Modelling in e-Business and Supply Chain Management

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Introduction: This paper summarizes some key modeling approaches and paradigms that emerge when looking at analysis and decision making in the areas of e-business and supply chain management. It provides three examples of application, two semi-automated systems that could be used in procurement and marketing and one from an e-business perspective on a large transport organization, the Indian Railways. We identify some key features of modeling as applicable to such real world situations.

Models, as generally understood, are abstractions that are useful and insightful, of a part of the real world. In the e-business world, models are abstractions that use appropriate data types and usually lead to computationally tractable algorithms that are then used for a variety of analyses and sometimes for automated decision-making. In supply chain management, models are useful for understanding the complexity of multi-player collaboration and end competition.

E-Business and Supply Chain Management: E-business largely refers to internet-based and ICT supported business models. Internal to firms, it is part of modern management practice, especially for data capture, reporting, communication, archival and retrieval of information. The full scope of contribution of e-business models to decision making is still being assessed.

Across firms, e-business technologies are being applied more and more, in the e-commerce mode in a variety of ways. Models of e-business have substantial potential to improve decision-making, but the extent of impact is still uncertain.

The term Supply Chain Management, on the other hand, has already become too large a concept for comprehensive analysis, so we shall not attempt anything of that nature here. Some of the main modelling implications are that we are moving from single actor to multiple actor models, and that we need to keep an eye on (final) customer satisfaction and effectiveness (e.g. service measures and responsiveness), while keeping costs under control. An important part of Supply Chain analysis is the identification of a supply chain driver, which would provide an unambiguous perspective on sequential decision-making in the supply chain. One hypothesis is that it is brand building and stake in brand ownership that defines a supply chain driver.

Some conundrums are inherent in the terminology and application of the principles of the paradigm of supply chain management. We list a few interesting ones below.

- The term “Chain” implies that there are different entities, but the term “Manage” refers to a single entity, as far as span of control is concerned.
- There is debate about whether a supply chain is really a value chain, or perhaps a demand chain. We stick to the term supply chain, for convenience.
- A customer of an organization would like to see maximum flexibility. Paradoxically, it is internal cohesiveness and streamlining within the organization, that would usually lead to outward flexibility as far as the customer is concerned.
- Most industries begin with economies of scale upstream and end with economies of scope downstream.

Types of models: We list four types of useful models below. These would cover the bulk of quantitative models used in the area.

- Statistical and other models for sampling of data and inference
  These include more recent models of data mining.
- Optimization
  These are models from a single decision maker’s perspective
- Game theoretic/equilibrium models
  Such models attempt to model multiple entities actively participating in defining joint outcomes.
- Decision support
  Simulation and system dynamics are one important class of models here, and we also include visualisation support and the provisioning of triggers for making decisions of various types.

Modeling paradigms: Models involve abstraction using different data types, such as algebraic variables, graphs, networks, tables etc. More recent models involve more aggregated notions of an agent.

The system description and behaviour could be hierarchical (reflecting a managerial hierarchy within a firm or business hierarchy), sequential (because of the way decisions are made or revealed) or distributed (synchronous or asynchronous).

We now look at three examples of models in different fields of e-business and supply chain management.

Example 1 - Modern procurement: In this, we consider a large number of (possible) suppliers, who are globally dispersed. A mix of relationships could apply. There could be close relationships with a few selected suppliers, while continuing to scout the market for newer possibilities for short term capacity smoothing and other goals.

