent has six attributes: role, decision process, goal, search strategy, and association. Agent combines some sort of goal information with current internal state and environmental input. Goal describes the desirable situation of an agent. To achieve the goal, sophisticated search and planning mechanisms are employed.

Task has two dimensions: task interdependence and task variety. The task interdependence can be of three types: pooled, sequential, and reciprocal (Thompson [1967]). The task interdependence is an important element of the model since different task relations may require different kinds of organization design and supporting information systems. In product development organizations, the task variety has two dimensions: product variety and design variety.

Coordination mechanism is an important requirement to ensure the cooperative decision processes and cohesive operations among individual agents. Coordination is defined as the act of managing interdependencies between activities of multiple agents working together for their goals. Depending on the types of task interdependence, we may adopt different types of coordination mechanisms one at a time or concurrently. Coordination mechanisms considered in the computational model are: frequency of information exchange, mode of information exchange, degree of information exchange, and resource allocation methods.

Control structure defines the ways in which distinct tasks are assigned to individual agents and coordination between them is maintained. There is a general agreement that no control structure is appropriate in all situations (Thompson [1967]; Galbraith [1977]). We consider three basic control structures: functional, decentralized, and distributed control structures. The functional team structure reflects the essence of the traditional functional organization where the primary responsibility of product development moves sequentially from one function to another. The decentralized team structure has highly self-contained teams of agents that are organized around products or product lines. The unique characteristic of the distributed team structure is that it is simultaneously function-oriented and team-oriented.

Environment defines the exogenous element of the model. By taking into account the environment, the proposed model views an organization as an open system that responds and adapts to environmental change. We consider two dimensions of market related environment: homogeneous-heterogeneous dimension and stable-dynamic dimension. The homogeneous-heterogeneous dimension concerns market and resource homogeneity. The stable-dynamic dimension refers to whether the market environment is dynamic. The dynamics of the market environment can be measured in terms of the frequency of the change and/or the magnitude of the change.

Simulation Experiments

To operationalize the model, we have developed a multi-agent simulation system where the detailed information requirements and decision-making procedures of human decision-makers are translated into object-oriented programming modules. The simulation system is used to simulate and measure quantitatively the effect of alternative organizational structures and coordination mechanisms on organizational performances and suggest the best alternative. The simulation system consists of five major computational agents: (1) product design agent, (2) manufacturing process agent, (3) marketing agent, (4) team management agent, and (5) resource management agent.

The following hypotheses are developed to test the relationship between design parameters and four performance measures (i.e., decision making time, payoff variance, payoff discrepancy, and total profit). These hypotheses will confirm or reject some of existing empirical evidence from the previous studies. More importantly, these hypotheses will provide additional insight into the dynamics of product development organizations that were not addressed previously.

H1: Performances in product development organizations are positively associated with agents' commitment to organizational goals.
H2: Performances in product development organizations are positively associated with agents' aspiration level.
H3: Performances in product development organizations are positively associated with team associations.
H4: Performances in product development organizations are positively associated with frequency of information exchange.
H5: Performances in product development organizations are positively associated with asynchronous information exchange.

Parameter Values

The five design parameters selected are: (1) goal commitment (team goals vs. organizational goals), (2) search strategy (neighborhood search vs. global search), (3) association (the number of channels with other teams), (4) frequency of information exchange (the number of search iterations before exchanging information with associated teams), and (5) mode of information exchange. Factorial Design

We will use a full factorial design to provide precise results. The total number of simulations will be 162 (i.e., 2*34), or 4860 runs (i.e., 30 replications for each simulation).

Analysis of the Experimental Results

The following are four regression models for organizational performances. Significance is at .05 level and below, unless otherwise indicated.

Total Profit = 516953.778 ASP + 120894.685 GC + 1120065.975
Adjusted R^2 = .5304

Development time = 802.074 ASP - 129.157 FIE + 92.426 ASS + 561.123
Adjusted R^2 = .887
Profit variance = 73310.852 ASS + 20488.056 GC + 8083.907 ASP + 116071.734
Adjusted R^2 = .768

Profit discrepancy = -1337281.185 ASS + 1146252.1605
Adjusted R^2 = .790

The regression model for the total profit suggests that organizational profit is positively associated with the aspiration level and the goal commitment of agents. Association (p = .145), frequency of information exchange (p = .199), and mode of information exchange (p = .296) are excluded from the model. The exclusion of association from the model is counterintuitive since the conventional wisdom says that the more associated teams are with each other, the better performance they exhibit. The second stage ANOVA test will explore this issue further. The exclusion of frequency of information exchange is also surprising since we expect that more frequent information exchange lead to better performance.

The regression model for product development time suggests that product development time is positively associated with aspiration level and association. However, product development time is negatively associated with the frequency of information exchange. Goal commitment (p = .075) and mode of information exchange (p = .613) are excluded from the model. Aspiration level came up as the strongest parameter for both profit and product development time.

The regression model for profit variance suggests profit variance between teams is positively associated with association, goal commitment, and aspiration level. The association comes up as the dominant parameter. This observation indicates that the more associated teams are with each other, the wider their profit gaps are between teams. The frequency of information exchange ($p = .702$) and the mode of information exchange ($p = .377$) are excluded from the model. Overall, the model suggests that some teams increase their team profits by exchanging information, but other teams decrease their team profits due to the information exchange.

The regression model for profit discrepancy suggests that profit discrepancy be negatively associated with association. This model indicates that more association lead to better estimation of their team profits. It is noted that while the association played a positive role for profit variance, it played a negative role for profit discrepancy.

In summary, these simulation experiments show that for product development organizations:1. Total profit and profit variance are positively associated with team members' commitment to organizational goals.2. Total profit and product development time are positively associated with team members' aspiration level.3. Profit variance is positively associated with team associations. However, profit discrepancy is negatively associated with team association.4. Performance of product development organizations is NOT positively associated with frequency of information exchange.5. Performance is NOT associated with the mode of information exchange.

References

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