

## Zone Selector Delivery Optimisation using Locality in Supply Chain Systems

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**Abstract:** Supply chain systems and logistics, play a key role in the transportation of goods in the industry. A buyer usually dispatches a request and a seller responds by sending the goods. However, this creates a massive overhead, due to geographic restrictions and cost of the logistics. For this reason companies often create systems that gather supplies in warehouses to support a number of buyers in the area. Thus, the notion of regional collector emerges. The collector essentially manages the sellers in the regions and responds to requests from the buyers. In this paper, we address this problem by creating zones that include sellers to create the zone collector. The zones are created based on a density that creates a community of sellers. The zone collectors, maximise their operations by using locality, in the sense that they collect the supplies from the sellers according to the demand of the buyers. Thus, we propose a solution based on junction tree, in order to increase the global utility function, We provide simulations to show the efficiency of our approach.

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### 1. INTRODUCTION

There has been a re-statement of purpose of the concept of operations management through the supply chain initiative, coming from the employment of upstream and downstream partners into the domain of investigation and management (Bettley and Burnley (2008)). Supply chain management (SCM) is defined as the efficient handling of physical, logical and financial operations in a network. These operations exhibit intra- and inter-organisational bonds, which result in the customer needs satisfaction and giving added value to a product (Mentzer et al. (2001)). In other terms, SCM is responsible for managing, sourcing, production and transport of inventory goods (Stephens (2001)).

Regional supply chains have been utilised to improve the efficiency of the supply chain of products, especially in the food industry. However, due to major players, such as large super markets, which make restricted agreements on the available supply, excess fruit and vegetables exist within supply chains (Kurnia et al. (2016)). This mainly causes farmers to be imposed of limitations regarding the distributions of these products. This situation constitutes a major threat in the sustainability of regional supply chains, whereby causing problems in the economic, environmental and social condition of the local communities in regional areas (Blay-Palmer et al. (2013)). An effective way of tackling the aforementioned problem is the Food Hub, which was introduced to improve local food supply systems. Food Hubs are defined as entities that aggregate, distribute and move goods to the market. These goods mainly originate from local or regional producers and the

operations they are work under improve sustainability by reducing the gap between producers and consumers (Matson and Thayer (2016)). However, there is a number of challenges that Food Hubs experience. A major concern is the lack of marketing strategies and systems, whereby governments have not established rules of recognition and operations, resulting in mainstream players of the food industry not to put them strongly in the supply chain game. Furthermore, awareness to local customers regarding Food Hubs is essential to ensure product differentiation and regional identity (LARSEN and Rose (2013)). With all that pointed out, we believe that regional collectors of goods are essential for a supply chain of specific products.

Small supply chains, especially in the food domain, can evolve in the following manners temporal, spatial, demand and associational or institutional (Marsden et al. (2000)). Also, actions like these contribute a great deal to rural development of specific regions. Coordinated supply chain is a significant progress on meeting actual needs of buyers and forwarding products to them from the sellers in a timely fashion, based on the demand. This falls into the domain of operational planning in supply chain logistics coordination (Bowersox et al. (2002)). We are particularly interested in the Production-Distribution coordination and Inventory-Distribution coordination strategies (Thomas and Griffin (1996)).

In this paper, we propose a system where the regional collector of products is essential a zone collector; thus, we separate the seller area to zones, in order to provide adaptive efficiency to the orders placed by the buyers, as can be seen in Fig. 1. In particular, there is an overlap in

