National Textile Center

FY 2005 for 2nd Year Continuing Project Proposal (04 Projects)

Project No.

S04-NS02

Competency: Systems

Quantifying the Value of Information in a Supply Chain

Project Team:

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Objective:

Since markets are becoming more spread out and global, optimizing the efficiency and effectiveness of the entire supply chain is becoming increasingly important for the success of the U.S. softgoods industry. With the explosion in E-commerce technologies, communication and collaboration are much easier among the entities in the entire chain from the fiber supplier to the retail store. For example, data such as inventory levels, demand forecasts, consumer demand information, and ordering policies can be shared among members of the supply chain to try to minimize the distortion that can occur along it, commonly known as the Bullwhip Effect. Curtailing this phenomenon has the potential to simultaneously decrease excessive inventory and stockouts as well as the variance in order fluctuations, consequently reducing manufacturing costs along the entire chain.

Several studies, including some NTC projects (e.g., [11-13]), have tried to develop methodologies that optimize supply chain design and management by determining good sourcing strategies for domestic and off-shore suppliers, facilitating the selection of the best set of collaborative partners and building tools that allow sharing of information. However, while models have been developed for specific cases, no general model exists for determining the level of cost savings that can be achieved as a result of the various forms of information sharing. In addition, characterization of the optimal forms of information sharing based on system characteristics has not been carried out. By quantifying the improvement in performance of the supply chain when different levels of information sharing are employed, a competitive advantage can be gained in the global market. Therefore, we will conduct a rigorous analysis developing new analytical models that will determine the value of information sharing as well as how the information being shared impacts this value (i.e., determine the best forms of sharing).

Progress Statement:

We have developed a computationally efficient procedure to determine control policies for an infinite horizon, undiscounted Markov Decision process (MDP) with restricted observations (ROMDP). An MDP with restricted observations is a special case of a Partially Observable Markov Decision process (POMDP). In the MDP framework, it is assumed that an agent interacts synchronously with a world (Kaelbling et al. 1998).

Although a ROMDP is a special case of a POMDP, it is still intractable to solve. We have developed a computationally efficient algorithm, based on the policy iteration method of Howard (1960), for the infinite horizon undiscounted cost case. The algorithm uses two forms of perturbation to move away from local optima in the search for the globally optimal solution. In the first form, the policy is perturbed while in the second the steady state probabilities are perturbed. In each case, perturbation is applied when the ROMDP converges in the normal sense of the Howard method. Based upon empirical studies to date, we have found that the algorithm finds the optimal deterministic policy for over 99% of the general ROMDP problem instances generated. In the instances where the optimal policy cannot be determined, the average error in the objective function is less than 1%.

This algorithm has been applied to supply chain ROMDP problems in order to study the value of information sharing, specifically inventory position. To date we have experimented with a simple two-member supply chain (supplier/retailer). For this model, there are four possible modes of information sharing: (1) No sharing, (2) Retail inventory shared only, (3) Supplier inventory shared only; and (4) Both retail and supplier inventory shared. In each case we have experimented with single agent, i.e. a fixed retail policy and optimized supplier policy, and double agent optimization, i.e. both entities optimized (See Figure 1 below).

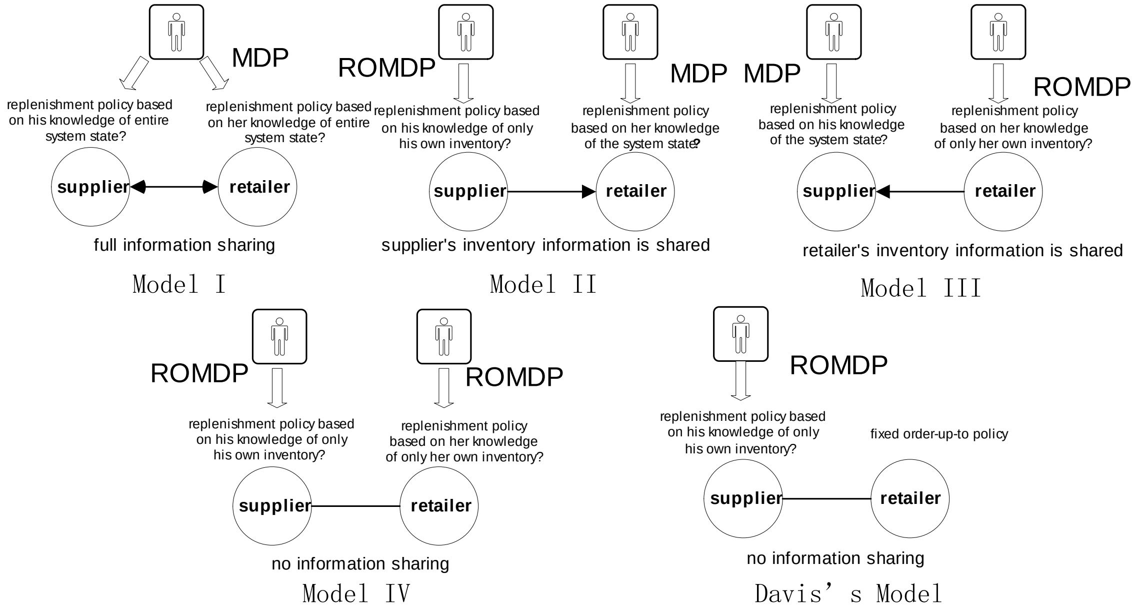

Figure 1

TAC Review Goals:

The goals of this project for the first 17 months are:

1. Develop the solution methodology for ROMDP problems and experiment on classic and supply chain problems to demonstrate the effectiveness of the approach.
2. Extend the methodology to large-scale models and apply it to an experimental design of supply chain problems to determine the value of information under different scenarios (design parameters such as costs, capacities, and supply chain structure).

