Integrated Service Operations Management in the E-Governance Paradigm: A Case of the Cooperative Sugar Sector

THESIS

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SHASHANK GARG

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Prof. Diatha Krishna Sundar, Ph. D
(Indian Institute of Management Bangalore)

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CERTIFICATE

This is to certify that the thesis entitled

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and submitted by **Shashank Garg** ID No **2003PHXF035P** for award of Ph. D. Degree of the Institute embodies original work done by him/her under my supervision.

Signature in full of the Supervisor: ----------------------------------
Name in capital block letters: **Dr. DIATHA KRISHNA SUNDAR**
Designation: **Assoc. Professor, Indian Institute of Management Bangalore**

Date: March 16, 2012

मैं यह शोधकार्य

अपने

आदर्णीय पिताजी स्वर्गीय डा. रमेश चन्द्र गर्ग एवं आदर्णीय माताजी श्रीमती कुसुम गर्ग

को समर्पित करता हूं

I dedicate this research work

to

my parents

the late Dr. Ramesh Chandra Garg and Mrs. Kusum Garg

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ABSTRACT

The Sugar industry, dominated by cooperative sugar factories, is the second largest agro-based industry in India, next only to the cotton textiles industry. It is the second largest producer of sugar in the world, engaging nearly 45 million farmers in sugar cane cultivation to form a critical component of the rural agro-economy. The consistently poor financial performance of the industry, in particular the cooperative sector, as well as its inability to diversify the product range has raised serious concerns about its long-term health. This thesis takes a holistic view of the sugar sector through the prism of an enterprise's supply-chain and the appropriate business enabling technologies. Building efficiencies by optimally selecting suppliers across the supply chain, developing optimal crusher scheduling approaches, and the distribution aspect of sugar through the public distribution system as part of e-governance, are the main areas of study in this thesis. Optimization models that have been developed include stochastic integer programming models for supplier selection, linear programming models for market intelligence curves, a simulation model for designing *a priori* penalty structure, and a single-server multiple-queues model with server vacation for developing and implementing static tabular policies for crusher scheduling. A mobile-phone based decision support framework incorporating these optimization models has been developed and implemented in software as part of the research work. The eCollect software has been developed for rendering XForms compliant electronic forms on different mobile devices, along with a workflows based server component to manage the various processes that provide services to different application front-ends. These software applications form the core of the decision support system that extends into an improved Public Distribution System. Each of these software tools has its own unique workflows and electronic forms for providing human interaction with the system.

Keywords: Optimal supplier selection, penalty structures, mobile decision support system, crusher scheduling, single-server multiple-queues with server vacation, SmartPDS

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LIST OF ABBREVIATIONS

AOA	Activity-on-Arrow
AON	Activity-on-Node
APL	Above Poverty Line
B2B	Business-to-Business
B2C	Business-to-Citizen
B2G	Business-to-Government
BPL	Below Poverty Line
CLD	Causal Loop Diagram
CSF	Cooperative Sugar Factory
DECOSS	Decision Support System for Optimal Supplier Selection
DSS	Decision Support System
FAO	Food and Agriculture Organization
FCI	Food Corporation of India
FPS	Fair-price Shops
G2B	Government-to-Business
G2C	Government-to-Citizen
G2E	Government-to-Employee
G2G	Government-to-Government
GDP	Gross Domestic Product
GPS	Global Positioning System
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
ICT	Information and Communications Technology
IP	Integer Programming
IT	Information Technology
LP	Linear Programming
MIC	Market Intelligence Curves
OHCHR	Office of the United Nations High Commissioner for Human Rights
PDS	Public Distribution System
PENSTRUCT	Penalty Structure model
RFID	Radio Frequency Identification
SOA	Service Oriented Architecture
SSC	Sugar Supply Chain

STOIP	Stochastic Integer Programming model
TPDS	Targeted Public Distribution System
TRAI	Telecom Regulatory Authority of India
UID	Unique Identity
UIDAI	UID Authority of India
UN	United Nations
UN-ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
USB	Universal Serial Bus
WTO	World Trade Organization

1. Introduction

1.1 An overview

The Sugar industry is the second largest agro-based industry in India, next only to the cotton textiles industry. As the second largest producer of sugar in the world, the sugar sector engages nearly 45 million farmers, constituting around 7.5% of the total rural population, in sugar cane cultivation and forms a critical component of the rural agro-economy. The sugar industry provides employment to an additional 500,000 skilled and semi-skilled people from the rural areas and is responsible for large-scale employment generation, income generation, and improvements in the rural infrastructure (Pandey, 2007; SINET, 2007). An important feature of this industry is that it is primarily rural-centric whereas the cotton textile industry is essentially urban-centric. Due the importance of the sugar industry to the agro industry in India, any improvement in the functioning of the sugar cooperatives through technology intervention has the potential to create large social impact.

