Augmenting Rural Supply Chains with a Location-Enhanced Mobile Information System

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Abstract— In recent years, there has been increased interest in the market potential of rural communities in the developing world. In the developing world, the lack of information and communications infrastructure has left companies with manual paper-based information methods as the only means of analyzing and aggregating data. This primitive approach to rural supply chain management creates a barrier to efficiency and a barrier to entry for many companies. In this paper we discuss a field study conducted with a company involved in the marketing, sale, and distribution of products in rural India. We describe the participants in this company's rural supply chain, highlighting inefficiencies in the information and material flow. We show how a technology-based solution could help optimize distribution routes and reduce inefficiency. By knowing the location and details of transactions, the company can better direct rural marketing strategies and manage human and material resources.

We present the high-level design of this system and enumerate the possible technologies that can be used to determine a user's location via a mobile device, including GPS, GSM triangulation and Placelab using GSM [1]. To assess the potential of GSM-based methods, we describe the results of an experiment we conducted to determine the extent of GSM coverage along common rural sales routes. Our results indicate that GSM-based methods are sufficient for some purposes, but can not be used to determine the exact position of all rural transactions, especially those that occur in rural villages. We discuss scanning location-specific barcodes as a possible way of localizing transactions to individual villages and customers.

Index Terms—mobile computing, mobile phones, rural development, ICT, client-server systems.

I. INTRODUCTION

Organizations operating in today's volatile and dynamic marketplaces have understood that in order to properly meet market demands, they must decrease customer response times while reducing overhead costs in product delivery. This has resulted in the need for more efficient and transparent supply chains that can be utilized as the main platform for information and material exchange between inter- and intra-organizational stakeholders of a product delivery cycle.

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Supply chain management refers to the planning and control of the transfer of goods, materials, and services from suppliers through a distribution channel to the end user [2]. Utilization of Internet-enabled supply chains has proven to enhance companies' efficiency and effectiveness in evaluating their business operations [3]. A study conducted in 2004 of Indian companies found that although 80% of Indian companies are now using the Internet in some form for supply chain management, only 49% of these companies are using technology as a means of managing purchasing and only 7% for production scheduling [4]. In [5] the authors elaborated three factors which have inhibited better integration of IT solutions for rural e-supply chains, namely the low IT maturity of its stakeholders, the complexity of supporting a system at geographically dispersed locations, and the reliability of telecommunications in rural areas. In order to properly utilize the benefits of the Internet and allow for information transparency between the multiple stakeholders involved in the delivery, sales and warehousing of products and services, information systems must be created which overcome such barriers to entry for rural e-supply chains.

In this paper we discuss a field study conducted with a company involved in the sale and distribution of health care products in rural India. We list the various participants in this process, and the coordination efforts required to deliver products and exchange information. The current use of manual, paper-based systems limits the efficiency of information and material flows between customers, the sales team and management. We discuss how this situation could be remedied by using a technology-based solution _ a location-enhanced mobile information system that can capture the details and locations of field transactions and other supply chain processes.

We present the high-level design of this system and enumerate several possible technologies that can be used to determine a user's location via a mobile device, including GPS, GSM triangulation and Placelab using GSM [1]. GPS provides the most accuracy, but also adds to the hardware cost. GSM-based methods can be used by mobile phones without extra hardware. To assess the potential of these GSM-based methods, we describe the results of an experiment we conducted to determine the extent of GSM coverage along common rural sales routes. Our results indicate that GSM-based methods are sufficient for some purposes, but can not be used to determine the exact position of all rural transactions, especially those that occur in rural villages. We discuss scanning location-specific barcodes as one possible way of localizing transactions to individual villages and customers.

II. NEED FOR RURAL SUPPLY CHAIN MANAGEMENT

Information plays a key role in the coordination of processes and interactions both in inter- and intra-organizational supply chains. In [6] the authors elaborated on the importance of *information transparency* between the various departments of a company involved in the delivery, sale, and management of goods and services. When information is generated it must become available to managers who use this data for decision making purposes. This information is then disseminated down the supply chain to the various officers and middle-management personnel entrusted to carry out their given tasks. In this section, we elaborate on why information aggregation is required in rural supply chains to properly meet consumer demand and coordinate efforts between various stakeholders.

Understanding the Customer

Upstream flow of information from the customer is essential for a company to properly understand customer demand, manufacture the proper amount of products, and distribute them in a time-effective manner. Having too much or not enough inventory can both have disastrous impacts on a company's profitability [7]. In order for companies to properly meet demand, exactly enough supply must be generated and delivered efficiently to the right locations. This requires the generation of three types of information - what amounts of products are needed, where they should be delivered, and when they are desired. This information is generated at the customer-level of any supply chain, but only becomes useful when it percolates up the supply chain back to the supplier where the products are produced. While supplies and materials are generated at the top of the supply chain and flow down, information flows the opposite way, from the bottom up [5].

