



MOBILE ENABLED OPERATIONS MANAGEMENT USING MULTI-OBJECTIVE BASED LOGISTICS PLANNING FOR PERISHABLE PRODUCTS

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ABSTRACT

The management of the mushroom supply chain is a complex task since mushrooms have a short shelf-life after production. Mushroom farming requires an environment in which the quality of the soil, the temperature and humidity of the chamber and flow of air between stacks of mushroom beds are to be strictly controlled under specified conditions in order to give maximum yield. Once mushrooms are plucked, sorted and packaged for delivery they must be delivered to the market within a few hours since the quality of mushrooms degrades very rapidly after harvesting. Small farmers may not have the necessary infrastructure for processing and packaging which is generally be done at nearby production centres where aggregation takes place. Hence, mushroom farming is generally done in regions which are close to the markets. In such a scenario, the role of logistics in transporting fresh produce to the retail markets or even end consumers is critical to the success of the mushroom business. Procurement of raw material (inbound logistics) in the form of harvested mushrooms as well as the distribution of mushrooms from production centres (outbound logistics) plays a vital role because of the perishable nature of the finished product. This situation warrants a dynamic procurement and distribution strategy. This paper describes a mobile technology based solution which models the typical mushroom supply chain and tracks distribution in real-time through a workflow based system. A multi-objective location-routing model with fractional and linear objectives is deployed to solve the procurement and supply problems in the mushroom supply chain. In the first stage of routing, a feasible solution is provided through TSP transformation and solving it through LIFO implicit enumeration and back-tracking, and this is further improved by a heuristic in the second stage.

Keywords: Mushroom farming, perishable goods, mushroom supply chain, location routing model, travelling salesman problem, electronic forms, mobile workflows

1. INTRODUCTION TO MUSHROOM FARMING

Mushrooms are a rich source of nutrition and are often used in health foods. Mushroom farming can be done in any enclosed space but requires a temperature and humidity controlled environment for obtaining high yields. Typically, mushroom beds are laid out in shelves stacked one above the other to allow the proper flow of humidified air. The process of spawning is very elaborate and requires aseptic sanitary conditions to obtain maximum yield. Cultivation of mushrooms occurs in two stages which require two different temperature ranges for successful cultivation; the first phase of vegetative growth or spawn runs require a temperature of between 22° to 28° Celsius whereas reproductive growth which deals with fruit body formation requires 15° to 18° Celsius. Humidity levels between 85-95% and good ventilation through the stacks are very important. Once the mushrooms are harvested various forms of processing takes place. Some mushrooms are sold as fresh produce which has a short shelf-life whereas a majority of the produce is processed through dehydration which results in longer shelf-life. Sorting, processing and packaging are typically done in production centres which can source mushrooms from nearby farmers. Consumer preferences decide whether fresh mushrooms or processed mushrooms in their food basket. The entire process of mushroom cultivation from the preparation of spawn runs to distribution of the finished product requires logistics support to handle perishable raw materials as well as perishable end product. For this reason mushrooms are primarily cultivated and processed in geographical clusters which are close to the markets.

Supply chain optimization of perishable commodities involves diverse strategies and techniques for different aspects of the supply chain such as minimization of costs in a logistics supply chain network (see Costa [1]), optimization of multiple objectives for multiple products in supply chain networks (Altiparmak et al. [2], Altiparmak et al. [2]) and for integrated logistics using a hybrid evolutionary algorithm (Lin et al. [4]). Since agricultural production involves the conversion of a perishable raw material to finished product in a short time to maintain high yields, the transportation logistics of raw materials from different sources to the production centre has to be scheduled efficiently. Specifically in the context of sugar production, sugarcane arrival at a sugar mill from farms of varying sizes and varying levels of capability has been studied in Le Gal et al. [5] for a South African mill and production scheduling and scheduling of vehicles for transport of sugar at an Australian sugar mill has been proposed in Higgins et al. [6] for a sugar supply chain, and improvements in harvesting and logistics in the sugar supply chain have also been suggested in Higgins et al., [7] and Higgins and Laredo [8]. Operational planning models can help decide between trade-offs due to higher costs incurred in reaching the products to the market in time or and increased losses due to perishability (see Ahumada and Villalobos [9], Ahumada and Villalobos [10]).