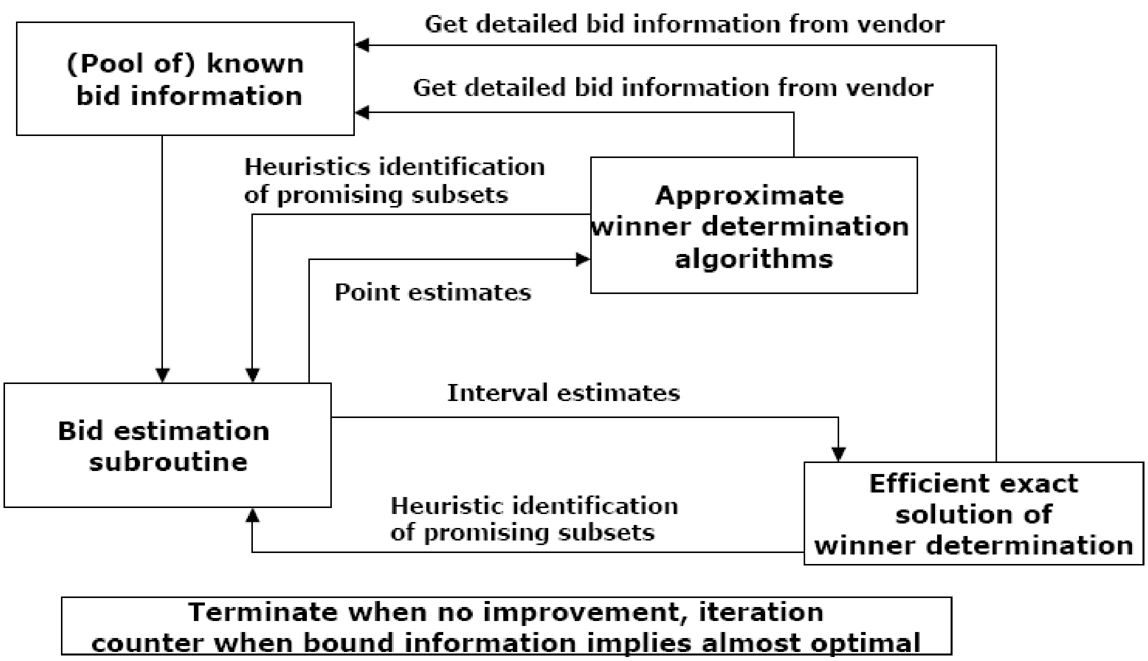
A feature of modern procurement, especially for commodity type products is to handle fluctuating prices in spot markets. There could be medium/long term quantity commitments with some suppliers

Combinatorial procurement in an E-business environment: A particular version of the procurement decision is where there are benefits in joint or combined procurement of items. Here, there are a variety of items, which have a certain complementarity of resources in manufacturing. There could be synergies in manufacturing and transport for the supplier, who would then seek to exploit economies of scope. There could be numerous constraints on desired/likely supply list from any one vendor.

In the e-business context, we would first need to deal with automated bid collection information. Then, there is the task of communicating with sellers about quantities required, timing of deliveries, quality concerns, servicing etc. Therefore, there are multiple attributes for purchasing and allocation decisions.

Consider a scenario where n items have to be procured (n could be a large number). If there are k vendors, then there are a huge number of possibilities for joint bids for multiple items. This is a large and tough problem to solve even with respect to number of bids available (and more so since the number of bids are potentially themselves exponential in n). Innovative methods are required to model and solve such problems.

For the problem with n items and k vendors, there could be $k2^n$ bids/subsets for supply. Even getting all bid information is daunting in such a case. An approach for this is the following (see figure below).



Using past data (or starting afresh), start with a (small) number of bids that cover all the items. Solve a restricted winner determination problem (for which a number of procedures are available). Using a heuristic, generate promising subsets that could be part of a winning basket. Use an estimate of the value of these bids in a larger winner determination problem. If a bid is part of a winning basket, get exact bid info. This adds to the pool of known bids for further estimates

Some features of this approach are that bid estimation is available as point estimates (based on likelihood) or interval estimates. Interval estimates converge to accurate estimates quite fast as the pool of available bid information grows. These interval estimates or bounds may be quite useful in some subroutines for winner determination, especially those based on branch and bound.