Sugar is also an important and cheap source of energy since it meets nearly 10% of the daily calorie requirements. In order to meet the social objectives of providing the food security needs of the vast population of rural and urban poor, successive governments have tended to protect the sugar industry from competitive market forces through regulation, intervention and subsidies. As a result, the sugar industry has not been able to adapt to changes in the external environment such as globalization and competition from other sugar producing countries.

1.2 The Sugar cooperative sector in India

The sugar industry in India functions largely through a cooperative structure and the sugar cooperatives are organized state-wise, with Maharashtra having the largest organized sugar cooperative structure. Based on the estimates in a report published by the Godbole Committee formed by the Government of Maharashtra in August 1997, there were 460 sugar factories in India in 1996-97, of which 254 were in the cooperative sector in Maharashtra alone (Godbole, 1999; Godbole, 2000). Maharashtra accounted for a total of 116 cooperatives and the entire cooperative sector produced over 60% of the sugar output of the country. As of 2010-11 Maharashtra alone had 173 sugar factories in the cooperative sector and another 23 in the private sector (Mahasugarfed 2011). Traditionally, the role of the sugar cooperative has been to act as an agent on behalf of its members and to provide an element of self-governance to minimize interference from the state in the day-to-day running of the institution. An extract from the Godbole report defines the role of the Sugar Cooperative and is reproduced below (Godbole, 1999):

> "A co-operative is essentially an agent of its members. It either pools member produce (including labour, skills, grains etc.) adds value where possible and markets these, or it procures inputs (including credit, fertilizer, consumer goods, etc.) based on member needs, and supplies these to them. In both instances, it needs to hold back for itself only such margins as are needed to meet the cost of operation, or for further improvement/increase in service to members. The rest of the surplus is returned to members, since the produce was underpaid for, or the inputs overcharged".

The Government of India's decision to free sugar from the licensing regime in August 1998 has posed formidable challenges to the sugar industry in Maharashtra and elsewhere. Market forces now largely determine if the sugar cooperative sector emerges as a global player and radical changes will be required to overhaul existing mindsets and methods of working. Since there is still a reliance on government intervention in the market and support for systemic inefficiencies, the industry may be headed towards endemic sickness unless the Sugar Cooperative acquires competence in market dynamics.

The sugar cooperatives that are owned and run by the farmers control approximately 60% of the national sugar sector, making the sugar cooperatives a powerful political force

(Ranganathan, 2005). However, poor financial performance and an inability to diversify the product range have raised serious concerns about the long-term health of the sugar industry (KPMG, 2006). A study sponsored by The Indian Sugar Mills Association and National Federation of Cooperative Sugar Factories Limited brought out a report titled, “Indian Sugar Industry – Sector Roadmap 2017” that recommended the removal of price controls on the sale of sugar by the Government of India. This study mentioned that the expected increase in cost of free sale sugar would not have a significant adverse impact on the consumer since sugar comprises a relatively smaller portion of the daily intake of food products (KPMG, 2006).

The annual India Yearbook series of publications of the Government of India provide annual performance data for the Indian agricultural industry. According to this data, sugarcane production was estimated at 273.16 million tonnes in 2005-06, which showed an increase of approximately 15.2%, or 36 million tonnes, over the production of 237.09 million tonnes in 2004-05; it reached a level of 340 million tonnes in 2007-08 but in 2008-09 it dropped to about 271 million tonnes (Government of India, 2007; 2008; 2009; 2010). According to various estimates on the Indian sugar industry, the total land area under sugar cultivation was 4-4.5 million hectares; roughly accounting for 2.7% of India’s cropped area in 2004-05 and the Indian sugar industry accounted for around 1% of GDP of the country during financial year 2005 (SINET, 2007).

1.3 The world ranking of the Indian sugar industry

India has been ranked number two amongst the world's top sugarcane producing countries for a long time. Figure 1-1 shows the ranking of countries in sugarcane production according to Food & Agricultural Organization estimates of 2010 and Table 1-1 provides the detailed quantities of sugarcane production in metric tonnes and by dollar value.