Mobile technology has been used extensively in many farm information management systems in recent years. Techniques such as a soft system methodology have been found useful in modelling of systems which involve human interaction at various complex decision levels based on comparing a conceptual model with a real-world problem situation that enables farmers to understand the tools in a simple way as they would not otherwise understand formal models (see Sorensen et al. [11] and Sorensen et al. [12]). Handheld devices have often been used in precision farming in which advanced farm equipment generates voluminous amounts of data and data is also acquired from various geographically dispersed sensors in real-time. Since precision agriculture has to conform to a variety of compliance standards, mobile devices such as smart-phones are used for farm management information systems and decision support (Nikkila et al. [13], Peres et al. [14] and Nikkila et al. [15]). Personal digital assistants have been used for record keeping and decision support for

cucumber production at a farm production centre in China (Li [16]). RFID tag-based tracking on mobile devices has been used for warehouse management in vineyards (Cunha et al. [17]). Typically, data acquired from various sources on the farm has to be sent to other applications and XML documents are often used for data exchange. This bi-directional exchange of data between handheld devices and the backend application may use a pre-defined set of rules and a high level abstraction implemented in a graphical user interface to provide an easier tool for farmers than expecting farmers to learn XML for data exchange (see Iftikhar [18]).

1.1 Description Of Problem

A typical mushroom growing region comprises several mushroom farmers who send their fresh produce to one of the production centres that services their geographical region and the finished product is shipped to retail outlets or end consumers through outbound logistics. A logistics service provider has the task of collecting fresh produce from multiple farmers, taking it to a production centre, delivering finished product along the way. Inbound logistics from farmer to production centre must be able to handle the perishable product (fresh mushrooms) in a defined time window such that processing yield does not get affected. Similarly, outbound logistics deals with ensuring that fresh produce is delivered to end consumers or retail markets within a defined time window and processed goods may not have the similar short time windows. Since on a single trip the logistics provider has to handle raw material (fresh mushrooms) from multiple farmers as well as collect finished products for delivery to the markets, he has to assign certain capacities for each item in a truck. Such a scenario is typical in the production and distribution of other agricultural products also. The task of facility location and route design is complex because of the defined time window in which service must take place.

For the location of production centres and design of a route considered in this paper, it is assumed that intuition may aid in reducing the set of feasible facility locations to a manageable size and hence that possible locations for distribution (production) centres are known *a priori*. The number of production centres that can be operative at any time and the number of vehicles available at each centre may also be constrained by financial considerations. However, the actual number of centres and number of vehicles to be associated with each such centre is unspecified. Though this paper deals specifically with mushroom production and distribution chain which may have a small number of products, it is also assumed that any production centre in the above setup will cater to a wide range of customers with diverse products.

There are multiple objectives that are considered here. The multiple objectives that are formulated are: the maximization of the minimum of profit to expenditure ratios of the production (distribution) facilities in operation; minimization of the maximum distance travelled by any vehicle; and minimization of the total distance travelled by all the vehicles of the system. The second objective acts as a surrogate to the managerial goal to reduce the response time to any customer demand. The third objective restricts the fleet size at all distribution centres. In the formulation presented here it is assumed that each production centre has a distribution channel associated with it. Also, each customer location has time-windows which prescribe that customer be served within the stipulated duration.

A great majority of contributions in logistics planning have been invariably oriented towards a single objective of minimizing total cost to evolve a viable cost-effective route designs and schedules for carriers (Bodin et al. [19]). In general, only operating costs incurred for maintaining logistics support are considered for analysis with the operating system constraints. This approach excludes explicit consideration of return on investments, value addition derived from timely deliveries by minimizing the response times (Current and Min

[20]). Temporal aspects play a key role in a drastically and rapidly changing technological environment which has been oriented towards reduction in product life cycles.

In logistics planning, it often becomes imperative to open up new facilities, in order to minimize response times, at suitable locations in the network. Installation of new facilities with associated design of route structures connecting the nodes that come under the purview of these facilities, many a time entails multi-objective decision approach (see Laporte et al. [21] and Laporte et al. [22]). Despite its ubiquity in many real world decision problems the multi-objective approach has not received desired attention from the analysts and decision theorists for reasons of inherent computationally complex procedures (Martins [23]).

This paper emphasizes the need for a multi-objective approach in logistics planning targeting a supply chain of a firm of reasonably manageable size. Due consideration has been given to temporal aspects by incorporating time-bound constraints and objectives to connote its role in short product life cycles. The formulation of the location routing model is provided in the appendix.