A tricky question is the method of validation for models where the entire data is itself too large to deal with realistically. An approach we suggest is the following. Under assumptions of production functions with scope/scale economies (fixed costs and joint cost structures), can simulate data and validate the model.

Example 2 - Marketing: The general issue is that of managing products with finite life, considering perishability and obsolescence. Two major elements of downstream policy are pricing and inventory positioning (including replenishment).

Discrete time cost-based models that model finite horizon problems with random demands are quite useful in these circumstances. With stationary demand, a cost-optimal replenishment policy follows a phasing out effect, by tapering of order-up-to levels. Suppose demand dependence on prices is known approximately. Then more complex ordering cum pricing decisions can be modeled and computational results obtained. In general, finding optimum policies in this setting can be modeled in the Markov Decision Processes (MDP) or Stochastic DP framework. The MDP framework allows a general description of states, action, rewards and state transitions. Various features, such as perishable inventory, product withdrawal, reverse logistics scenarios and variants with salvage and many end conditions can be modeled in this setting.

Many computational features are known for such problems, including for constrained MDPs. However, structural results difficult to prove for finite horizon MDPs. An example of the type of policy that emerges from computations through MDP modeling is below, where a product is being withdrawn at the end of period 6. The product has a lifetime of 4 units and the state of the system at any time is the amount of inventory of various ages that is present at the beginning of the period. For example, the inventory state vector [3, 1, 1, 0] refers to 3 units which are to outdate after 1 period (if not used to fulfill demand), 1 unit each that is to outdate in 2 and 3 periods and 0 units that is to outdate after four periods. So in each period, we have not only to track the amount of inventory but the freshness of different units of stock. For some typical cost values of inventory holding, the following table represents optimal decisions if that state vector is encountered in a certain time instant. Here, N refers to no-promotion (i.e. dropping the price to stimulate demand) and P refers to the promotion decision. Also to be decided is the number of units replenished.

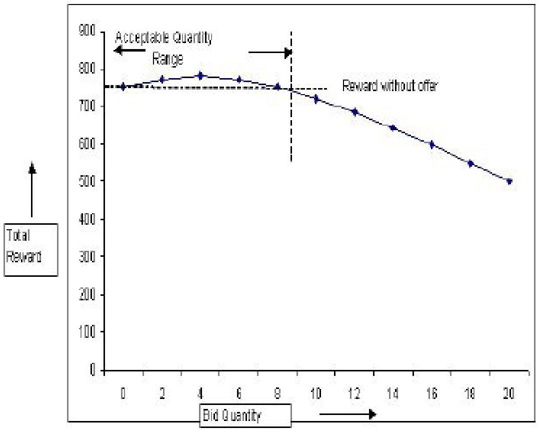
For example: If the inventory state vector [3, 0, 0, 0] is encountered in period 5, the optimal policy is *P2*, i.e. to promote the product and replenish the inventory to the extent of 2 units. Note that this is not an obvious policy and depends on the fixed cost of promotion, where once we decide to drop the price to clear stock, we may still want to re-order to some extent! See the figure below for an illustrative policy.

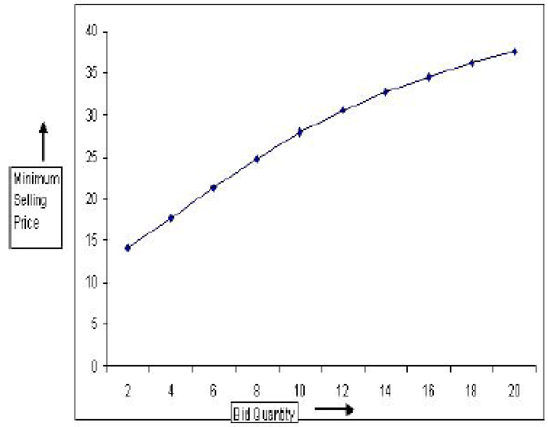
	Time period					
Inv vector	1	2	3	4	5	6
2000	N3	N3	N3	N3	N2	N0
3000	N2	N2	N2	N2	P2	P0
4000	N1	N1	N1	N1	P1	P0
5000	N0	N0	N0	N0	P0	P0
1110	N2	N2	N2	N2	N0	P0
1310	N0	N0	N0	N0	N0	P0
3110	N0	N0	N0	N0	P0	P0