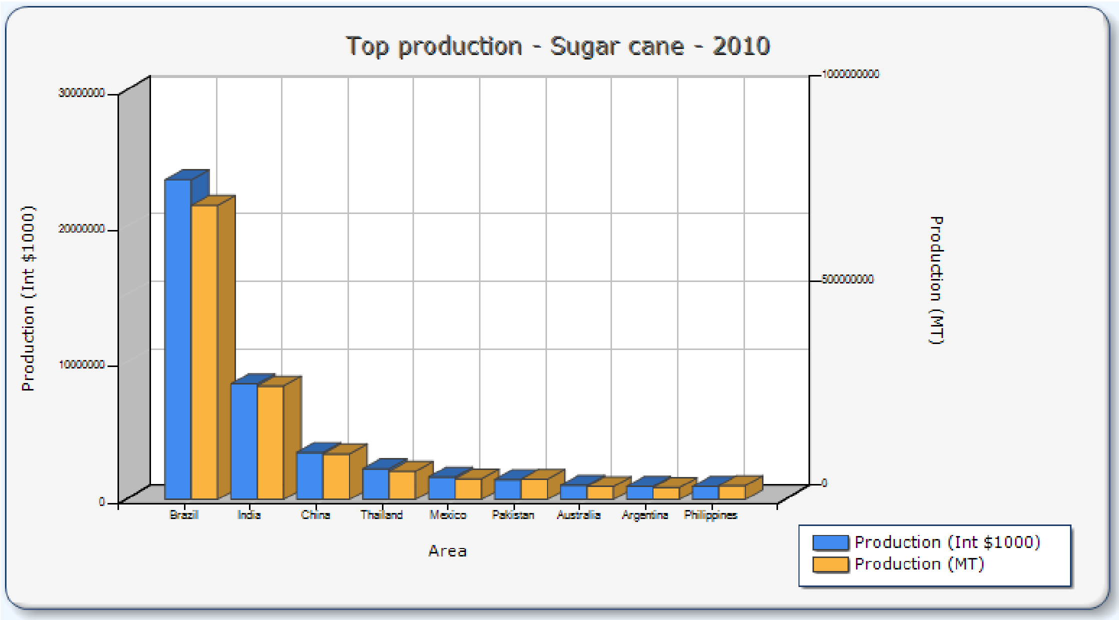

Figure 1-1: Top production – Sugar cane – 2010

Source: FAO Online Database, Food and Agriculture Organization (2010)

Table 1-1: Ranking of countries for sugar-cane

Rank	Country	Production (in $1000)	Production (in MT)	Footnote
1	Brazil	23,450,773	719,157,000	
2	India	8,482,043	277,750,000	
3	China	3,456,697	111,454,359	
4	Thailand	2,259,441	68,807,800	
5	Mexico	1,655,694	50,421,600	
6	Pakistan	1,459,132	49,372,900	
7	Australia	1,032,953	314,57,000	
8	Argentina	952,273	29,000,000	F
9	Philippines	950,093	34,000,000	F
10	Indonesia	870,180	26,500,000	F
11	United States of America	760,852	20,272,600	
12	Colombia	665,691	18,391,700	
13	Guatemala	601,629	16,015,600	F
14	South Africa	525,904	15,946,800	
15	Viet Nam	517,884	15,708,900	

Source: FAO Online Database, Food and Agriculture Organization (2010)

Notes: No symbol = official figure, * = Unofficial figure, F = FAO estimate

India has ranked second in sugarcane production for several years, with a production of 277.75 million tonnes in 2010, which declined from 285 million tonnes in 2009 (FAO, 2009; 2010). On the other hand, Brazil's production increased from 672 million tonnes in 2009 to 719 million tonnes in 2010. While India's position is significantly lower than Brazil, it is far ahead of rest of the producers of this important commodity (FAO, 2009; 2010).