The goals for the final year are:

1. Characterize the optimal control policies with and without information sharing.
2. Implement the characterizations within a supply chain simulation.
3. Experiment with the simulation for problems of a scale beyond the capability of the ROMDP approach.

Approach:

In the literature, no one has examined this problem from the perspective of steady state optimal control. A Markov model is a natural way to represent a system where information is completely shared. However, in order to determine its value, optimal control under limited information must also be determined. A decision maker for an entity in the supply chain may know his/her own inventory, demand, etc. but not that of all other members of the chain. Partially Observable Markov Decision Processes (POMDP), in particular, MDPs with restricted observations provide the framework under which to determine optimal control policies under differing information sharing strategies. Based on the supply chain structure being used, the definition of the state space indicates the available information known to the decision maker at any point in time. By grouping system states, information can be restricted to certain entities in the supply chain. The steady-state optimal policy and gain can then be determined for any configuration for a consistent and equivalent measure of performance between alternative configurations and is the basis for determination of the value of information.

We use the completely observable Markov model to define a state partition where states in the partition must have the same control decision. Conceptually, this can be thought of as a partially observable system where the observable outputs are some aspect of the state space. For example, the observable output for a decision maker in a two-stage supply chain, with state space defined as inventory level at each stage, would be the inventory position. While the completely observable model reflects information that is known at both stages, we want to quantify the difference associated with the level of information sharing by comparing the optimal control decision and the gain of the process under all levels. In a POMDP, the optimal control for the entire space of vectors must be determined, which is not easily implemented or usable. The restricted observation model determines optimal control the decision maker would choose given he possesses partial information about the process; his observable outputs. Therefore, we seek the optimal control decision for the available outputs that are linked to the internal process.

The optimal gain and associated control policy when information is completely shared can be determined using Howard's dynamic programming solution method [9]. However, finding optimal policies for the restricted observation undiscounted cost case is not straightforward. Current research is dominated by enumerative based searches. Although these have provided acceptable locally optimum solutions for their applications, a more robust and computationally efficient algorithm must be used to study the information sharing. In addition, some of the heuristics have no guaranteed performance bound [8,21] or guarantee of finding a deterministic policy [19]. The method proposed in [7,21] cannot handle very large problems, as their algorithmic structure is enumeration based. The algorithm in [8] finds locally optimal solutions. To determine optimal policies for the undiscounted cost case, when partial or no information is shared, we propose to augment Howard's method based procedure with a combination of policy and state probability perturbations. The algorithm determines the policy by altering Howard's policy iteration to calculate the expected transition cost as a function of the payoff structure for each state in the set and their corresponding steady state probabilities.

While the large-scale techniques extend the size and types of models that can be optimized, modeling of real systems will still be limited. Based on characterization of the optimal control of the MDP-based models, insight will be gained into the value/impact that information sharing has on the supply chain. This insight can be incorporated into a more detailed supply chain simulation and is key, since effective characterization of optimal policies helps define the control structure for the more general model discussed below.

Computer simulation will allow us to accurately incorporate the uncertainties that are inherent in supply chains into a computer model. However, simulation evaluates alternatives that we determine. The proposed supply chain simulator will be applied to scenarios that contain a large number of SKUs, operating conditions and forms of information sharing. Since the number of decision possibilities is extremely large, finding good/optimal control is very difficult. Several methodologies have been proposed for simulation optimization; however, they are limited to continuous variables only. Due to the stochastic nature and potential non-linearity of the problem as well as the fact that some of the variables are discrete, a solution methodology using genetic algorithms will be used. In addition, GAs are invariant to noise generated by the evaluation function which makes them a perfect candidate for stochastic simulation optimization.

In order to build an effective simulation optimization methodology, we will investigate several factors. First, we must consider the stochastic nature of simulation. Often several simulation replications of one decision point are performed to determine a mean and variance of a solution. The GA technique used has to take into account that the solution is not a scalar but a distribution. Usually, the more replications that are performed the better the estimate (i.e., the lower the variance). However, the more replications that are performed the slower the optimization technique. Therefore, we must balance accuracy with efficiency in determining how many replications to perform.

Second, we need to decide how to partition the time spent searching for solutions, since this can have an effect on solution quality. Early in the search, the GA does more global exploration for good areas of the search space. While later in the optimization routine, it will perform more local exploitation. We propose to do fewer replications early in the search (i.e., will be more fuzzy about the space) and more later in the search to become more precise.

Third, we must build the decision surface of our solutions. Building a surface is important to increase computational efficiency. A hybrid combination of meta-models and simulation will be explored for this purpose. After generating the initial population, the GA will evaluate newly generated decision points using the meta-model and then simulate the most promising points. These new points will be used to build a better meta-model on the fly.

Outreach to Industry:

The research team has developed a computerized version of the Supply Chain Game which has been shown to be a valuable tool in disseminating the ideas of the dynamics of a supply chain to the industry, suppliers to the industry, as well as students. The different forms of information sharing will be added to the computerized game and used to illustrate the value in a structured gaming environment.

New Resources Required:

Funding is required for student and faculty salaries plus travel funds to the annual forum, industry sites, and conferences. All other necessary resources are in place**.**