The counter bid problem: Another specific problem that we consider in this setting is the counter bid problem. With amount S in stock, and a horizon of decision-making, whether to accept a bid for *n* items at a price *p*', as opposed to regular sale (with uncertain demand) at price *p* > *p*'?

The normal economic rationale would ask for more discounts at higher volumes but it may not be true in the counter bid scenario. The range of volume for a given price prevents us from selling too much at a low price. If policies can be encapsulated neatly (with a small number of parameters), then they can form part of an automated response to bid queries. The challenge is to present (multi-dimensional) policy parameters in a form that can be easily queried or computed.

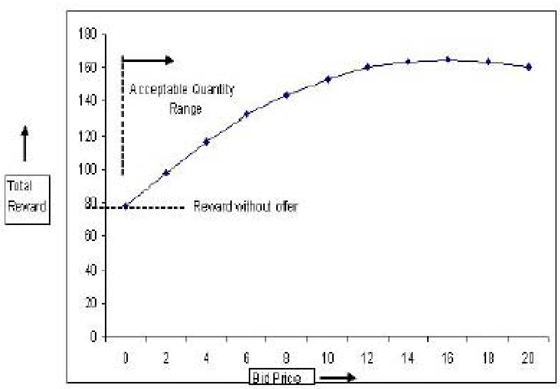
The figures below indicate the different outcomes of acceptable price-quantity pairs.

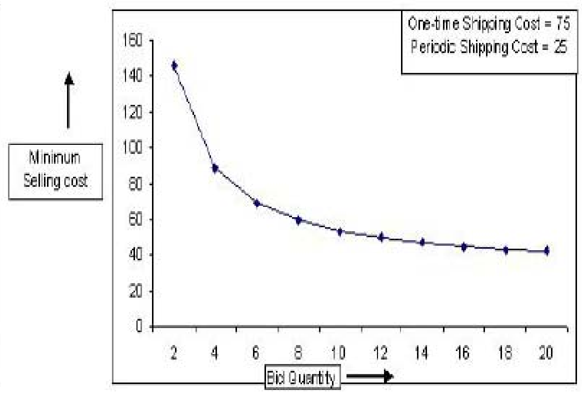




Total expected reward for different bid quantities with bid price = 25

Bid quantities and minimum selling prices





Total expected reward for different bid quantities with bid price = 8

Minimum selling price for different bid quantities

Example 3 - Operations on Indian Railways: Indian Railways (IR) is undergoing a renaissance (as also railways in the United States and some other regions). IR is a vast organization, with more than 1500000 people, 16 zones, more than 7000 stations; more than 2,00,000 wagons (units), almost 40,000 coaches and 7,739 locomotives. It runs more than 14,000 trains a day and carries 100 million passengers and 1 million tonnes of freight a day.

IR as an e-Business: The following are some aspects of Indian Railways from an e-business perspective.

- Passenger reservation system (PRS)
  This is successful as a transaction management system, and is one of the largest such systems worldwide. One challenge is to use it as a revenue management tool and for market research.
- Freight Operations Information System (FOIS)
  The main contribution of this system is in accurate and timely data capture. Some of these procedures are still getting systematized. FOIS has a very big potential for decision-making.
- Coaching Operations Information System (COIS)
  This is still at a rudimentary stage and includes monitoring of train running for punctuality and coaching stock utilization modules.
- Long Range Decision Support System
  This has a number of modules to do with strategic marketing and planning.