2. THE ARCHITECTURE OF THE MOBILE SOLUTION

The mushroom logistics management system presented in this paper is a mobile solution in which various stake-holders such as consumers, mushroom farmers, production centres, logistics service providers, truckers and the retail outlets access the system through mobile enabled electronic forms. A range of mobile devices such as low-cost Java-enabled cell-phones, smart-phones, tablets can be used normally based on personal preferences of the stake-holders. The system uses electronic forms for the primary interface between user and the system. This is possible because the mobile devices incorporate a small forms interpreter that renders electronic forms based on the metadata embedded within the forms. Electronic forms are based on XForms technology, thereby providing a level of platform independence for such electronic forms (Boyer [24]). The backend server comprises a built-in workflow engine to manage interactions between the various users in the system. It also incorporates a module for tracking the trucks in near real-time since trucks are equipped with a GPS-enabled Android smart-phone which provides location information in real-time. The delivery of shipments to the retailers or end consumers is managed through a route planning module managed by the workflow engine. The route planning module, which runs at the back-end server, incorporates a location routing algorithm that uses a multi-objective a multi-objective location-routing model with fractional and linear objectives to solve the procurement and distribution problems in the mushroom supply chain. In the first stage a feasible solution is provided through TSP transformation and solving it through LIFO implicit enumeration and back-tracking, and which is then further improved by a heuristic in the second stage. While the initial route provided to the trucker is a static route, service requests can occur along the route which may necessitate the calculation of a fresh route for the remainder portion of the route. This is feasible in our solution because the trucker has access to information that allows the remainder of the route to be recomputed at the back-end server and the new static route is provided to the trucker.

Figure 1 presents a diagrammatic representation of the mushroom supply chain comprising raw material providers, the mushroom farmers, the logistics providers, retail outlets and end consumers.

