

Decision Making Simulator for Supply Allocation under Uncertainty

V.Beddoe¹, S. Shiradkar^{1,2}, J. Venkateswaran¹

¹Industrial Engineering and Operations Research, Indian Institute of Technology Bombay, Mumbai, India

(²sayli.bhide@gmail.com)

Abstract - This work presents a simulation-based testbed for evaluation of supply distribution strategies in a single product multi-period two-stage social welfare supply chain with a divergent network configuration of n supply points and m demand points. Further, the supply and demand per period are assumed to be uncertain, which necessitates the use of simulation. The testbed is demonstrated through a test scenario, which in turn is based on an existing supply network. In the demonstration, specific identified strategies were used to allocate the available supply among the demand points. Each of these strategies was individually used and simulated over a year and performance measures indicate how one strategy cannot be used for a prolonged period. Future work would consist of an automation element in the testbed for decision making in supply allocation.

Keywords - Decision making, supply uncertainty, social welfare program

I. INTRODUCTION

Supply allocation is a challenging decision when a limited supply quantity is to be distributed among multiple markets or facilities, under some sense of fairness. Decision making under uncertainty substantially affects the performance of the supply chain as over-allocation, or under-allocation can result in financial losses [1]. In industries such as agrifood, chemical and pharmaceutical, the situation of limited supply often occurs, forcing decision-makers to allocate available supply to different markets [2]. However, the goal of every supply chain management (SCM) is not to optimize costs to maximize profits. For example, social welfare programs have similar supply chain structures as for-profit businesses except that their output measures are defined differently. Welfare programs have more significant outcome measures, such as societal improvement [3]. For example, a welfare program will choose a local farmer to procure grains instead of a multinational vendor to meet the goal of promoting agriculture and providing a fair opportunity to farmers. Social welfare programs are complex systems due to the product category and management of the supply chain. These programs are generally managed, controlled and financed by the government. Public Distribution System (PDS) in India distributes mainly staple food like rice, wheat, sugar and essential fuels such as kerosene at a subsidized cost to the disadvantaged population [4]. One of the barriers that hamper the effectiveness of grains distribution in PDS is the uncertainty of supply occurring due to monsoon and weather conditions in India [5] along

with prices, demand for a particular food, local food habits and government policies [6]. Therefore, SCM of social welfare programs is challenging considering the vulnerability of customers, the non-profit nature, and the involvement of community-based organizations to achieve the development of the disadvantaged population. There lie voids in the PDS supply chain like wastage during storage, high lead times and distribution imbalance [5]. In this paper, we seek to address the issue of distribution imbalance by creating a testbed for the evaluation of supply distribution strategies.

A. A Solar lamp distribution project in India

This research is inspired by a social welfare program which aims at distributing solar lamps to rural students in India, for studying in dark hours, at a subsidized price and providing employment opportunity to locals. Local facilities are set up where locals assemble, distribute and service solar lamps to fulfill the demand of local students. To achieve scale, project management tries to replicate the facility set up model in parallel at multiple blocks, across districts and states. To attain speed, the assembly and distribution for any block are designed to be completed in 3-6 months [7].

In the solar lamp project, multiple suppliers are responsible for supplying raw materials in packs termed as component kits. As per the demand, a supplier supplies these kits to a specified rural facility. Instead of each facility raising an individual demand, a manager from a central coordinating agency monitors, facilitates and raises demand for raw materials on behalf of these facilities. For various uncertainties, suppliers are not able to supply the required number of kits within the required time to all facilities. The problem that arises is: how to allocate the available supply of raw materials to demanding facilities when supply quantity is less than demand?

There are several parameters, such as the location of facilities, current inventory level, capacity (holding, storing and producing), utilization of the facilities, current demand and final target of facilities, which need to be considered while making the raw material supply allocation decision. Suppliers are not able to supply the required quantity of raw materials to all facilities in the given time, making the supply of raw materials uncertain and stochastic. In the supply chain of this project, a manager analyses various parameters and allocates insufficient supply quantities to different facilities at her discretion.

