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Complexity Science as a New Strategic Tool

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CAP GEMINI ERNST & YOUNG

Complexity Science as a New Strategic Tool

At the dawn of the new millennium, the business environment is undergoing unprecedented rapid and radical change. The new economy, driven by globalization and the exponential growth of the Internet, is forcing firms to re-evaluate not only their strategies, but also their entire belief systems. To cope with today's complex business problems, executives need to strive not to predict and control, but to understand and adapt. Simultaneously, they need to adjust their thinking from decision planning during design time to decision-making during run time. New tools that can aid in this transformation have emerged out of the study of natural systems and are rapidly being adopted by the architects of the new business paradigm.

By Tony Plate, Senior Scientist, BiosGroup, Inc. and Dale Perrott, BiosGroup Liaison - CGE&Y Office of Supply Chain Technology, April, 2001

Complexity Science

The science of complexity had its origins in the study of non-linear phenomena at MIT and Los Alamos National Laboratory, popularized under the name of "chaos theory." As an offshoot of these studies, the Santa Fe Institute was founded in 1984 by Nobel Laureates and other world-famous scientists to pursue studies of non-linear behavior. Although the Santa Fe Institute remains the world center of basic research into the science of complexity and complex adaptive systems, a burgeoning number of commercial enterprises are bringing complexity science to the business world.

The sciences of complexity are a relatively new way to understand our world. The traditional scientific approach to natural phenomena, popular since Newton's time, is reductionism, i.e., a system is understood by taking it apart and understanding its constituent parts in isolation. This approach has pervaded our understanding of the world for over 300 years, and for good reason - it works wonderfully for many phenomena. The reductionist approach is also the classical approach to solving business problems: companies are typically understood and operated as a collection of aggregate parts, such as departments or divisions, and reductionist thinking has influenced how these parts ought to be managed.

Complexity science adopts a different, complementary view of the world. Complexity science is the study of systems composed of many and varied parts that interact, typically, in complex and non-linear ways. Unlike traditional approaches, complexity science recognizes that such systems cannot be understood simply by understanding the parts - the interactions between the parts and the consequences of these interactions are equally significant. Hence systems are looked at in their entirety, recognizing that many phenomena are more than the sum of their parts. This fundamentally new approach often yields deep, new insights into the nature of systems and potential solutions to their problems.

SFI scientists found that much of the complex behavior of systems, from weather to markets, resulted from the interactions of their individual sub-components or agents. Agents can follow extremely simple rules, but their interactions over time often result in surprisingly complex behavior patterns (e.g., why birds flock). Such behavior, called "emergent behavior," is difficult to predict using traditional reductionist approaches that study agents in isolation. Agents may also have more complicated strategies, including goal-directed behavior and the ability to adapt to their environment. Another common property of complex systems is phase transitions: their behavior proceeds in a series of abrupt "jumps" in response to a gradual change in external conditions or agent activity (e.g., ice melts, hot water boils).

Complex adaptive systems include many business systems as well as biological systems. In business systems the agents are diverse: consumers, workers, companies, associations, governments, etc. The emergent properties of these agents include behavior such as consortium formation, monopolies, marketplaces, product promotions, obsolescence, product lock-in, inventory pileups, ordering delays, and glitches.

Complexity scientists have brought a host of tools to bear on the understanding of complex systems, and have advanced the state of the art in many areas. Modeling and simulation, visualization tools, data mining, and a host of other techniques are part of the complexity science toolset. Far from being only a theoretical or academic pursuit, complexity science offers some of the most promising new concepts, insights, and tools for understanding interconnected systems and for solving gritty business problems, particularly those presented by today's emerging supply networks.

Supply Networks

In today's increasingly interconnected business environment, the old concept of the "supply chain" - a linear process - is being replaced by the idea of the "supply network." Supply networks are made up of multiple companies, working both competitively and cooperatively to produce, transport, and sell products to the consumer.

Management of the supply chain has evolved rapidly. In the 1980's, firms strove for cost reduction through individual departmental optimization (i.e., each department within the organization drove down its own costs). The time frame for this operating model was measured in weeks and months. The supply chain remained the province of the back office, of interest to the executive suite only insofar as the operations research department was able to deliver cost reduction through un-integrated point solutions.