Pipeline Coordination

Whenever an organization uses a supply chain as a means of distributing products or services, there are various organizational structures and hierarchies that must coordinate efforts for a particular sale to take place. Such *collaborative supply chains* are required to optimize profitability by meeting present and future customer demand with adequate supply [8]. Management must work to synchronize efforts between their marketing departments, sales teams, and distribution forces. A well-tuned supply chain must be *flexible*. It must deal with variable demand by coordinating the different departments involved in supplying the product to the end user. Due to the number of stakeholders involved in delivering and selling goods to consumers in rural areas, and the large geographic distances between them, collecting and aggregating information manually is inefficient and time-consuming. A technology-based solution could definitely make this process more efficient and timely.

Minimizing Ambiguity

Periodically the key decision makers in a supply chain evaluate how well their business is infiltrating the market, and redesign business processes to take advantage of new market potentials or to expand upon current ones. Such iterative business processes require the repositioning of sales and distribution routes, marketing strategies, and organizational structures and hierarchies. However, inadequate information measuring supply chain performance can lead decision makers to make impromptu decisions that could lead to misaligned business strategies [8][2]. Technology can automate a number of labor-intensive information processes required for providing decision makers with timely and complete data to evaluate present business growth, thereby maximizing the potential of building successful future business strategies.

III. AN EXAMPLE RURAL SUPPLY CHAIN

Over the past year we have worked closely with a company in a medium-sized city in India to understand the organization of an example of a rural supply chain. This company (referred to anonymously as *Company X*) is involved in the manufacturing and distribution of health products in rural areas. Company X has a team that assumes complete responsibility for the warehousing, delivery, sales, marketing and management of all products and services. In this section we will elaborate on the key responsibilities and roles of each participant in Company X's supply chain.

Management

The management team at Company X is responsible for overseeing the delivery and sale of products throughout the supply chain. They strategically plan sales and marketing strategies, predict future customer demand, and manage distribution and sales personnel.

Supplier

The supplier is a distinct company or organization responsible for product production and delivery to the *CFA* (Carrying and Forwarding Agent). The supplier uses a PC-based information system to manage inventory distribution cycles between themselves and the CFA. Company X utilizes one supplier for all of its products.

Carrying and Forwarding Agent (CFA)

The Carrying and Forwarding Agent is a warehouse that serves as a distribution and holding point between the supplier and the stockist. CFAs are located so as to minimize travel distances between themselves and stockists. Still, in Company X, the distance between a CFA and a stockist can be up to 250 km. Company X relies on two CFAs to deliver stock to all of their stockists.

Stockists

Fragmentation of the consumer base necessitates the presence of stockists that serve as a localized warehouse for use by the rural sales team [5]. When product is delivered from a CFA to a stockist, it is held until the RSOs (Rural Sales Officers) procure it to sell to retail stores in nearby villages.

Territory Sales Manager (TSM)

Territory Sales Managers are the local managers for Company X. They are responsible for carrying out pre-planned sales objectives and managing a team of 6-8 RSOs.

Rural Sales Officer (RSO)

A Rural Sales Officer (RSO) is responsible for picking up products from stockists and selling them in their territory. Their territory is predetermined by the management of Company X. RSOs follow a RPJC (Rural Planned Journey

Cycle) and visit all village retail stores found along the route. There are usually 3-8 villages along a single RPJC. RSOs generally travel 30-70 km from their location to reach the stockist, and then travel to rural retailers that lie within 5-30 km from the stockist along their RPJC.

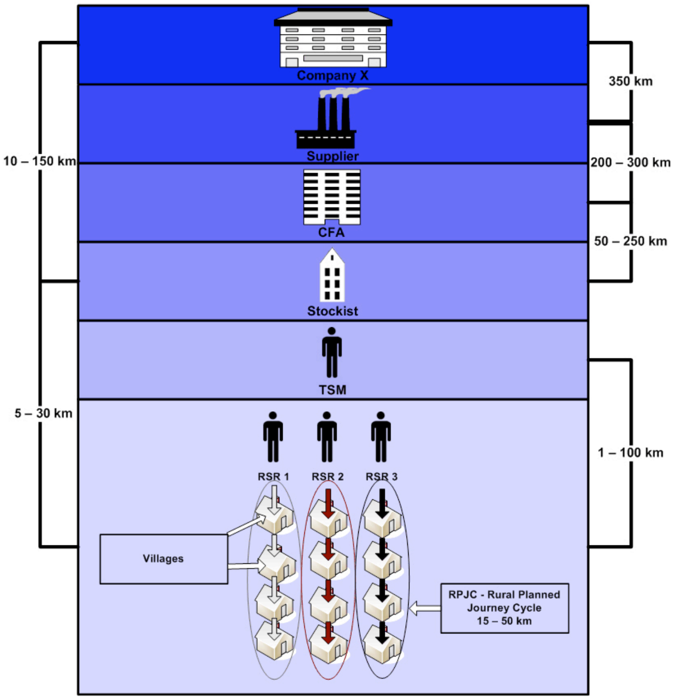

Figure 1 - Average distances between the supplier, Company X's head office, the CFA, the stockists, and the RPJCs traveled by RSOs.