Table 1-2: Comparison of Sugarcane production between India and Brazil (Source: FAO Online Database, Food and Agriculture Organization)

	Sugar-cane Production in million tonnes (MT)	
Year	**India**	**Brazil**
2001	295.96	345.94
2002	297.08	364.39
2003	287.38	396.01
2004	233.86	415.21
2005	237.09	422.96
2006	281.17	477.41
2007	355.52	549.71
2008	348.19	645.3
2009	285.03	672.17
2010	277.75	719.17

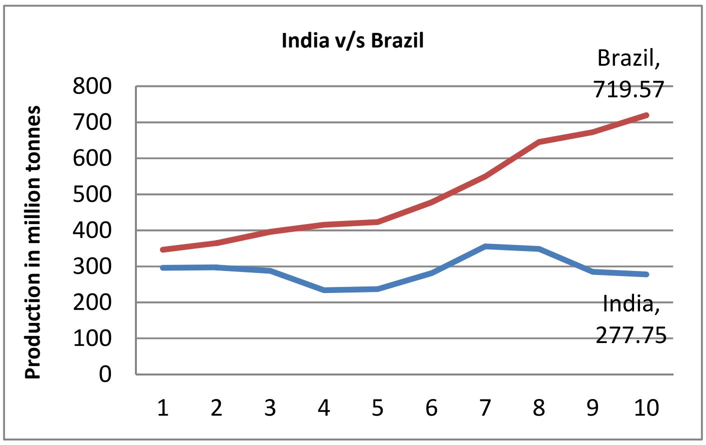

Table 1-2 and the embedded graph show a comparison of the sugarcane production between Brazil and India over the time period of 2001 to 2010. While Brazil's production has steadily increased from 354.94 million tonnes in 2001 to 719.57 million tonnes in 2010, India's sugarcane production has declined from a value of 295.96 million tonnes to 277.75 million tonnes over the same period. In 2001 India's share of sugarcane production was roughly 85.5% that of Brazil but in 2010 this percentage had declined to 38.6% that of Brazil. This shows how poorly India's sugarcane production has fared in the last decade relative to the market leader, even though India has remained at number two position throughout this period. This data demonstrates that India's production of sugarcane has virtually stagnated below the 300 million tonne mark for the entire last decade and should be a cause for concern considering that it is important food item in the food-basket for our food security. Another disturbing trend is that sugarcane production in India appears to be cyclic in nature, with a few years of increased production being followed by a few years of reduced production.

1.4 The problems of the Indian sugar industry

The process of globalization and opening up of the agro-products markets through WTO mandated policies has placed increasing demands on the Indian Sugar Cooperative for which it doesn't have the appropriate expertise in its service delivery framework. Further, the relative performance of the Indian sugar industry in terms of sugarcane production against the performance of Brazil over the last decade, as highlighted in Table 1-2, reinforces the argument that the Indian sugar industry has been unable to modernize in the decade after the sugar sector was globalised in 1998.

The role of the Sugar Cooperative is no longer merely a regulatory role but that of a market interventionist, an auction house, a policy maker, an aggregation agency as well as a disintermediation agency, all combined in one vast portfolio of services for which there needs to be a strategic framework in place. Based on data available from various sources, the importance of the Sugar Industry to the Indian economy, primarily to the agro-economy, is already well established (Pandey, 2007; Ranganathan, 2005; KPMG, 2006; and SINET, 2007). The importance of the sugar industry to the Indian agro-economy and its poor performance since globalization started in 1998 emphasizes the need to invest in further research and it also presents an opportunity to develop an integrated set of optimization tools for improvements in several components that comprise the Sugar Cooperative's supply chain.

Simplified causal loop diagrams (CLD) have been used to describe the inter-relationships between sugar production, sugar stocks, sugar pricing and sugarcane cultivation in an earlier study of the Indian Sugar Industry (Javalagi & Bhushi, 2007). It has also been observed that the sugar sector frequently faces periods of vast swings in the fortunes of the stake-holders with a periodicity of 4-5 years due to natural factors and the policy regime. This often results in build-up of sugar stocks, decline in prices and financial losses to sugar factories and farmers who grow sugar-cane.

While Brazil has increased sugarcane production every year for the last several ten years, India has stagnated and therefore needs to increase its area under sugarcane cultivation or increase yield from existing acreage, in order to increase total sugarcane production. This will require increased research effort by the sugar cooperatives, agriculture universities and agricultural research laboratories and Government policy initiatives should encourage this research intervention by the sugar cooperatives.