The 1990's witnessed the widespread installation of Enterprise-Wide Resource Planning (ERP) systems. Organizations now looked across departmental boundaries and sought corporate-wide optimization. Service performance was coupled with cost minimization as the goal of supply chain management. The operating time frame shrank to days. And, because of the major impact that supply chain performance could have on shareholder value, its management became a mission-critical process.

With the arrival and rapid adoption of the Internet, the web-connected economy, and increased collaboration, the supply chain world has changed again. Optimization is moving towards a decentralized process, but not to a departmental focus. Today, companies must dynamically configure and reconfigure their supply networks, matching up with specific suppliers, transportation providers, and distributors to maximize the network's performance given the real-time constraints on all participants. This requires tools that can optimize "on the fly" on an individual transaction basis. The new goal of supply network management is to deliver operating flexibility, without which corporations will not only fail to prosper but will face the distinct possibility of rapid extinction.

This is indeed a brave new world. Through the advancements in technology and communications, today's new supply networks have an order of magnitude more "links" or business relationship contact points than those in the past. The rate of change in the business world and its increasingly competitive nature make it necessary to re-evaluate and re-configure a supply network in real time rather than every few years. The companies that succeed in the future will be those that bring new approaches to supply network management: holistic approaches that consider the overall system impact of local decision rules, and that enable continuous adaptation.

Neither the traditional reductionist approach of local optimization, nor the sequential optimization provided by an ERP system, can capture system-wide emergent properties. By attacking local operating efficiencies, these approaches can achieve small, incremental improvements. But major performance phase transitions are invisible to tools located within the system itself, and it is impossible to determine which system parameters are the key drivers of overall system performance. Tools that permit the examination of all of these systems as a whole, and subsequent optimization along the multi-dimensions of this rapidly changing space, are only just emerging. Complex adaptive systems are very effective in addressing these problems because they can capture and model both the processes and the decision-making that occur in such systems, as well as searching for optimal strategies and adapting as the environment changes.

Another great advantage of the complexity science approach over traditional reductionist thinking is its ability to incorporate an organization's ability to adapt into the complexity-based dynamic models. By examining biological systems, scientists have learned much about adaptation, and are applying these findings to the business problems that arise as a result of unpredictable events or rapidly changing environments. One of the most challenging problems faced by businesses in such environments is scheduling, especially the ability to reschedule when unpredictable events occur. Dynamic scheduling problems arise in all kinds of situations, from irregular airline operations to Internet routing to manufacturing. The need for adaptable solutions is heightened by the growing interconnectedness of companies in the new economy, where a seemingly small problem in one part of a business process can become amplified as it cascades down a production line and across a supply network.

The Theory in Practice at P&G

Procter & Gamble is perhaps the world's best-known consumer products company. P&G is renowned for its cutting-edge approach to many aspects of its business, including supply systems. P&G has recognized that there is much room for improvement even in their (and the industry's) best current supply networks. Driven by their desire to stay at the front of the industry, and to define its future direction, P&G has turned to complexity science for new insights into how to improve their supply networks.

As a first step in applying complexity techniques, the supply network for a single P&G product was modeled end-to-end from several vantage points. The goals were to understand how system behavior as a whole was influenced by the behavior of individual agents, and to evaluate what the potential for improvement was in the system. Agent-based models were driven by actual point-of-sale data, product formulation information, and the configuration of the supply and distribution network. Agents included stores, consumers, warehouses, trucks, plants, etc. The models simulated the flow of multiple SKUs. Two powerful themes emerged from these models:

- The existence of key system levers (i.e., those that produced phase transitions in the system), for example, the number of trucks redistributing products among stores to prevent out-of-stocks The models also showed at what values the levers operated optimally (i.e., where the system operated just on the efficient side of a phase transition curve).

- The prevalence of local operating constraints that have an unforeseen negative system-wide impact. These constraints, such as requiring shipments to go only in full truckloads, are often instituted for sensible reasons, e.g. controlling local costs. But this constraint impacts the whole system by slowing and disrupting the flow of information about consumer demand, leading to an unnecessarily long replenishment cycle and high inventories.