Rural Retail Store

In rural Indian villages, small, locally-owned retail stores are the most accessible place for people to purchase goods and services. Many companies operating in rural markets have understood the importance of this delivery channel [9]. In Company X's supply chain, RSO's sell products directly to retail stores. There are usually 3-5 stores in a single village.

Figure 2 - An example rural retail store.

Marketing Department

The marketing department is responsible for ensuring that customers are aware of the goods and services the company is offering. Marketing strategies developed at Company X are disseminated down the supply chain to be carried out by RSOs and TSMs in the areas surrounding their assigned RPJCs.

IV. NEED FOR TECHNOLOGY AND LOCATION-ENHANCED SERVICES

Company X is currently only utilizing technology at the top tiers of their supply chain. The supplier uses a PC-based solution to manage product inventory and distribution arrangements between themselves, the CFAs and stockists. Company X's management also uses a PC-based system to aggregate paper-based records gathered from TSMs and RSOs.

Paper is used ubiquitously throughout Company X's supply chain. The current use of manual information systems restricts the ability of decision makers to obtain accurate, timely and meaningful observations about the current state of demand and supply in outlying areas. Due to the large geographic distances between the company and its stockists, sales force, and customers, paper becomes an even more inefficient medium. The RSOs use fax machines in urban hubs located near their sales routes to transmit sales data to the head office. At times, we observed RSOs traveling up to 50 km to find an available fax machine, and having to wait for a prolonged period of time due to the unavailability of electricity. This greatly limits the efficiency of the information flow between the sales team and management.

In order for management to have the accurate and timely information to direct future marketing schemes, and evaluate individual and group sales performance, these solutions are not sufficient. Technology-based solutions should also 1) automatically collect information about the whereabouts of sales and distribution officers, and capture all of their sales transactions and 2) deliver relevant information to the management and suppliers. In this section we motivate the need for a mobile information system that couples transaction capture and location-enhanced services to better inform rural supply chain processes.

Location of Officers

For the management of Company X to know where any one particular TSM or RSO is currently operating, they must call them on their mobile device. If the TSM or RSO has cellular coverage at the time, then management can only determine where he is and evaluate his status based on a verbal discussion. The company has no guarantees whether the information obtained from the staff is accurate. Moreover, in Company X, it is infeasible for management to maintain contact with all of their officers, consisting of over 900 RSOs and 100 TSMs. Monthly meetings are the only formal mechanism for management to monitor the performance of its sales teams, and to re-plan marketing and distribution schemes to meet the observed consumer demand.

If the location and actions of the RSOs and TSMs were automatically captured and transmitted back to management, they would be much better equipped to manage the team. A common practice for rural sales officers is to avoid travel by trying to sell products closer to home. This limits the market penetration of Company X's products. Based on their travel history, management could make sure that sales officers were covering all of the RPJCs assigned to them. They could also observe which sales teams were able to meet customer demand, and which were performing below expectation.

Location of Transactions

Using their current manual information system, Company X's marketing and sales teams are able to document consumer spending patterns for a set of villages along a particular RPJC. In order for Company X to properly target marketing efforts and meet current demand, it is not sufficient to have information at this large granularity. A better approach would include analysis of sales successes at a much smaller scale. In [10], the authors argued the need for understanding *individual* customer behavior. By analyzing the spending patterns of individual consumers (rural retail stores), they could then calculate the *value* of each customer. Information could be generated that documented not only what products they are currently buying, but which products they have not bought. Historical spending patterns could also be analyzed to determine if that customer was "keeping pace with prior spending patterns" [10]. Special promotional events could be offered to consumers who have had significant spending patterns, so that a company could express their gratitude for that individual's loyalty, and encourage them to remain a steadfast customer. Finally, when the location of each transaction is captured and delivered to the management of Company X, this information could be analyzed to evaluate how well different marketing schemes were working in different geographic areas. Fine-grained location data about individual transactions is required to compare historical sales trends to individual spending patterns, tailor marketing schemes to specific geographic regions, and maximize customer satisfaction through promotional events targeted to specific customers or groups.

Location for Managing Stock

Currently suppliers and CFAs can only find out that a stockist needs more inventory when he notifies them of what products he wants, and at what quantities. If the CFA has the desired product in stock, they send a delivery vehicle to supply the required products. Otherwise, the CFA must request that stock from the supplier. These deliveries are not coordinated with the needs of nearby stockists. For example, another stockist may request the same products shortly thereafter. This might require the CFA to again request additional stock from the supplier, and again send another delivery vehicle to the same area. If the CFA had more timely access to stockist inventory levels, restocking routes could become automated and optimized. This would also reduce the currently labor-intensive coordination efforts required between participating agencies in the supply of products in rural areas. This motivates the need for location information about individual stockists, their current stock, and their historical restocking patterns. If this information is gathered and made available to the CFA and the supplier electronically, planning restocking routes and predicting demand for a particular product would become automated and thereby more efficient.