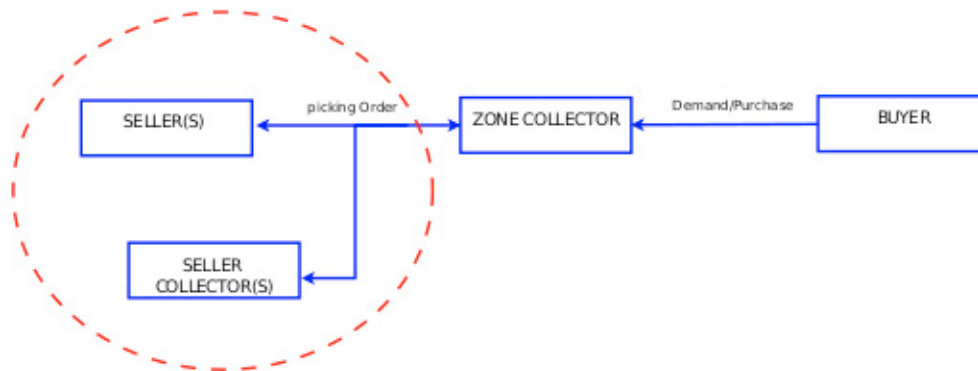


Fig. 1. Basic Zoning of Zone Collector

the zones, where sellers can maximise their efficiency to satisfy high demand of orders.

On the other hand, zones that do not participate in the purchase order can be eliminated from the optimisation process. The essence of zoning is the fact that high demand on orders may create a joint maximisation of supply in different zones to satisfy the requirements. Hence, the zoning optimisation process is highly dependent on the buyer demand. This adaptive approach not only enhances the responsiveness of the supply system but also reduces computational complexity by excluding non-contributing zones from the optimization process. The fundamental motivation behind zoning lies in its ability to facilitate joint supply maximization, allowing sellers to strategically allocate resources while meeting fluctuating buyer demands. Through this framework, we aim to enhance scalability, minimize inefficiencies, and create a more responsive supply allocation mechanism tailored to real-time market needs.

To this end we show the following contributions:

- We separate the seller domain in zones of interest
- We define the zones in the form of communities in a graph
- We formulate the zoning-demand as an optimisation problem.
- These zones can maximise the sellers efficiency when high demand is necessary.
- Zones that do not participate in the demand from buyers can be excluded from the optimisation process.

## 2. RELATED WORK

There is a number of surveys available for supply chain management applied to different problems and different countries (Akintoye et al. (2000); Olhager and Selldin (2004)). Since then significant amount of research has been undertaken to push supply chain management from infancy. Moreover, a recent survey addresses the sustainable supply chain coordination by extensive literature review and directions that will be faced in the future. The increase of supply and demand has led researchers to work

extensively in this problem. Some of the most recent works are given below.

In (Mitsugi et al. (2013)), the authors proposed a regional collector of products. The regional collector can have inventory in its warehouse and also it can delegate a portion of inventory to each farmers or to contracted collectors. E-mall systems usually provides a showcase in Internet and payment options, while the shipment and delivery is the responsibility of sellers.

In (Choi et al. (2018)), the supply chain scheduling problem is addressed for a particular scenario, taking into consideration coordination and radio frequency identification technology (RFID). In this scenario a manufacturer receives orders from a number of retailers. As such, the manufacturer needs to estimate the optimal order set and production schedule. The problem is formulated as an optimisation problem. During its analysis and revealing of the problem's structural properties, the authors prove that it is NP-hard to find the optimal solution. A practical and pseudo-polynomial dynamic algorithm is devised, which aims to identify the globally optimal solution for this problem in reasonable time. Furthermore, the authors propose a win-win coordination of the supply chain and they highlight the importance and flexibility of RFID performance in its use in this problem. Finally, the critical threshold of the order number with respect the increase of total manufacturing capacity is defined, in order to contribute in profit increase of companies utilising the supply chain.

In (Lee et al. (2001)), the authors attempt to identify a supply chain selection and management system through incorporating information from supplier selection processes. This system comprises purchase strategy, supplier selection and supplier management subsystems. The integrated system, is able to identify the managerial criteria obtained from the supplier selection process and they redirect it to be utilised in the supply chain management process. The authors applied the methodology for this system to a real scenario. During this application, they distinguish between key and weak criteria. Key criteria consist of the ones that evaluate and make the best selection of products from suppliers. The weak criteria indicate

the problems that arise in the selection of certain suppliers comparing the selection of alternative suppliers for the job. The efficiency of this system is evaluated using t-tests and a correlation analysis.