One model revealed the importance of information sharing between partners. When retailers shared information about upcoming product promotions with other supply chain participants, there would be a significant savings of inventory in the system as a whole, while sales would increase slightly, and out-of-stocks on the store shelves would decrease.

Another model was constructed to see whether it made sense to wait until the last minute to assemble the ingredients or packaging for a particular SKU. This model, which looked at distribution centers, trucks, and stores, was based on the geographic location of the distribution centers and four months' worth of actual point-of-sale data. The model revealed that shipping the ingredients for several SKUs in undifferentiated form helped the supply chain deal with fluctuations in consumer demand. In some cases, a delay in the differentiation of packaging was all that was needed to improve supply network performance.

A third approach taken by P&G was to look at warehouse operations. Modeling suggested that supply network efficiency could be improved if a warehouse, upon receiving an order from a distribution center, was empowered to remove certain SKUs from the order and reallocate them to other warehouses that were close to being out-of-stock in those items. This reallocation could deliver up to a 35% reduction in excess inventory.

Combined, these models provided P&G with insights that either had previously not been revealed, or had been inferred through a combination of managerial experience and intuition, but not confirmed. The potential operating improvements are perceived to be well into the nine-figure dollar range.

Scheduling Cargo at Southwest Airlines

Southwest, a major U.S. airline, needed to reduce costs and improve the efficiency of its cargo operations as this revenue source continued to grow. The airline was experiencing significant bottlenecks at three airports. Close scrutiny of the problem airports failed to uncover the cause. Southwest opted to engage complexity scientists to look at the system as a whole and to identify improvements in the areas of transfer reduction, easing congestion and bottlenecks, and reducing overnight volumes. The resulting simulation modeled the flow of cargo through the system and allowed users to isolate specific factors that could be improved.

Data was obtained concerning actual flight schedules, manifested cargo, and bin utilization reports. Individual flights were defined by origin/destination city pairs, takeoff and landing times, flight number, and route number. Routes involving multiple planes were defined as same-plane or transfer routes. From the cargo perspective, the first was preferable because it required only one loading and one unloading operation per route. The movement of freight in Southwest's system is not automated: the ramp agents physically unloading and loading the freight make decisions about what route the freight should take, based on what is written on the parcels and what they know about the flights. Southwest required a simple solution to the problem with their complex system: a maximum of several rules that could be followed by ramp agents, and no new information systems.

Scientists focused their attention on the freight house receiving and manifesting area, which was critical to effecting changes in the flow of freight through the system. They modeled both the current handling strategy, nicknamed "Hot Potato," and several alternative strategies. The Hot Potato strategy is to put a parcel on the next flight going in the right direction.

The best alternative strategy involved a simple modification of the Hot Potato strategy: let the ramp agents know the final destination of the plane, not just its next stop, and have them route according to that. Together with an improved initial freight assignment algorithm, this strategy has reduced parcel handling by 75%, and significantly impacted the number of transfers that remained overnight. In addition, congestion and bottlenecks were reduced, especially at those stations that transferred the most weight.

Conclusion

Complexity science is just now evolving from academic research to the intellectual basis for a host of new products. This commercialization is enabled by a confluence of two key factors. The first is the need for new solutions. The increasing interconnectedness of companies and business processes, the increasing pace of change, and intense competitiveness mean that traditional approaches based on isolated business unit optimization are no longer satisfactory. As companies strive to understand their operations and how to improve them, they are finding invaluable insights and borrowing tools from complexity science.

The second factor is the emergence and maturation of complexity science itself. While nature has been applying complexity science for over 4 billion years, the science is relatively new to humans. This field of study was almost completely unknown 15 years ago, and many of its principles were still unproven 5 years ago. The science had to go through a natural maturation period before it was ready for commercialization, and it needed the computing power that has only recently become commonly available.

Nowhere in the business world is this science more powerful than in its application to the non-linear supply network of the future. Consisting of a dense web of commerce allies and competitors, the future "supply chain" will stand or fall on its ability to adapt and dynamically optimize. Complexity-based business applications have already proven their usefulness in performing system-wide, multi-objective, real-time optimization in supply chains and similarly complicated logistics processes. As supply networks continue to evolve, complexity science will continue to provide them with the tools to do so.

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