Creating the Collaborative Supply Chain

Asymmetric information refers to "different parties having different states of private information about demand conditions, products and chain operations" [8]. In rural supply chain management, asymmetric information generally arises due to the nature of manual information systems. For instance, information shared between the stockist and the CFA is not necessarily shared with the management of Company X. Information delivered by a team of RSOs and TSMs to management is not necessarily shared with another team of sales officers. When transactions, accounting, organizational plans, and marketing schemes are all conducted on paper, it is difficult to share information in a timely and efficient manner. A technology-based solution would facilitate the flexible aggregation and dissemination of this valuable data.

V. PROPOSED INFORMATION SYSTEM

We propose a mobile client-server IT solution that addresses these requirements. The authors in [5] have suggested that mobile devices be put directly in the hands of sales representatives. We extend this idea for rural supply chains by observing that mobile devices can also be used at the stockist-level, obtaining many of the same benefits at a fraction of the cost (due to there being many fewer stockists than RSOs).

In our proposed system, mobile phones carried by RSOs and stockists are used to capture transactions and location information. This data is aggregated in a centralized database accessible by various managerial parties. We have already developed a prototype client for this application that uses the CAM mobile browser to process paper documents used in supply chain transactions [11]. Location information is provided by PlaceLab, which can estimate a users' location based on the identity of nearby GSM towers [1].

In the next section we discuss the operation of both the RSO and stockist-based systems.

For Stockists

Stockists have two interaction points which generate useful information - when inventory arrives, and when inventory is sold to a customer or an RSO. This information would be gathered through the use of a mobile device and delivered to a centralized server for use by the management of Company X.

Immediate knowledge about inventory levels will allow for better cooperation between the CFA, the stockist and the supplier to plan distribution routes. When a stockist receives stock from a CFA, the mobile phone can record the quantity and identity of each product. Using a camera-equipped mobile phone, barcode labels uniquely identifying each product can be scanned. When a product is sold to a third-party customer, or to an RSO, that transaction can also be captured, and inventory levels adjusted appropriately.

This solution requires the use much fewer mobile devices than those intended for use by the RSO. In Company X, there is an order of magnitude fewer stockists than RSOs. This makes this model attractive for companies that do not have the resources to supply their entire rural sales force with mobile devices.

Aggregate sales data from stockists to RSOs will help management to understand which RSOs are successfully selling products along their RPJCs. The management will know when an RSO bought how much and what stock at what price, and from which stockist. However, this is not sufficient to understand the purchasing patterns of individual customers (rural retail stores). For this granularity of information, RSOs themselves have to be equipped with mobile devices to capture sales transactions as they occur along their RPJC.

Figure 3 - An example stockist.

For RSOs

RSOs interact mainly with the stockist and the rural retail stores along their RPJC. Between these two interaction points a wealth of information is generated that can support the management of both human and material resources at the bottom tiers of the supply chain, while also gathering information related to individual spending patterns and trends.

TSMs currently manage their RSOs using two kinds of information. Because TSMs and RSOs are not always operating in the same geographic area, telephone conversations and group meetings are the most regularly used means to evaluate RSO performance. Based on instructions handed down to them from management about what RPJCs RSOs should cbe operating in, TSMs must monitor the RSOs location, and their current sales and marketing progress. Such a method of gathering and analyzing data has obvious limitations. It becomes hard to tell how well an individual RSO is performing because 1) exact sales figures are not exchanged, 2) the location of the RSO can not be verified and 3) there is no means by which a TSM can compare the relative performance of their team to other teams of RSOs and TSMs. If the location and transactions conducted by each RSO were automatically captured and delivered to a centralized database accessible to the management, this could be used as a much more objective and thorough evaluative tool.

If transactions between the RSO and individual rural retail stores are captured, this information could be analyzed to understand what products are selling well in what areas, and to better tailor rural marketing schemes for creating demand in under-served markets. Information about individual consumers and their behavior would help predictive sales and marketing models to be tailored for small geographic areas. TSMs would better understand in what areas sales efforts should be augmented or diminished. RPJCs could be optimized so that RSOs and TSMs would be best positioned to maximize sales while reducing traveling time and costs.

VI. MOBILE PHONES AND POSITIONING TECHNOLOGIES

Mobile phones are a uniquely appropriate device to combat various barriers to entry for technology in rural supply chain management. Solid-state memory, extended battery-life and a compact, rugged form factor are all great design choices for the rural environment. Even in a developing country like India, cell phones are the most ubiquitous computing platform, making it an excellent candidate to be the end-user device [12].