In (Ware et al. (2014)), the dynamic selection of suppliers problem is addressed, which is one of the key factors of making a company or an organisation successful in the market. Since we have dynamic demand by an organisation, time-varying key factors such as suppliers' capacity, quality level, lead time, unit part cost and fixed transportation cost of supplier are essential to be taken under consideration. Thus the authors propose a mixed integer non-linear problem (MINLP) methodology to solve the dynamic nature of supplier selection. Two examples are given and analysed to show the effectiveness of the approach.

In (Sawik (2015)), address the problem of fair optimisation when having to deal with conflicting but equally important objective functions. These are the cost and customer service level, when the supply chain can be under disruption risks. This decision making targets normalised expected cost and customer service values to reside as close as possible; thus reducing the conflict. This problem is formulated as a combinatorial stochastic optimisation problem and especially as a stochastic mixed integer problem with the ordered weighted averaging aggregation of the two conflicting objective functions. Their findings claim that minimum cost and cheapest supplier is usually selected. For the maximum customer service subset of most reliable and most expensive suppliers is usually chosen. However, the problem is with the increased unfulfilled demand and the suggestion that the customer service level follows the customer demand with the smallest expected unfulfilled demand.

### 3. METHODOLOGY OUTLINE

In this section, we present a structured methodology to optimize the distribution of sellers and zone collectors within a dynamically evolving marketplace. Our approach is based on a graph-theoretic framework, where the seller-zone collector network is represented as an undirected graph. The zoning process enables efficient order fulfillment by leveraging overlapping seller zones to respond to fluctuating demand while minimizing logistics costs. By defining a mathematical criterion for zone formation, we ensure that sellers are optimally assigned to collectors, considering both geographical constraints and supply chain efficiency. Additionally, we introduce a utility-based optimization model that balances seller loads with logistics costs, allowing zone collectors to maximize their operational efficiency. To achieve this, we formulate an optimization problem that incorporates locality-based decision-making, ensuring that sellers contribute effectively to their respective zones. The proposed approach not only enhances supply chain adaptability but also reduces redundant resource allocation, leading to an overall improvement in order fulfillment efficiency.

### 4. DEFINING THE ZONE

In a sellers and zone collectors network, we need to define a zone. We will do so with notations from graph theory.

We consider the entire seller zone collector network as an undirected graph  $G = (V, E)$ , where  $V$  is the set of  $N$  sellers and zone collectors and  $E$  is the set of links between them. Furthermore, we consider  $C = \{C_1, C_2, \dots, C_k\}$  the structure of the zones of the network. where  $C_i \in C$  is a zone in the network graph. In this network, we have the case of  $C_i \cap C_j \neq \emptyset$ , where zones overlap with each other. We also denote as  $C$ ,  $C \subseteq V$  as the connections where both endpoints are in  $C$ .

Thus, we can utilise the function proposed in (Nguyen et al. (2011)), in order to define the zone between sellers and a zone collector as

$$\tau(C) = \frac{\sigma(C)}{\binom{|C|}{2}} \quad (1)$$

The term  $\sigma(C)$  is the threshold on the connections between the sellers and the zone collector that suffices to establish a zone. In particular, a subgraph  $C$  can be characterised as a zone iff  $\Psi(C) \geq \tau(C)$  or  $|C| \geq \sigma(C)$ . As presented in the same paper, we define a zone as groups of sellers and a zone collector, which has a size larger or equal to 3 (Leskovec et al. (2008)).

### 5. ADDING/REMOVING SELLER

The operation of an addition or removal of a seller according to the demand is a straight-forward task. Upon receipt of the demand from the buyers the zone selector communicates with the sellers to get information about their current supplies. Thereafter, the zone selector makes the decision on the number of sellers she will use. Thus, the available sellers will not always be part of the selection; hence if we consider the graph of the previous section, it is easy to remove an edge from the zone selector to the seller not utilised and vice versa. Note that in the case of the removal, which might result in a number of sellers being less than 3, the zone remains defined, since it is a process that occurs to characterise the available sellers and not a dynamic operation of them.

It would be an interesting idea to construct the aforementioned graph as seller-to-seller and seller-to-zone selector, in order to mitigate the logistics cost. In this way, a seller who would be further than the zone selector warehouse, can distribute her supplies to the nearest seller with the available capacity in her vehicles. Hence, she would be able to reduce the cost and participate in a further optimisation of the global utility function. However, this is beyond the scope of this paper.