A challenge for operations management – a three level perspective: The whole of operations management on IR is an enormous task. A major challenge in modeling is to fix on quantifiable and meaningful performance measures that can be linked to various business processes. Even though supply chain management principles can be usefully applied to many sub-processes on IR, we look at a very specific issue, that of monitoring wagon holding and performance of a key asset, while meeting customer requirements in an aggregate sense. This is analogous to a corresponding principle in lean manufacturing, where inventory holding and inventory turns are taken as surrogate measures of performance. The relevant time-based measure is Wagon Turn aRound (WTR) which measures the time between successive loadings of a wagon.

From an e-business standpoint, an important aspect is that these parameters (WTR and wagon holding can be monitored, interpreted, and most importantly, acted upon, at various levels in the IR hierarchy.

- Divisional level: asset utilization, productivity and cost control – while meeting specific customer centric goals
- Zonal level: facilitate investment proposals within budgets and prioritization parameters for operations – while maximizing revenues
- Corporate level: long term investments, product/service definition and organizational structures to achieve corporate goals

At another level of hierarchical planning is the following time-based planning scheme for the same set of measures.

- Operational model: Single period transhipment (allocation model) which balances spatial demands
- Tactical model: Multi period (finite horizon) model which balances empty running vis-à-vis waiting costs, with known demands and (stochastic) imminent demands
- Strategic model: Long run fractions of empty running, demand rates and revenues from loaded movements, viewed as a queueing network

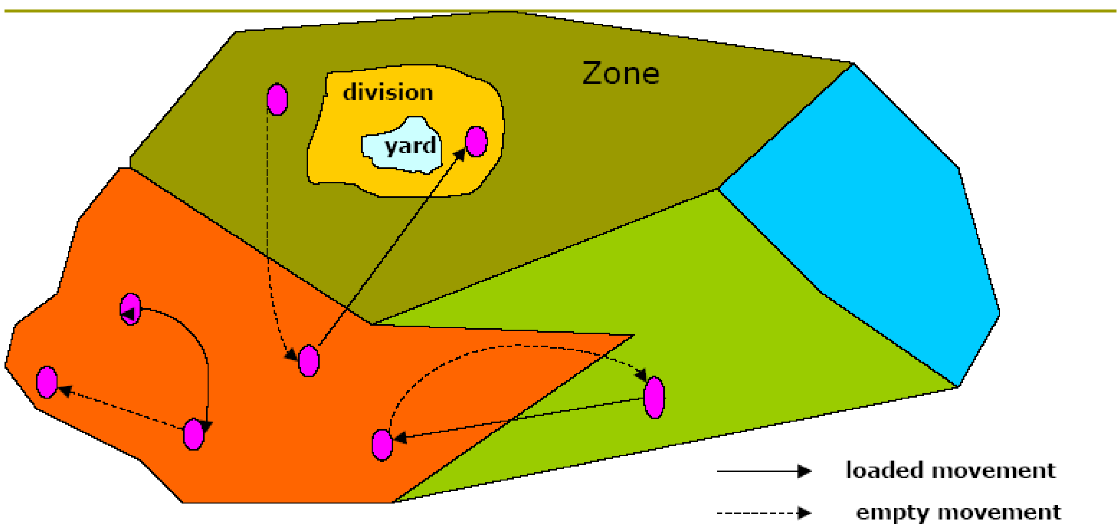
Wagon Turn Around (WTR): WTR, measured in days, captures the utilization of wagons in terms of time spent in a system vis-à-vis their revenue earning movements. For a closed system (e.g. the entire Indian Railways), the governing equation is

Fleet size = WTR (days) x demand (wagons/day)

For any zone/division

$$\text{WTR} = \frac{\text{(Effective) wagon holding}}{\text{Number of wagons loaded + Number of wagons received}}$$

The figure below highlights the way in which WTR is applicable at different parts of a large railway network. In Indian Railways, there are 16 zones, subdivided into divisions and further containing important yards. For any unit, empty or loaded flows could be partly or wholly within the unit, as shown below.