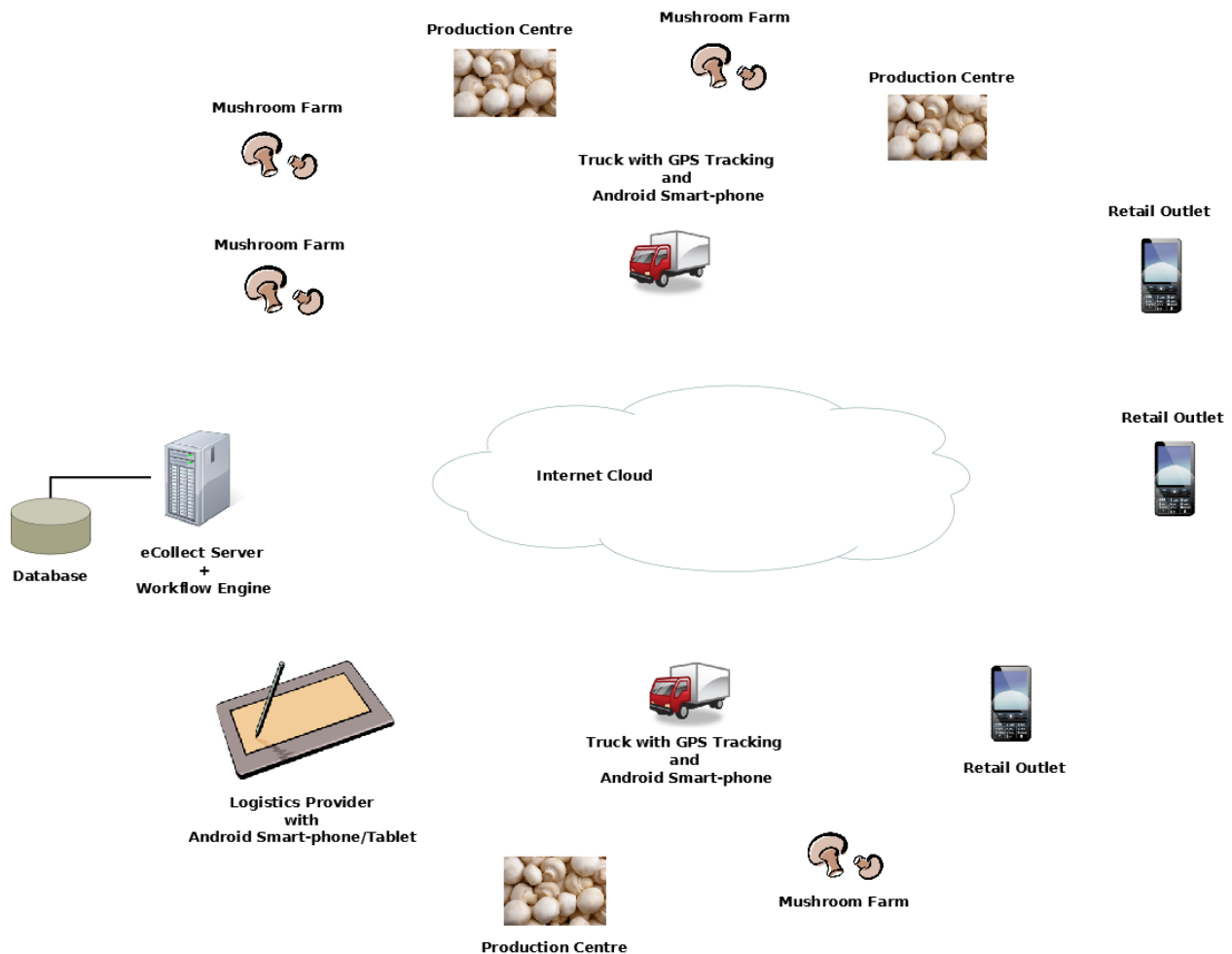


Figure 1: The Mushroom Distribution Supply Chain

2.1 The Rationale For A Mobile Phone Based Solution

All stake holders in the mushroom distribution chain have access to information in near real-time which is only feasible with the use of a cellular communications infrastructure at the core of the mushroom logistics management system presented in this paper. Cellular connectivity enables the real-time exchange of data between mobile devices in the field and the application servers. The cellular communications provides last-mile connectivity infrastructure and the same digital communications infrastructure is capable of being used for simultaneous support of voice and data applications, it is now feasible to develop mobile applications that are capable of real-time access to information. Thus there is sufficient justification for developing a mobile solution for the mushroom distribution chain in which the raw material and finished goods have short shelf-life and there is a small time window in which the goods must reach their destination.

2.2 Key Technologies In The Mushroom Supply Chain

The mobile logistics management system presented in this paper uses several key technologies to enable the mobile phone to function as an access device. Electronic forms are developed using XForms technology which provides a certain level of platform independence since such forms can be rendered on a variety of mobile devices (Boyer [24]). Android smart-

phones with built-in GPS are used for location tracking of trucks in near real-time. Thus, there is no need to use specialized tracking hardware. A location routing algorithm has been developed for the optimal planning of a static route for each truck based on the multiple objectives of maximization of the minimum of profit to expenditure ratios of the production facilities; minimization of the maximum distance travelled by any vehicle; and minimization of the total distance travelled by all the vehicles. The routing algorithm has been implemented as an optimization module that runs on a server accessible from any mobile device.

XForms technology provides an open standard for the design and implementation of electronic forms which are used to generate a service requests to the system. Platform independence is achieved by using an XForms interpreter that interprets the embedded metadata to display the form and implement the control logic to capture user input. XForms provides a rich set of data types for fields within a form, field level validation rules to minimize errors in input, skip rules to change the flow of sequence within a form, and client-side computation capability. In the solution presented here, an Android smart-phone client is used in the truck since it has all the interfaces such as GPS for recording of location, a communications module using GPRS or 3G for sending location data to the server for tracking in real-time and an interpreter for electronic form to communicate with the back-end server. Different stakeholders such as mushroom farmers, production managers, retailers and end consumer may use different mobile devices to interact with the logistics management system.

2.3 The Server And Workflow System

The logistics management server uses a workflow engine to manage the interactions between various processes in the system. The server comprises a web-based forms designer, a workflow engine and workflow servlets (see Aalst & Hee [25], YAWL [26]), and a set of platform services for the administration of the server.

Users interact with the server through a set of electronic forms on a mobile client application. Though the same set of forms is available on multiple mobile devices, the forms look different on each device. The mobile client application allows the use to download a form to the mobile device and then operate in disconnected or offline mode, enabling the application to be used even if no connectivity is available. An additional feature of the mobile client application is its ability to work in sync with the workflow engine and perform only those tasks (workflow items) assigned to it by the workflow engine. This ensures that even offline mobile devices are able to synchronize with the workflow system.

The server provides the forms that can be downloaded to client devices and receives completed forms as service requests from the users. A workflow servlet analyses the service requests arriving from different users and passes on information to other processes, using XML documents to exchange data between processes in the workflows. When a process is ready with its response, a pre-filled form is queued up as a workflow item and all workflow items are managed by the workflow engine. When a mobile device connects remotely to the server, it is able to synchronize its workflow. The mobile device uploads completed workflow items to the workflow engine and downloads any new workflow items that may be pending for it. This synchronization enables the mobile devices to operate in essentially disconnected or offline mode for extended periods of time. Another servlet tracks the trucks in real-time by recording GPS information from each truck in the central repository. The routing module computes an optimal static route for each truck based on information collected through service requests. An architectural overview of the server and workflow system is shown in Figure 2 below:

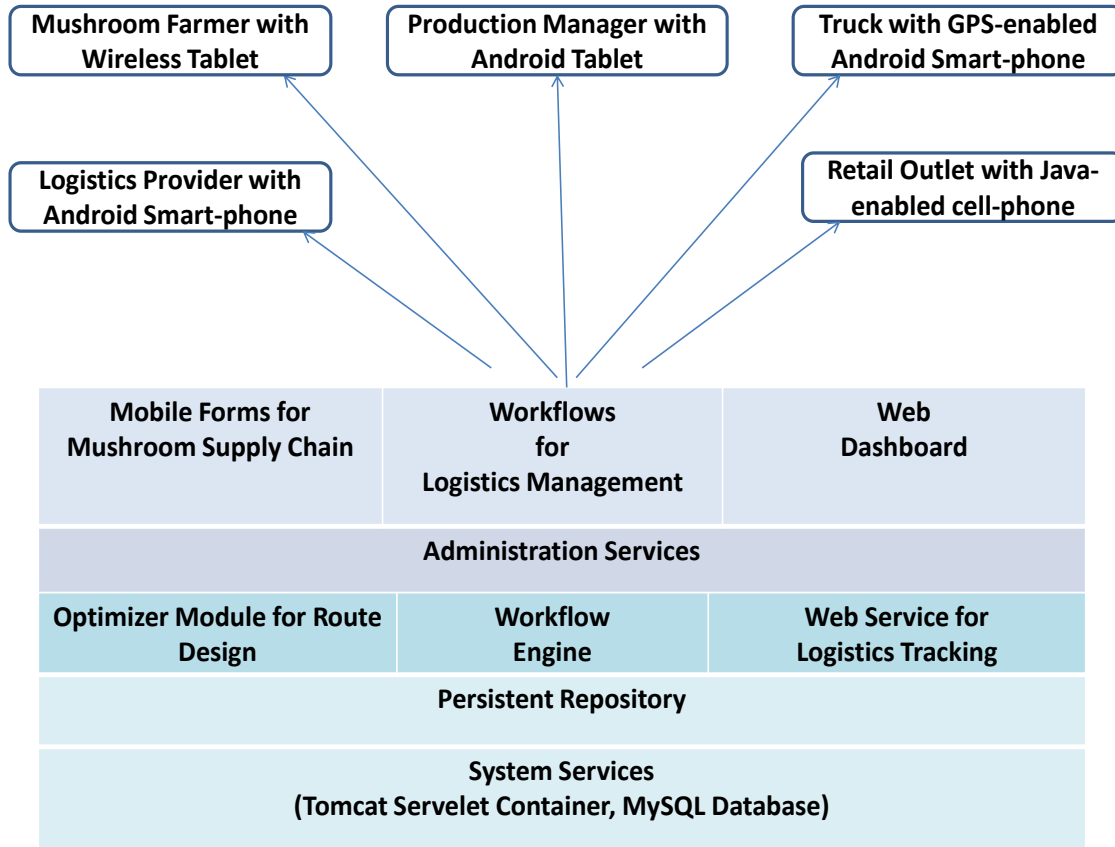


Figure 2: Architecture Of The Logistics Tracking System

2.4 The Use Of Electronic Forms For Service Requests

In the mobile solution presented in this paper, a mushroom farmer may generate a service request to the logistics provider by filling up a form which indicates the quantity of mushrooms, date and time by which the goods should be picked up. Different mushroom farmers generate service requests for different quantities of mushrooms to be collected. The production centre informs the logistics provider about the quantity of finished goods that are ready for shipment.

The mushroom farmer and the production centre use the same service request form to request for logistics service. Figure 3 provides a display of the service request form filled by a mushroom farmer and uploaded to the server where the workflow engine consolidates all requests and passes them on to the route optimizer. Using this form, the mushroom farmer can specify the type of goods he wishes to ship to the production centre, the quantity of each item and its dimensions.

Capture Data : Logistics_service_request

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Service Request Form

Requestor ID: 0012001 Date & Time of Request: 04/13/2012 02:53:48 PM

Requestor Address: 1 Fresh Mushroom Farms
20, Mysore Road
Bangalore - 560096 GPS Location: [Empty]

Type of Goods

Goods	Weight of Shipment (Kg)	Length of Box (cm)	Width of Box (cm)	Height of Box (cm)	
Fresh Button Mushrooms	10	30	30	30	Delete
Fresh Oyster Mushrooms	10	30	30	30	Delete

Add New

Expected Date of Collection: 04/14/2012 Expected Time of Collection: 08:00:00 AM

Figure 3: Mushroom Farmer's Service Request Form

When the production centre has processed goods that it wishes to ship to retail outlets or end consumers, it fills up a similar form shown in Figure 4 below. Similarly, retail outlets and end consumers fill up another service request form, shown in Figure 5, to specify how much quantity of a particular product they are willing to purchase in a specified time-window. While the service request forms are simplified versions for clarity, the form may have many other fields that are required to ensure an error-free collection or delivery by the trucker. For example, information on destination of the shipment has not been shown in the farmer's service request form since it is assumed that the fresh produce will be delivered to the nearest production centre. The service request forms may even contain an electronic voucher for a cashless payment system between the various entities in the distribution chain (Garg and Sundar [27]).