### 6. GLOBAL UTILITY OPTIMISATION

We consider the scenario of Fig. 2 to show our optimisation of the zoning taken advantage by the zone collectors. Here, we take advantage of the demand that the zone collectors require and the fact that certain sellers may be in two different zones. We describe the demand as utility functions that need to be maximised, in order for the zone collectors to obtain the necessary load to move to the buyers.

We formulate the problems in terms of utilities where each zone collector  $N = \{A, B, C, i\}$  has a utility func-

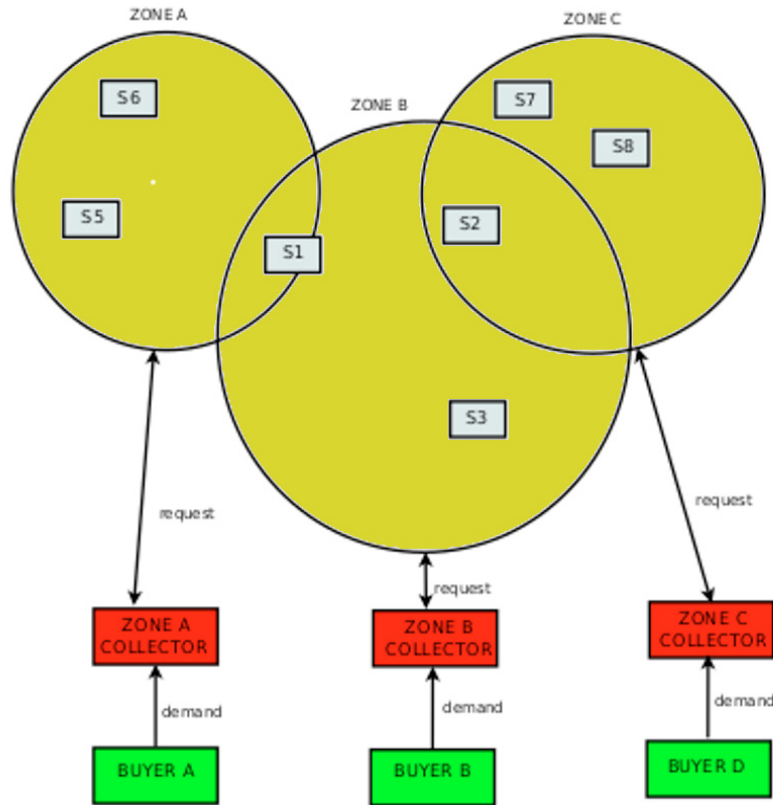


Fig. 2. Zoning Example

tion  $V_i(x_i, \mathbf{S})$ , where  $x_i$  represents the zone and  $\mathbf{S} = (S_1, S_2, \dots, S_m)$  is the load vector for each seller. For instance, depending on the load available at each seller, we can see the ease of the zone collector by means of her utility function.

We generalise the problem by considering a number of zones in a region, which have utility functions  $V_1, \dots, V_i$  that need to be maximised, in order to gain the necessary seller load to move to the buyers. Since we are taking into account the zone collectors benefit from the sellers load we are required to identify the joint setting of the sellers load that maximises the sums of the utility functions of the zone collectors, when they include the sellers in their zones as

$$u(\mathbf{S}, \mathbf{x}) = \sum_{i=1}^n V_i(\mathbf{S}, x_i) \quad (2)$$

thus, we need to perform

$$\arg \max u \quad (3)$$

,which gives us the optimal control strategy  $\mathbf{S}^*$ .

This simple formulation needs to encapsulate the logistics costs from the sellers to the zone collectors. Thus, we define the logistic cost as  $C$ . We assume that our problem to a linear combination of the utility functions as

$$u(\mathbf{S}, \mathbf{x}) = \sum_{i=1}^n V_i(\mathbf{S}, x_i) + \beta C(\mathbf{S}) \quad (4)$$

where  $\beta$  is a scalar which is utilised to solve our multi-objective optimisation problem as it is found in (Boyd and Vandenberghe (2004)), and  $\mathbf{x} = (x_1, \dots, x_n)$  is the set of the zone collector locations. Note that parameter  $\beta$  is responsible for the regulation of the logistics cost. Thus, we perform the maximisation process of equation (3) with equation (4).