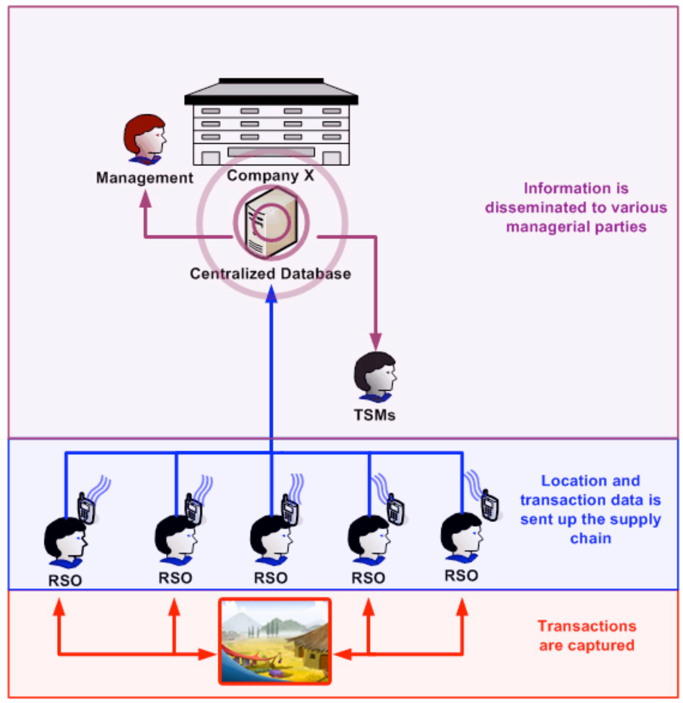

Figure 4 – Transaction and location information collected from RSOs is disseminated to various managerial parties.

By capturing the user's location (and other contextual factors) automatically, the user interface requirements for our proposed mobile solutions can be greatly reduced. This is an important consideration given the difficulty of using mobile user interfaces, and the fact that RSOs and stockists generally do not have much education and are unfamiliar with computing devices. There are a variety of positioning technologies that mobile devices can use to automatically determine their location. In this section we discuss some alternatives given the context of the rural supply chain management application.

GPS

Perhaps the most widely-used example of a positioning system that provides ubiquitous coverage is GPS [12]. GPS relies on satellite observation to determine the user's location precisely in any outdoor setting. However, GPS does not work well indoors, as satellite signals are "too weak to penetrate most buildings" [12]. GPS provides excellent accuracy of between 8-10 meters, suitable for most outdoor applications. GPS devices that can interface with mobile phones are now widely available. However, purchasing a separate GPS device can add significantly to the cost of the end user solution [13].

GSM Triangulation

A GSM phone can *triangulate* its location by listening to a series of base station signals and measuring the time and distance between each pair of arrivals [14]. Cell phone based location services currently work by measuring time difference of arrival (TDOA), angle of arrival (AOA), and carrier phase, and relaying that back to the user's phone [12] [14]. However, if too few measurements are available, GSM triangulation will result in "ambiguous position estimates" [14]. In areas with ubiquitous GSM coverage, GSM triangulation can provide an accuracy of between 100–200 meters. GSM triangulation requires a relatively large number of GSM towers to triangulate a location, but does not require extra hardware beyond a mobile phone.

Placelab

Placelab also uses the detection of GSM signals as a means of calculating location on mobile devices [1]. The Placelab approach is known to work better in dense urban or metropolitan areas than in less populated rural areas where there is sparse wireless coverage [12]. Before Placelab can be used to calculate a location, the user is required to create a GSM map of the area by *stumbling* around the geographic area with a mobile device coupled to a GPS. This creates a *beacon database* correlating GSM tower (beacon) signals to GPS locations. This database can be referred to at a later time to calculate the user's location based on GSM readings, without a GPS device. Experiments have shown that this can deliver an accuracy of up to 107.2 meters [12].

Choosing a technology

Company X is currently testing the use of GPS-equipped vans to track RSO movements. However, due to cost considerations, the management is wary of deploying this technology to all 1,000 of its sales representatives.

In the next section we describe an experiment conducted along rural sales routes in and around Lucknow, Uttar Pradesh, India, to determine whether it would be possible to calculate location using GSM-based methods in Company X's operating area.

VII. EXPERIMENTAL RESULTS

The potential for calculating location using GSM-based methods depends on the density and coverage of GSM towers in three kinds of areas frequented by RSOs: metropolitan areas, highways, and rural villages. To determine these factors, we gathered a series of GSM tower readings and GPS readings to produce *GSM coverage maps* of typical sales routes followed by RSOs. We examined our results to determine if localization would be possible given the observed coverage. Our results show that it is feasible to determine the location of RSO transactions down to a village or set of villages, but not to an individual customer (rural retail store).

Method

Our field study began in August of 2005, and lasted for two weeks. We shadowed several RSOs during their regular sales and delivery cycles - from the point of product pickup at the stockist, to the sale of those products to rural retail stores along their RPJC. Our first objective was to understand the utilization of human and material resources throughout the rural supply chain. Our second objective was to determine whether GSM-based methods could be used to estimate RSO and transaction locations.