B. Performance parameters

Effectiveness and efficiency are two major performance parameters on which public services are accessed [3]. For effectiveness, the manager should be able to serve the right facility at the right time. In the solar lamp project, effectiveness involves identification of the needy facilities and delivering component kits to the right facility at the right time in sufficient quantity. Secondly, the efficiency of the entire project lies in reaching the maximum target in a given time frame. This is achieved by avoiding periods of idleness and fulfilling the demand. Effectiveness is required to achieve efficiency.

Efficiency can be related to the number of individual facility projects completed in a time frame. In this study, we set performance parameters as the percentage of facilities which received complete supply target and the average number of weeks required for a facility to receive complete supply target in a given time frame.

The objective of this research is to develop a testbed simulator to evaluate the efficacy of the supply distribution decisions under uncertainty, in meeting performance objectives.

The rest of the paper is organized as follows. The testbed development is discussed and demonstrated through a test scenario based on an existing supply network in Section II. In Section III, simulation results of the test scenario and its limitations are presented, followed by the conclusion in Section IV.

II. TESTBED DEVELOPMENT

A single product multi-period two-stage social welfare supply chain with a divergent network configuration of n supply points and m demand points ($n \ll m$) is considered. The demand points are assumed to maintain some inventory (up to maximum capacity), which is used to meet the demand in that period. Each demand point orders, as per their ordering scheme, from the suppliers who then supplies as per the order quantity. However, the quantity available for supply is uncertain. Any unfulfilled orders are backlogged to be fulfilled in subsequent periods. The critical decision in each period is the allocation of available supply to meet the orders among the demand points, under some measures of fairness. It is assumed that all information is known, and a central coordinator makes the decision. Also, the number of active demand points m in a period can also vary.

A. Implementation and algorithm

Python is chosen for the development of the testbed considering various advantages, including flexibility, ease of programming and handling extensive data, and availability as an open-source language. Fig. 1 shows the decision-making flowchart for allocating supply to facilities and updating their inventory over the span of simulation by utilizing different allocation strategies. The

system is initialized by setting the number of supply points, the number of demand points (with varying start dates), max supply capacity per period, probability distribution function (pdf) of order fulfillment, ordering logic of demand points, consumption pattern at the demand points, etc. In each period, all the m demand points update their orders and share the information with the suppliers, who then update their available quantity for supply as per the pdf of order fulfillment. As per some decision logic, the available supply quantity is divided and assigned to each demand point. This is the crux of the testbed, where it is envisioned that various decision logic can be incorporated and evaluated. The inventory at the demand and supply points are then updated according to the distribution plan for that period. The simulation continues until the end of the time horizon.

B. Test Scenario

The test scenario is based on the solar lamp project [7]. The demand points are akin to assembly-distribution facilities, and they are provided with lamp kits by the suppliers. The following assumptions are made/specifications are used in the test scenario:

1. The decision time units are by weeks, with a total simulation time horizon of 52 weeks.
2. A single supplier and 50 facilities or demand points are considered.
3. Each facility (demand point) is assumed to have a random target or cumulative demand quantity to be eventually fulfilled.
4. When the target exceeds 30000 units, it is divided by 6 and each part (i.e., $1/6$ th of target) is assumed to be ordered by a facility every two weeks. On the other hand, if the target is below 30000 units, it is divided by 4 and each $1/4$ th is assumed to be ordered in intervals of 3 weeks.
5. From the historical data, it was assumed that about 80% of the time, the supplier was able to send the whole order or consignment, 15% of the time supplier sent 65% of the consignment and 5% of the time only 50% of the consignment was supplied.
6. A facility (demand point) cannot receive a consignment bigger than 8000 units.
7. Physical distances between supplier and facilities are not considered, and orders are assumed to be filled in the same period.
8. The supplier capacity is assumed to be 30000 units/week (for scenario two, as described in Section III).
9. All facilities are identical to each other and no facility is given priority over another.