A greedy approach could be at hand where zone collectors' preferences are maximised. However, the asynchronicity of the requirements will not be met with such approach; hence, we have to encapsulate the geographical properties of our scenario, with which we established the zones of the collectors. Specifically, a seller has an impact on the requirements of the zone collector only if she is in the zone of interest. For instance, if we revisit Fig. 2, we can see that seller  $S_4$  is placed in the zone of Zone D Collector; on the other hand, sellers  $S_1, S_2, S_3$  coexist in zone B and zones A and C. In this way, we can take advantage of locality to show that each zone collector is affected by the load of a smaller number of sellers than the entire set. Moreover, locality of the logistics cost is also present. Hence, we can re-write the optimisation problem using zoning as

$$\mathbf{S}^* = \arg \max \sum_{i=1}^n V_{i,\mathbf{x}}(S_{i1}, \dots, S_{ik}) + \beta C(S_j) \quad (5)$$

where  $S_j$  represents the locality of the logistic costs of the sellers existing within a zone and  $V_{i,\mathbf{x}}(S_{i1}, \dots, S_{ik})$  is the utility function of a zone collector being affected by sellers within her zone.

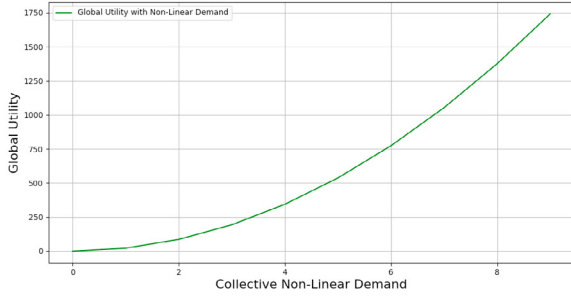


Fig. 3. Global Utility with Demand

The literature provides us with efficient approaches to take advantage of the locality of zoning, in order to acquire the optimal load of the sellers necessary for the zone collectors (Guestrin et al. (2002)). The idea is to minimally violate the zone selectors' preferences from the sellers by adjusting the utility functions appropriately using locality. In this sense, we coordinate our moves towards the maximisation of the sum of the utility functions of the zone collectors. We provide an example to provide a better understanding of the methodology. If we want to maximise

$$F(y_1, y_2, y_3, y_4) = F_1(y_1, y_2) + F_2(y_1, y_3) + F_3(y_3, y_4) + F_4(y_2, y_4) \quad (6)$$

We see that  $F_1$  and  $F_2$  are independent of  $y_4$ ; thus, we can write the the maximisation process by utilising locality as

$$\max_y F(\mathbf{y}) = \max_{y_1, y_2, y_3} (F_1(y_1, y_2) + F_2(y_1, y_3) + \max_{y_4} F_3(y_3, y_4) + F_4(y_2, y_4)) \quad (7)$$

For values of  $y_2, y_3$ , the maximisation of  $y_4$  can be carried without any dependencies of  $y_1$ . We denote

$$E(y_2, y_3) := \max_{y_4} F_3(y_3, y_4) + F_4(y_2, y_4) \quad (8)$$

we can re-write the optimisation problem as

$$\max_y F(\mathbf{y}) = \max_{y_1, y_2, y_3} (F_1(y_1, y_2) + F_2(y_1, y_3) + E(y_2, y_3)) \quad (9)$$

As we can see, we eliminated variable  $y_4$ . Repeating this process will result in eliminating variables one at a time. The values of  $y_i$  variables can be obtained by computing and setting the partial solutions in reverse order. In the general, the maximal domain size of the  $F_1, F_2$  and  $E$ , called the treewidth, depends on the order in which variables are eliminated. Picking the optimal elimination ordering is NP-complete and solutions can be found in (Singhvi et al. (2005)) and references therein.