WTR makes sense for any organisational unit, including intermediate divisions where there is through traffic, as well as partial traffic (loading/unloading in the unit plus transit in and beyond the unit). It can also be interpreted as a performance measure at yards, where detention is measured, rather than transit. It is therefore a single measure that serves as a diagnostic for managerial prioritizing of train paths, traffic types and local investments.

This measure is in fact available for monitoring at various levels in IR, based on the Freight Operations Information System, apart from several resource mobilization decisions like loco allotment, allotment of empty wagons, crew planning, etc. All of these, while important in their own right, contribute to supply chain and business goals through the effective matching of activities and tasks. One of the key measures that brings these elements together is the wagon holding and WTR statistic.

Discussion: We finally take a look at two of the important classes of models, optimization and game theoretic/equilibrium models and identify some key features for their possible application in e-business and supply chain management contexts.

Optimization: Optimization problems in practice, could be multi-objective, and have time dependant objectives and even constraints. Aggregate models that ignore these features may have only an indicative value in planning and cannot be used at more detailed levels. Models increasingly have to encompass stochastic attributes, as management of risk and uncertainty is a key expectation from formal models. Optimization models should be easy to formulate, possible to validate, efficient to compute, and be amenable to post-processing to fit in with various processes in an organization.

Trade-offs in an optimization model: Two questions that arise in the formulation of optimization models are: Do we want to solve one large problem, encompassing all decisions or several small ones? Do we want to solve one large multi-period problem or several single period problems?

A general technique is that of decomposition. There is a close interplay between the various elements of a decomposition approach. Approximate solutions to the large problems often serve as good targets for defining smaller sub-problems (which have to serve a "larger" purpose). In turn, solutions to smaller problems are useful in defining bounds for larger problems, and sometimes guaranteeing solution quality. It is useful, from the points of view of validation and implementation, if the decomposition mimics "real" decision-making.

Game theoretic/equilibrium models: Game theory models in supply chain management arise because two (sometimes more) players are perhaps trying to optimize their own payoffs in an environment that is determined by the actions of both. Applications of non-co-operative game theory arise even in simple settings such as order placements by multiple retailers, where the extent of supply is uncertain. Another similar setting is that of target setting by manufacturers for distributors and dealers. Price revelation, discounts and other actions based on mutual information on valuations of different players provide for a number of applications of non-cooperative game theory.

Although equilibrium situations are hard to compute generally (although relatively easy to verify), the concept is a useful one to explain hostile and partly co-operative behaviour of different players.

More subtle applications of the concepts of game theory arise in the context of combinatorial auctions, where each item can be thought as taking part in a coalition of bids with different values. The value of a player to a coalition is due to synergies with other players (e.g. because of economies of joint manufacture or transport) can be modeled using principles of co-operative game theory.

Conclusion: Models may be constructed in a variety of ways for a given situation. The successful ones seem to achieve the following.

- Tractability and computability: Models should be tractable in terms of data requirements and should have computable procedures that can yield useful quantitative information. There are a few models that are stylistic and yield insight through means other than computable outcomes, but these are of somewhat limited use for actual decision-making.
- Verifiability and conviction: However large and sophisticated a model, it has to be verifiable by users. While in technical areas of software testing and reliability, verification itself is becoming an automated procedure, in applications to do with e-business and supply chain management, the managerial stakeholding, often with direct performance and even financial implications, verifiability by a human is quite important. This is often a major hurdle in implementability of models.
- Realism: This states the obvious fact that a model must capture enough features of the real decision or scenario to be useful.

All these principles are very relevant in e-business applications. In summary, modeling appears to be an art based on scientific principles.

References (Note: These list only some modeling attempts that the IEOR group at IIT Bombay has been involved in recently)

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