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Distributed decision making in complex organizations: the adaptive enterprise

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Abstract

In this paper, we give a tutorial overview of how the convergence of business decision making (BDM), information technology and computer aided process decision making can make organizations adaptive. One framework for advancing the conflux of these ideas is provided by distributed network theory and non-equilibrium thermodynamics. In this theory, the integrated system of decision makers, software and physical devices are viewed as a network of semi-autonomous activities that interact through boundary conditions. The dynamics of such systems can be stabilized using inventory and flow control. Decision making based on value analysis leads to trajectories that are stable and minimize cost. We describe the basis for evaluating business performance using the intrinsic value of new processes and products. We finish by reviewing very briefly how the drive towards excellence can make it easier for universities and industry to carry out cooperative R&D.

Keywords: Technology management; Convexity; Information technology; Finance; Business systems ; Process control; Stochastic process; Inventory control; Flow control ; Entropy; Dissipation; Risk; Separation principles; Agents; Lean manufacture

1. Introduction

The organizers of PSE2003 challenged us to consider the integration of business decision making (BDM) and process systems engineering (PSE). In particular, we were asked to address the following issues:

1. What kinds of decisions do business executives make?
2. How can the PSE community help facilitate business decision making?

These questions require a precise definition of the terms business decision making and process systems engineering. We can then apply the formal methods of information technology, communication and computation to provide answers to these challenging questions and develop architectures for the integration task at hand.

A business is a system encompassing financial relationships, material and service flows. Business decision making is concerned with allocating resources in order to maximize the expected value of the business without incurring undue risk. The decisions can be grouped into the three distinct categories: (1) Investment, (2) Operation and (3) Finance. Competitors who persist over time make decisions in these areas so that they maintain a competitive advantage by differentiation. Managing that differentiation is the essence of long term business strategy (Stern & Stalk, 1998).

Mr. Helfert (Helfert, 2001) argued that focusing on accounting measures like Return on Investment and Profit, as reported on the balance sheet, gives a myopic view of decision making since they do not include how new markets and products impact earnings in the future. Business decision makers therefore use measures based on value creation like the Net Present Value (NPV), payback time or Internal Rate of Return (IRR) when they develop the business plan. Business leaders also understand that they need to balance the expected return against risk. Mr. Warren Buffet (Buffet, 2002), one of the country's more successful investors, argues that the project portfolio should be balanced using an underlying and potentially subjective measure he calls the *intrinsic value*

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which captures the multi-dimensional aspect of decision making.

The objective of the business leader is therefore two-fold: (1) He must develop a portfolio of processes and products to differentiate his company from the competition. (2) He must ensure that he has the management structure in place to execute plans in the best manner possible. The following four points, as highlighted by Mr. R. McNamara (McNamara, 1995), form the cornerstone principles for project management:

1. Defining clear business objectives,
2. Developing plans to achieve the objectives,
3. Systematically monitoring progress against the plan and
4. Adapting the objectives and the plans as new needs and opportunities arise.

A student of process systems engineering recognizes the feedback loop and sees how it provides adaptivity, stability and robustness properties that planning alone cannot provide.

The idea of modeling process decision making and industrial dynamics using feedback and dynamical systems theory is quite old and goes back to the pioneering work of Prof. Herb Simon[1] of Carnegie Mellon University (Simon, 1957). He studied the dynamics of enterprises using Laplace transform methods and developed the separation principle that plays a critical role in the development of modern process control systems. The study of industrial dynamics was advanced further by Forrester (1979) who elucidated an instability in supply chains referred to as demand amplification. His ideas on feedback loops and systems theory formed the basis for very fruitful developments that continue to have a significant impact to this day (Sterman, 2000).

What is new however, is the development of information technology (IT) systems encompassing extensive networks of hardware and software for data storage, information processing, computation and communication. IT is responsible for the most profound change to affect our industry since mass production became common early last century. The use of IT has led to enormous savings and improved efficiency. A well implemented IT system simplifies data entry, unifies information representations, keeps track of transactions, smoothes data flow and facilitates information exchange and control using highly distributed resources. These distributed networks integrate physics, computation and communication as they adapt and change as technology develops and new needs arise (Ydstie, 2002).

Hierarchical business models, suitable for long production runs in static markets, have in the same manner given way to decentralized and flexible systems that allow innovation and continuous improvement. Distributed business systems, introduced under various guises like lean manufacturing, just in time production, total quality management (TQM), pull scheduling, six sigma, etcetera, have been developed to manage inventory, improve flexibility and reduce wastage (Stadtler & Kilger, 2000; Taylor & Brunt, 2000). These techniques are implemented and adapted for use in almost all major US manufacturing industries and contribute towards faster turn around, lower inventory and improved cost structure for their supply chains.

In order to help business decision making, PSE research should therefore be aimed towards developing methods that are suitable for implementation in highly distributed environments and capable of dealing with the analysis and display of complex information. The problems we need to come to grips with are many and not limited to the following:

1. Multiple objectives need to be satisfied simultaneoulsy.
2. Decisions are usually discrete (go/no go).
3. Risk and uncertainty are important.
4. Modern organizations rely on highly distributed and decentralized decision making.
5. PSE tools need to be integrated into distributed communication and data base storage systems.
6. We need to develop clever methods to display key results. Decision makers usually rely on highly abstract information (often graphic) that capture key concepts and ideas. They rarely act on one single number, no matter how well it has been optimized.
7. Tools to address complex (hybrid/discrete/multi-scale) dynamics need to be developed.
8. Adaptivity and learning in complex systems and networks of physical processes need to be better understood.

In this paper, we model a business organization as a network of physical and computational activities coordinated over a high bandwidth communication network. We call such a network an *adaptive enterprise*. The adaptive enterprise should be flexible and agile so that it can respond to changing needs as the boundary conditions and even its internal structure changes. In this way, the enterprise acts as a complex adaptive system (Gell-Mann, 1994). The very tentative technical ideas we put forward are based on our previous work on supply-chain management (Ydstie, Coffey, & Read, 2003), business decision making (Ydstie & Jiao, 2003) and stability and control of distributed process systems (Ydstie & Alonso, 1997). In these papers, we sought to exploit self-stabilising and self-optimization principles derived from thermodynamic network theory and electrical circuits. The similitude between business finance and thermodynamics follow because:

1. Thermodynamic and business systems are input–output systems with behavior constrained by conservation laws. The cash balance plays the role of the first law of thermodynamics since cash is conserved. It is this property which allows us to develop a balances for income and cash flow.
2. There exists a concave extension which gives rise to dissipativity. In thermodynamics, concavity follows from the non-negative rate of entropy generation (there exists no

[1] Nobel Prize in Economics, 1970.