## 7. RESULTS

As dictated in the previous sections, the system is separated in three zones with overlapping sellers. The loads of each seller is given below:

- Zone A: 3 units of S1, 2 units of S2, and 1 unit of S3.
- Zone B: 7 units of S3, 7 units of S4 and 1 unit of S5.
- Zone C: 1 unit of S4, 2 units of S6 and 1 unit of S7

As we can see in Fig. 3 the global utility when we have demand increases. As the sellers are given more load (higher demand), they provide greater utility to the zones they serve. This suggests that the system benefits

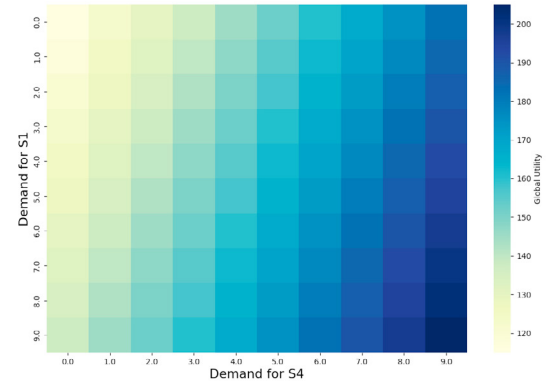


Fig. 4. Heatmap of S1 and S4

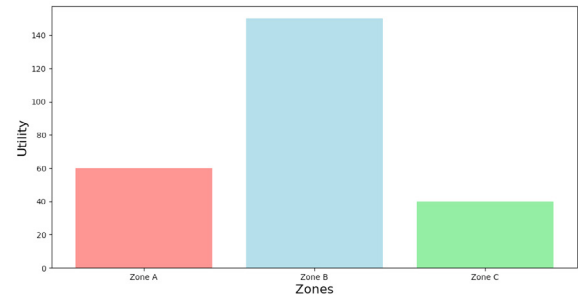


Fig. 5. Zone Utilities

from having sellers take on larger responsibilities. The sellers' efforts are being utilized efficiently, and the gains from their contribution outweigh the costs associated with higher demand.

In this scenario, it implies that the sellers can handle more load without a significant penalty. It may mean that each additional unit of demand placed on a seller still brings about a considerable increase in utility, and the system is not yet at a point of overload.

In Fig. 4 the reader can see the heatmap of S1 and S4. Here we see that Zone A benefits more when S1 contributes less load. This implies that increasing the load on S1 might be detrimental to the overall utility. Zone A may not require heavy load from S1, and optimizing global utility might mean reducing this seller's contribution. Similarly, the global utility improves when S4 (the overlapping seller in Zone B and Zone C) has a smaller contribution. This suggests that Zone B and Zone C perform better with a lower demand or load on S4, which could indicate that the overlap between these zones doesn't require Seller 4 to take on a large load.

In Fig. 5 the reader can observe the values of the utilities for each zone. It is clear that the utility of Zone B is greater since it contributes more to the system than Zone A and Zone B.

## 8. CONCLUSION

In this paper, we addressed the global maximisation of zone selectors utilities when the sellers are placed in zones

and the buyers have a demand. Initially, we define the zone with the density of the community that is being built and utilising a threshold, which ends up with zones having members larger or equal to 3. We take on board a scenario with three seller per zone of a total of three zones. Thereafter we employ a methodology with uses this zone locality and we formulate it with a junction tree method. The zones that participate in both zones show more contribution to the global utility value. Also there are other results that show the heatmap of two sellers and an increase in the global utility.

The proposed seller-zone collector optimization model has diverse applications across various industries. It can optimize logistics in e-commerce and retail, improving delivery efficiency and reducing costs. The model also applies to food delivery networks, ride-sharing services, and air cargo management by enhancing resource allocation and minimizing congestion. In energy distribution, it ensures efficient power dispatch, while in emergency response, it optimizes the allocation of critical supplies. Additionally, the model can be used in urban planning to balance commercial activity and infrastructure, contributing to smarter, more efficient resource management in various sectors.

Our future work aims to design a game theoretic algorithm to provide a distributed solution, where sellers will be individual players that will maximise their revenue and reduce their cost by maximising their utility functions. We aim to compare a game theoretic formulation with this approach and see the benefits as well as the drawbacks. Moreover, we aim to validate the model and suggest applying it to a real case study.

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