While we shadowed RSOs, we carried a Nokia 6600 mobile phone running the Placelab stumbling software. We also carried a GPS receiver to correlate GSM readings with latitude and longitude information. Our trips all started in Lucknow, and lasted between one to three days.

Experimental Setup

Due to API restrictions, the currently available Placelab application for Nokia phones is only able to retrieve information about one GSM tower _ the one the phone is currently bound to. Information about the other cellular signals picked up by the phone is not available. The phone will switch to a new tower when it determines that the tower is offering a better connection, or if the previous tower is experiencing excessive load. Using the Placelab stumbler, we were gathered a sequence of GSM signal readings and GPS locations. Coverage density is assessed by determining the maximum, minimum, and average signal strengths recorded in different geographic regions. If there were many cellular towers in an area, the phone was expected to switch towers more often as stronger signals were encountered from new towers. In less dense areas, the phone will remain connected to one tower longer and over a wider range of signal strengths.

In order to estimate coverage density, we iterated over a series of GPS and GSM readings. The tower ID, signal strength, and GPS location for each reading was mapped. During this process, we observed that the phone never logged any readings with zero signal strength. However, we have reason to believe that there are some readings that *should* have been zero or near zero. When the phone lost contact with a GSM tower but did not connect to another one, it continued logging the last recorded signal strength and GSM tower ID. We have therefore estimated areas of zero signal strength based on the following three parameters: 1) the recorded signal strength is less than thirty, 2) the recorded signal strength does not change for a series of twenty iterations, and 3) the phone does not switch to a new tower.

Figure 5 depicts a typical sales route covered by a RSO in a given day. The RSO starts in Lucknow and first travels to the stockist to pick up stock. In this case, the stockist was also located in Lucknow. He buys the necessary amount of product that he believes he can sell to the rural retail stores along his RPJC. The route covers five different villages where the RSO must market and sell the product to different shops. As noticed in the figure 5, in this case 3 of the 5 villages he visited did not have GSM coverage.

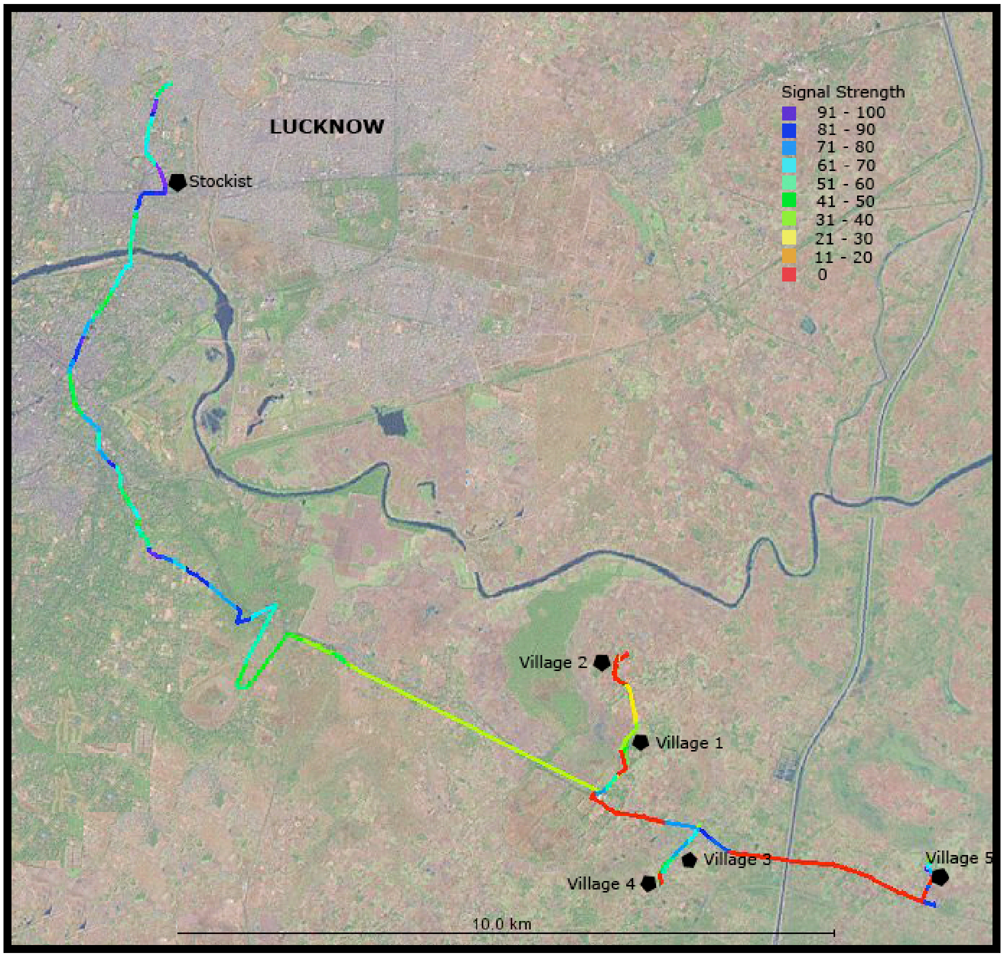

Figure 5 – A typical sales route of an RSO. He picks up products at the stockist and then follows his RPJC selling products to various retail stores in the villages he visits. The range of recorded signal strengths for each section of the journey is displayed