In the test scenario, the simulation is run for 52 weeks for a given distribution policy and the average duration to complete target supply and the percentage of facilities whose target supply is completed in that time frame is analyzed. Average output is displayed as a result of 100 simulation runs.

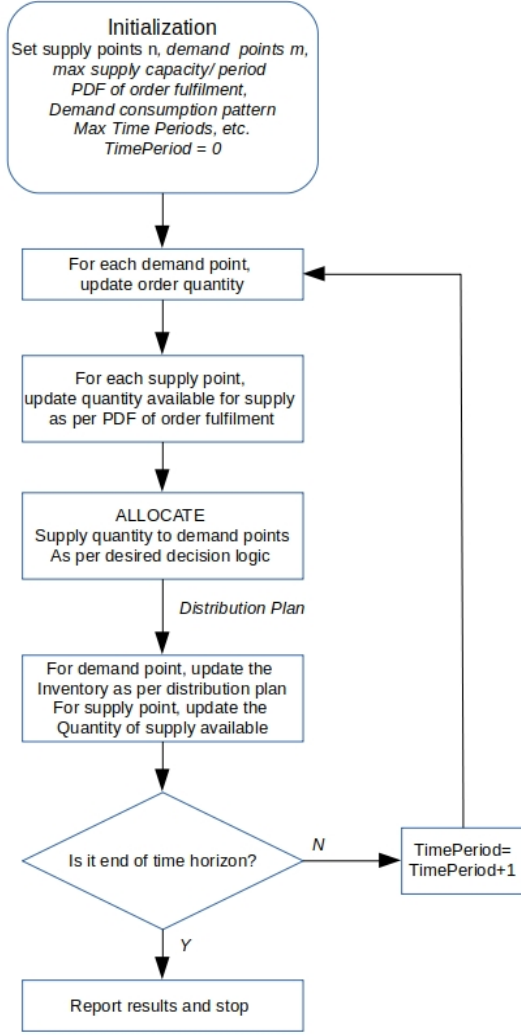


Fig. 1. Flowchart of testbed implementation

C. Supply Distribution Strategies

Three supply distribution strategies typically used by this project were simulated. They are described as follows:

1) *Equal Distribution of Supply*: Irrespective of the size of an assembly-distribution facility, the supply is equally distributed among all demanding facilities. In case any facility's demand is less than the equal share, they are supplied with the quantity they demand and the remaining supply is equally divided among the remaining demanding facilities. In the event of the same case arising, this is done iteratively, till all the demanding facilities' demanding quantity is more than the equal share. These remaining facilities are then supplied the equal share quantity, and in case their demand is not fully met, the excess demand is shifted to the next week.

2) *Proportional Distribution of supply*: Demanding facilities get a share of the supply in proportion to their demand in the given period. Once supply quantity has been distributed to the demanding facilities, unmet demand is shifted to the next week. (1) is used for proportionate division of supply,

$$SQ = \frac{FacilityDemand}{TotalDemand} * WeeklySupply \quad (1)$$

where SQ is the Supplied Quantity, Facility Demand is the demand of the facility for the week, Total Demand is the total demand of all demanding facilities and Weekly Supply is the supply quantity available that week.

3) *First come first serve(FCFS)*: This strategy prioritizes orders of those facilities who demand earlier. In case there are ties, these are served arbitrarily. In our model, in the event of ties, the order in which facilities are listed is followed. Unmet demands are shifted to the next week.

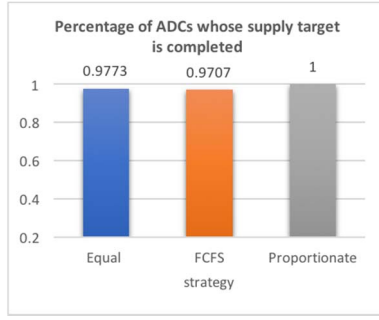
III. RESULTS

Two scenarios are analyzed in the testbed, one when the supplier capacity is infinite and the other more realistic case, when the supplier capacity is constrained at 30000 units/period. For each scenario, different distribution allocation strategies were chosen and run for the whole year (52 weeks). The performance of these strategies was analyzed and compared. The first scenario results are shown in Fig. 2.