Capture Data : Logistics_service_request

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Service Request Form

Requestor ID: 0022001 Date & Time of Request: 04/13/2012 02:38:56 PM

Requestor Address: Mushroom Products Ltd.
25, Mysore Road
Bangalore - 560096 GPS Location: [Empty]

Type of Goods

Goods	Weight of Shipment (Kg)	Length of Box (cm)	Width of Box (cm)	Height of Box (cm)	Delete
Dehydrated Button Mushroc	10	50	50	50	Delete
Dehydrated Oyster Mushroc	10	50	50	50	Delete
Pickled Mushrooms	20	100	100	100	Delete
[Dropdown]					Delete

Goods dropdown menu:
Fresh Button Mushrooms
Fresh Oyster Mushrooms
Dehydrated Button Mushrooms
Dehydrated Oyster Mushrooms
Pickled Mushrooms
Others

Expected Date of Collection: 04/14/2012 Expected Time of Collection: 10:30:00 AM

Figure 4: Service Request Generated By Production Centre

Capture Data : Retail_request_form

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Retail Request Form

Retailer ID: 0032004 Date and Time of Request: 04/13/2012 03:00:51 PM

Retailer Address: Fresh Foods Retail Ltd.
1, Mahatma Gandhi Road
Bangalore - 560001 Retailer GPS Location: [Empty]

Type of Goods Requested

Goods Requested	Quantity Requested (Kg)	Delete
Fresh Button Mushrooms	3	Delete
Fresh Oyster Mushrooms	3	Delete
Dehydrated Button Mushroc	5	Delete
Dehydrated Oyster Mushroc	5	Delete
Pickled Mushrooms	3	Delete

Add New

Expected Date of Delivery: 04/14/2012 Expected Time of Delivery: 11:30:00 AM

Figure 5: Service Request Generated By A Retail Outlet

Thus the logistics provider has all the information required, including capacity requested by each entity and the time window in which collection or delivery is expected, to plan an optimal route. Multiple farmers, production centres and retail outlets participate in the

distribution chain. The optimal route is computed by the optimizer module and passed on to a trucker on his mobile device. While the initial route is computed based on requests available at the start of the computation, service requests may come in asynchronously when the trucker starts a trip. Thus the balance route may have to be recomputed periodically. Since each truck is GPS-enabled the truck's location is continuously tracked at the server. This information is provided to the route optimizer module to enable a re-computation of the route based on the current location of the truck. The flowchart for the route optimizer module is shown in Figure 6 below:

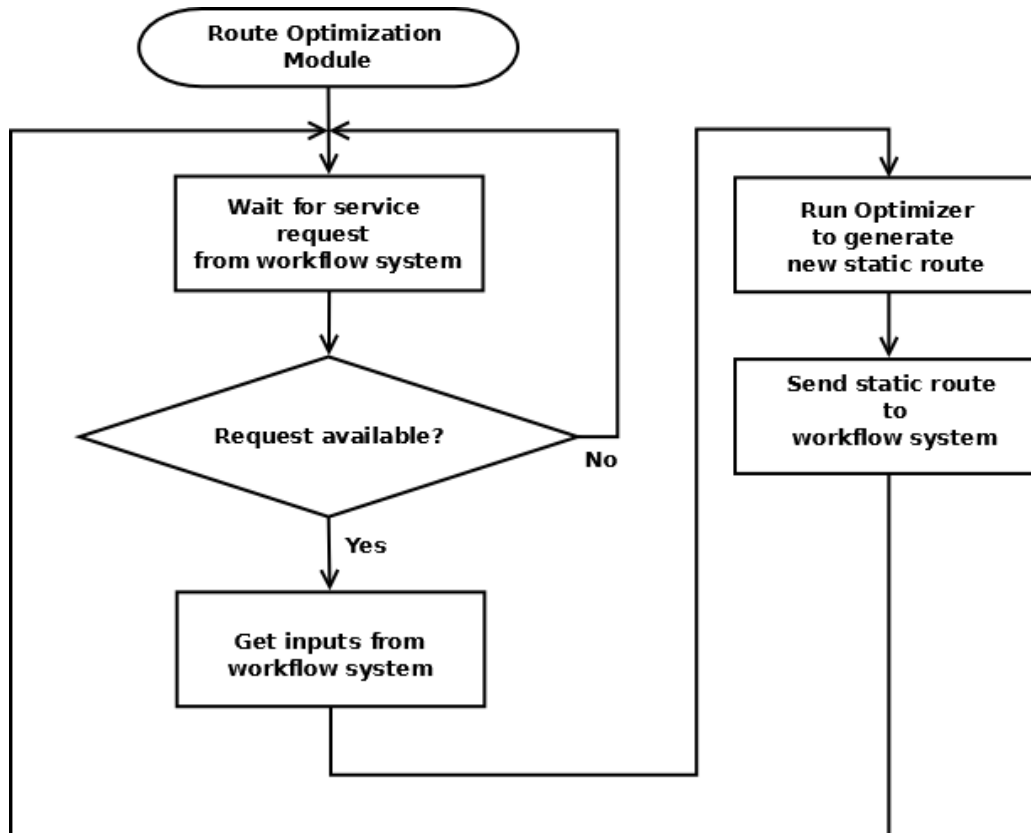


Figure 6: Flowchart Of Route Optimization Module

While the initial route is computed based on requests available at the start of the computation, service requests may come in asynchronously when the trucker starts a trip. Thus the balance route may have to be recomputed periodically. This is feasible since the current location of each truck is tracked in real-time since the truck driver uses a GPS-enabled Android smart-phone for continuously sending its location to the server. The route optimizer module then recalculates another optimal route for the remainder of the journey that this truck has to make.

3. CONCLUSIONS

This paper addresses one important aspect of the mushroom supply chain which deals with the distribution logistics in a defined time-window because of the perishable nature of the product under shipment. The task of the logistics system is to collect fresh mushrooms from farmers in defined time-windows, move the produce to production centres, collect finished products from the production centres and deliver the goods to retail markets and end consumers. A mobile solution is presented which comprises a backend workflow management

server with a routing optimization module and the different stake-holders interact with the routing system through mobile forms. A location routing algorithm has been deployed for finding the optimal route the trucker must take to collect raw materials on inbound trips and deliver outbound shipments of products to a chain of retailers.

In this paper we have emphasized multi-objective aspects of logistics in supply-chain management. We have presented a two stage algorithm for the problem described. An initial weak efficient solution is obtained by a computationally efficient implicit enumeration algorithm. As opposed to many enumeration algorithms, our proposed algorithm surmounts the thrashing effect, a common pitfall in back tracking strategies, by a penalty based reshuffle mechanism over the stack of edges. Frequent shuffling of the stack has been found to be very effective in terms of computational time involved. The initial weak efficient solution thus obtained has been improved by an efficient heuristic. Dimensionality of the logistics problem in any supply-chain and its intrinsic complexity necessitates that exact analytical procedures be supported by efficient heuristic procedures. The solution methodology adopted here can pave way for solving many realistic size problems of the same genre.

The routing algorithm is run on a backend server and the optimal route is presented to the trucker on a GPS enabled Android smart-phone. The trucker's location is tracked in real-time by the workflow engine. Though the initial route is statically computed, the logistics system may receive new service requests which could be serviced by a truck which is already on its route. The system recalculates another optimal route for the remainder of the trip and passes it on to the truck in real-time. This ensures that the trucker is able to adapt to changing requirements dynamically.

APPENDIX

In this paper it is assumed that the possible locations for distribution (production) centres are known *a priori* since intuition can aid in reducing the set of feasible facility locations to a manageable size. Financial constraints may also restrict the number of centres that can be operative at any time and also the number of vehicles at each centre. However, the actual number of centres and number of vehicles to be associated with each such centre is unspecified. We also assume that any production centre in the above setup will cater to a wide range of customers with diverse products, though in this specific instance, only mushroom related products are considered.