Coverage Results

Several other trends can be noticed in this figure that held true for most of the areas observed during our experiment. When inside metropolitan areas or traveling close to one, there is excellent GSM coverage. However, the farther one travels from a metropolitan area, like Lucknow, there will be a diminishing number of towers available. This can be seen in the gradual decrease of the average signal strength as the RSO travels further from Lucknow. Also, when the RSO ventures off of the highway for any appreciable distance, the average signal strength and number of observed towers usually drops dramatically. On smaller rural roads, we found that almost half of the time there is zero coverage. Coverage while traveling on a highway is much better in most cases. Obviously there are parts of the highway that have no coverage, but eventually another tower is observed.

Based on all of the data we collected over two weeks, in Table 1 we have calculated the average GSM signal strength for the different kinds of regions that we encountered (urban, highway, and rural road). For each of these three kinds of areas we have also noted the observed minimum and maximum GSM tower signal strengths. As a control, we also collected data in and around Seattle, WA in the United States. Starting from downtown, we traveled outside the city and then into the mountains to approximate the same kind of coverage experienced along rural roads in India.

Table 1 – Signal strengths for urban, highway, rural and mountain areas both in Seattle and in India.

Area	Maximum	Minimum	Average	% Time Connected
Downtown Seattle	95	46	73.08	100 %
Highway (Outside Seattle)	88	0	52.16	97.06 %
Mountain Road (Outside Seattle)	69	0	27.49	68.20%
Lucknow	100	23	73.55	99.86 %
Highway (Outside Lucknow)	98	0	39.10	72.77 %
Rural Road (Outside Lucknow)	93	0	27.18	52.67 %

This data confirms our observed trends. In both metropolitan areas one can expect to see enough GSM towers to remain connected 100% of the time, usually with high signal strength. In Downtown Seattle, we observed that there was 100% connectivity. The average signal strength was 73, never falling below 46. Likewise, in Lucknow, another metropolitan area, we also observed almost 100% connectivity. The average signal strength was 74, never falling below 23.

While on the highway outside of a metropolitan area, one can expect to see a diminishing number of GSM towers. On the highway outside Seattle, while there was 97.06% connectivity, the average signal strength was only 52.16. In India, the situation worsened significantly as we traveled away from Lucknow. While on the highway, we were connected only 72.77% of the time, with an average signal strength of 39. This trend can also be observed in figure 5. When the RSO is about 15km from Lucknow, connectivity and signal strength both drop dramatically. Figure 6 shows another path that an RSO took starting in Lucknow and continuing on the highway towards another semi-urban area, Mahmudabad. As the RSO traveled away from Lucknow, the connectivity and signal strength again diminished rapidly. However, when he approached Mahmudabad, connectivity returned and signal strength started increasing again.

VII. DISCUSSION

Our data indicates that calculating location using GSM-based estimates will only be possible for certain areas. Metropolitan areas and highways in semi-urban areas were the only areas where we consistently found connectivity. However, if the highway is far from a metropolitan area, the connectivity will rapidly decrease. On rural roads, GSM signals were unavailable more than 50% of the time.

In this section we discuss the implications of these observations in choosing a positioning technology for tracking rural supply chain processes.

Localization of Personnel

RSOs tend to travel through three major areas - metropolitan areas, the highway, and rural roads. Our results indicate that GSM-based methods are not sufficient to determine the exact position of RSOs or of transactions along their RPJC. In particular, it is not possible to determine whether an RSO has visited a particular village or store. Sales can not be localized to a particular customer without the user providing additional identifying information. However, management could use GSM readings to monitor whether RSOs were more generally following their RPJC as scheduled.

Location of Transfers

There are two types of product transfers that take place - between RSOs and stockists, and between RSOs and the rural retail stores. Calculating the location of transactions occuring between the RSO and the stockist could be possible using GSM-based methods, as stockists tend to be located in more metropolitan or semi-urban areas. Our data indicates that these two kinds of areas have enough coverage to determine a reasonably accurate location. However, when RSOs are selling products to rural retailers, only sometimes could this transaction be localized to the granularity of a village. It would probably be impossible to localize the transaction to an individual consumer (rural retail store) using only location estimation.