Under unconstrained supplier capacity, 97.73%, 97.07% and 100% of the facilities received complete supply target when equal distribution, FCFS and proportional distribution strategies were used respectively.

In the case of this scenario, it takes ~10 weeks for all strategies to complete the target supply. This is an ideal situation, as all backlogged supplies are met at once when the supplier response turns out to be 100%. In comparison to the current average of 17 weeks obtained from actual operations data, the average number of weeks taken to complete target supply, in this case, is unrealistic.

The results of the second scenario with supply constraints are shown in Fig. 3. In contrast to the first scenario, the second scenario with supply constraints show that 72% of the facilities received complete supply target when equal distribution was used, 89% of the facilities received complete supply target under FCFS and 1.67% of the facilities received complete supply target for proportional distribution strategy. The average number of weeks to complete target supply was 23, 18 and 11 weeks respectively for equal distribution, FCFS and proportional distribution. These seem comparable to the average of 17 weeks obtained from actual operations data. However, it should be noted that the 11 weeks taken by the proportional strategy is not advisable as only 1.67% of the facilities complete target with this strategy.

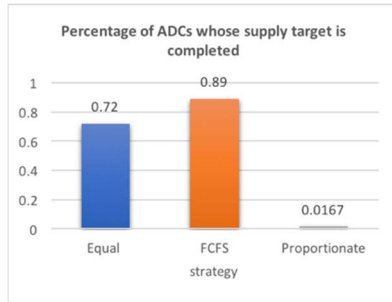


(a)



(b)

Fig. 2. Simulation scenario without supply constraint(a) percentage of facilities with completed target supply, (b) average number of weeks taken to provide complete supply



(a)



(b)

Fig. 3. Simulation scenario with supply constraint(a) percentage of facilities with completed target supply, (b) average number of weeks taken to provide complete supply

The poor performance observed with the proportional strategy has reasoning. If a facility was demanding a small quantity as 400 units, it would receive only a portion of the quantity in the current month. Again, in the next month, it would get a part and not the whole of the otherwise minimal remaining quantity. Due to this lingering effect, the supply target is not met on time and project lengths

keep increasing, resulting in facilities not receiving the target quantity in a year.

The equal strategy also has a slight drawback for facilities with a higher target. They get their supply in small installments as compared to other smaller facilities. The equal portion may be too small for their size and as a result, target supply is extended.

IV. CONCLUSION

A testbed that allows managers to input supply and demand pattern and outputs the best strategy for allocating supply among multiple facilities is developed. With inputs from the team manager and the demand pattern of assembly and distribution facilities, the quantity of supply was simulated. Also, considering the parameters used by the manager to allocate supply under uncertainty, different strategies were defined and simulated. Three strategies: 1) equal division 2) first come first serve (FCFS) and 3) proportionate division were simulated for 52 weeks over 100 runs. Outcomes were analyzed and compared. In comparison to the current scenario, it was realized that no one strategy could be run for one whole year to achieve the target. A mix of various strategies will be required to achieve this and an automation tool will have to decide which strategy will work best in a particular period considering various constraints.

In the future, each assumption can be relaxed and simulated to make the model more realistic. The super supplier considered will be replaced with multiple suppliers. The capacity of inventory held by each facility, both assembled and unassembled will also be introduced along with an element of distance between facilities and supplier. Appropriate lead times for different facilities will also be included. Ultimately, we would like to develop an intelligent algorithm which would decide every week which strategy would give the best results for that week. Learnings from this phase will be incorporated in the next phase of automation to show the manager which strategy is optimum for the week using historical data and demand and supply inputs for a specific week. As a result, the project will have an automated decision-making tool to help minimize disruption caused by supply uncertainty.

Such an automated decision-making simulator can help run various scenarios such as demand uncertainty, single vs. multiple suppliers, different policies along with supply uncertainty. It can be helpful to decision-makers involved in operations of social welfare programs involving PDS.

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