The objectives formulated include maximization of the minimum of profit to expenditure ratios of the production (distribution) facilities in operation, minimization of the maximum distance travelled by any vehicle and finally minimization of the total distance travelled by all the vehicles of the system. The second objective acts as a surrogate to the managerial goal to reduce the response time to any customer demand. The third objective restricts the fleet size at all distribution centres. In the formulation, it is assumed that each production centre has distribution channel associated with it. Also, each customer location has time-windows which prescribe that customer be served within the stipulated duration. With the features mentioned above, a multi-objective formulation is given as follows:

Formulation: (F1)

$$\text{Maximize } \text{Min}_k \left(\frac{\sum_{i \in P_k} S_{ik} * Pr_{ik}}{Fc_k + \sum_{i \in P_k} S_{ik} * Cp_{ik}} \right)$$

$$\text{Minimize } \text{Max}_v \sum_i t_i * (\sum_{j=1}^n x_{ij}^v) + \sum_i \sum_j t_{ij} * x_{ij}^v$$

$$\text{Minimize } \sum_{v=1}^m \sum_{i=1}^n \sum_{j=1}^n d_{ij}$$

Subject to

$$1. \quad \sum_{i \in I} y_i \leq n_0$$

$$2. \quad \sum_{v=1}^m \sum_{j \in J} x_{ij}^v = 1, \quad i \in J, \quad i \neq j$$

$$\leq m_i * y_i + M * (1 - y_i), \quad i \in I$$

$$3. \quad \sum_{v=1}^m \sum_{\substack{i=1 \\ i \neq r}}^n x_{ir}^v = \sum_{v=1}^m \sum_{\substack{j=1 \\ j \neq r}}^n x_{rj}^v, \quad \forall r$$

$$4. \quad \sum_{v=1}^m (\sum_{i \in I} Q_i * x_{ij}^v) \geq D_i * Y_i, \quad \forall i \in I$$

$$5. \quad \sum_{v=1}^m (\sum_{i \in I} Q_i * x_{ij}^v) \leq K_j * Y_j + K * (1 - Y_j), \quad \forall j \in I$$

$$6. \quad \sum_{i=1}^n (Q_i + e_r - d_r) * x_{ir}^v = \sum_{j=1}^n Q_r * x_{rj}^v \leq Z_v, \quad \forall v \text{ and } r$$

$$7. \quad \sum_{i \in I} \sum_{j \in J} Q_i * x_{ij}^v = \sum_{i \in I} \sum_{j \in J} d_i * x_{ij}^v, \quad \forall r$$

$$8. \quad a_j \geq (a_i + t_i + t_{ij}) - (1 - x_{ij}^v) * T$$

$$9. \quad a_j \leq (a_i + t_i + t_{ij}) + (1 - x_{ij}^v) * T$$

Where,

a_i = arrival time of a vehicle at the i^{th} node

Cp_{ik} = unit cost of production for item i at plant k

d_{ij} = distance between nodes i and j

D_i = break-even amount of distribution for the plant located at node i

e_i = load picked-up at node i

Fc_k = fixed cost for plant k



I	=	index set of nodes for possible plant locations
J	=	set of collection and distribution nodes
k_j	=	capacity of the plant located at node j
K	=	$\max k_j, j \in I$
m_i	=	maximum no. of vehicles located at plant i
M	=	$\max m_i, i \in I$
n_0	=	maximum number of candidate plants that can be located
P_k	=	index set of items produced at plant k
Pr_{ik}	=	Expected unit profit for item i produced at plant k
Q_i	=	total load that can be carried by a vehicle just after it leaves node i
S_{ik}	=	amount of production of item i at plant k
t_i	=	service time at node i
t_{ij}	=	minimum travelling time between nodes i and j
T	=	maximum allowed time for any route
y_i	=	1 if a plant is located at node i 0, otherwise.
x_{ij}^v	=	1, if the arc (i,j) is in the route of vehicle v 0, otherwise
R_k	=	$\{r_{k,s} : s = 1, 2, \dots, m_k + 1\}$

Algorithm:

The algorithm proposed in Krishna Sundar & Ravikumar [28] has been improvised for mushroom logistics and is carried out in two stages:

Stage I : LIFO implicit enumeration to get an initial w-efficient solution.

Stage II: A heuristic approach to get an improved solution.

In the first stage, constraints (4) to (6) are deleted from consideration and a modified Hungarian method is adopted for solution to the resulting assignment problem. Infeasibility as regards to constraints (4), (5) and (6) can be dealt with in which some of the arcs are fixed at 0 or 1.

In the final reduced cost matrix of the assignment problem, any edge (i,j) fixed out to exclude from assignment will induce a penalty, p . A weak lower bound for p can be computed by adding up the smallest other element in the i^{th} row to that in j^{th} column of

the final reduced cost matrix. In a similar fashion, any edge can be fixed in by assigning value one to the corresponding variable.

At any stage both the fixed out and fixed in edges can be freed to restore their true costs. To minimize the penalty computations, at each stage, one of the shortest infeasible subtours is selected and the edge with least penalty is fixed out.

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