Other methods might prove more viable for localizing transactions at this level. In [11], the author describes a system using a camera-equipped mobile phone to decode printed two-dimensional barcodes. Unique codes could be generated for individual customers, RSOs, TSMs, and stockists. When a transaction is conducted between any two parties, barcodes can be scanned to determine the identity of the transacting parties. However, this requires that the location of individual consumers be pre-determined and linked to barcodes, which must then be distributed to individual retail stores. This would be a non-trivial operational exercise.

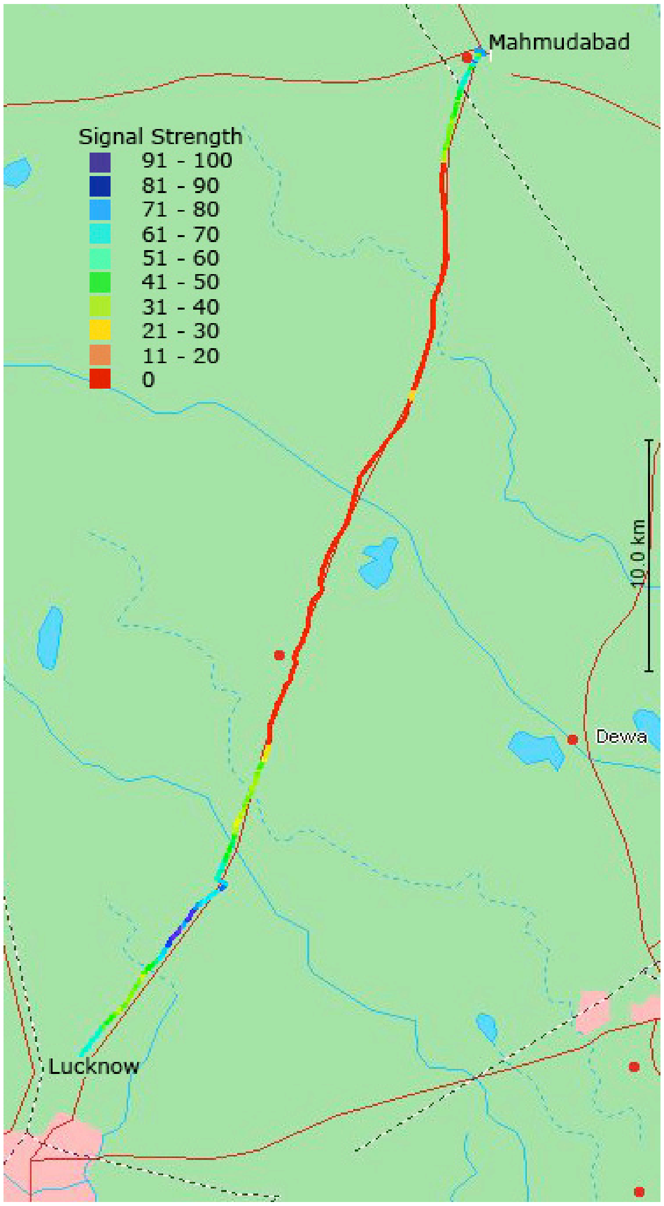

Figure 6 – A path taken by an RSO from Lucknow to Mahmudabad.

VIII. CONCLUSION AND FUTURE WORK

In this paper, we have discussed the need of technology-mediated solutions for managing supply chains in rural areas. Based on a field study conducted with an example company, we have identified the structure of a typical rural supply chain, describing the participants involved in the marketing, sale, distribution, and delivery of products from the supplier through to the end customer. From this analysis we have identified two potential users of a mobile phone-based information system to automate information processes at the bottom tiers of the supply chain, namely at the stockist and the RSO level. We presented the high-level design of this system, motivating the need for a mobile positioning technology to automatically determine the location of transactions and participants in the supply chain. We discussed some possible alternatives for this technology, including GPS, GSM triangulation and Placelab using GSM.

The potential for calculating location using GSM-based methods depends on the density and coverage of GSM towers. To assess the potential of these methods in rural areas, we conducted an experiment to determine the GSM coverage along the sales routes frequented by RSOs. Based on the results of this experiment, we have determined that location can be estimated with the most consistency in metropolitan areas, semi-urban areas, and on highways in close proximity to populated areas. Our data shows that connectivity on rural roads or in villages is very inconsistent.

These results indicate that GSM-based methods are not sufficient to determine the exact position of RSOs or of transactions along their RPJC. In particular, it is not possible to determine whether an RSO has visited a particular village or store. However, management could use GSM readings to monitor whether RSOs were generally following their RPJC as scheduled. We discussed barcodes are one possible way to address the issue of localizing transactions to individual customers.

It is yet to be determined whether the option of using a combination of GSM readings and barcodes to determine the location of rural supply chain transactions is a more accurate, cost-effective and flexible solution than simply using a GPS-enabled device. We are currently developing such a system so that it can be deployed and compared in parallel to our partner company's existing GPS trial. Whether or not they choose to adopt our solution, given the slim operating margins in rural areas, will be the truest test of its efficacy.

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