1.5 An overview of the proposed work

This thesis addresses some critical components in the entire Sugar supply-chain to define the basis for improvement in its functioning by developing a modeling framework of its various components. The primary emphasis is on developing a set of mathematical and information technology enabled models to enable the sugar supply chain managers to optimally manage the critical components of the entire chain. Different components of the sugar supply-chain are studied to develop an integrated framework for the supply-chain. In the first step, the entire sugar supply chain is studied as a network of activities for which multiple service providers are available for each specified activity. The objective is to develop an optimization model that can assist supply chain managers in the sugar industry to find the optimal set of suppliers on a periodic basis. In addition, a penalty structure is derived for those selected suppliers whose activities lie in the critical paths and might result in network delays if these activities are delayed. The second critical aspect of the sugar supply chain is crusher scheduling which is studied as a scheduling problem of a single-server multiple-queues model, with server vacation. The reason that the study of crusher scheduling is important is that sugar yields are inversely proportional to the waiting time experienced by raw sugarcane before it can be crushed. Hence, the longer the time spent by the raw material during transport and waiting for access to the crusher, the lower will be the eventual yield due to the perishable nature of sugarcane. Yield drops drastically within 24 hours. Hence, optimization of crusher scheduling becomes an important requirement. In the literature on agro-products crusher scheduling has not received much attention.

Finally, the public distribution system is studied and the role of mobile technologies in improving service delivery is highlighted. Architecture for a mobile logistics platform and a framework for mobile applications based on electronic forms are also presented in this thesis.

1.6 Role of mobile technologies in the sugar sector

Another important objective of this research work is to develop a mobile-phone based decision support system for optimal supplier selection, a model for crusher scheduling and a mobile platform for service delivery in the Public Distribution System. These tools enable the supply chain managers in improving productivity in the critical areas of the sugar supply chain.

The Public Distribution System (PDS) is another critical component of the sugar supply chain that is addressed in this thesis and a mobile-phone based service delivery system has been developed. The PDS is one of the important developmental programmes in the Government of India’s portfolio of social sector initiatives as it affects a large segment of the population below the poverty-line. Within the PDS itself, sugar is one of the most important commodities and the sugar industry comprises a large proportion of the Indian agricultural sector. Therefore, an integrated framework for service operations management in the sugar sector would be worth investigating, with special emphasis on the sugar supply chain, in which the Public Distribution System directly interfaces with the citizens. Mobile and communications technologies can improve productivity in the area of service delivery in the Public Distribution System (Garg & Sundar, 2011).

A critical aspect of rural empowerment is the quality and effectiveness of the service delivery mechanisms which can be improved if data is available in a timely manner to the service providers and decision makers. Using mobile computing devices and communications technologies for field data collection in a variety of applications can result in several benefits listed below:

1. Improvements in the quality, accuracy and reliability of field data through simple, forms-based data entry
    i. Since several data validation checks can be done at the source of input, thereby reducing the time required to correct input errors
    ii. Survey-oriented questionnaires can be implemented with skip-logic conditionality so that the data-entry worker is automatically guided to the next series of questions based on answers to previous questions, thereby eliminating question sequences that might be infeasible
2. Potential reduction in time required to take decisions due to timely transmission of data for backend analysis of data such that data arriving from multiple field locations simultaneously can be analyzed in near real-time
3. Potential reduction in response time for the completion of a service request through two-way communication between a mobile-enabled field worker and his backend organization

4. Reduction in transaction cost can occur, since data inaccuracy and data duplication are virtually eliminated at the source itself

Mobile devices can be deployed in various parts of the sugar supply chain to improve operational efficiencies. Creating e-chains where embedded mobile technologies can be deployed consists of the following components in the chain:

- Farmers
- Logistics Providers
- The Cooperative Sugar Factory [CSF]
- The Sugar Cooperative and (or) Regulatory Authority
- The Market

Each of these stake-holders would benefit from mobile devices since data collection is the primary requirement for the various applications that are an integral part of improving the sugar supply chain.

A Mobile device could be useful in several other areas that are of relevance to the various stake-holders in the Cooperative Sugar sector:

- For Farmers
  - Field Data Collection
  - Agricultural Information Dissemination
  - Micro-banking
  - Education
  - Auction Trading
  - Land Surveys [GPS-assisted]
- For Logistics Providers
  - GPS-assisted tracking and management of mobile assets in real-time

- At the Sugar Cooperative
  - Auction Trading and Transaction Terminals
  - Client Device for other Applications that are of direct relevance to rural populations

1.7 Structure of the thesis

This section describes the structure of the thesis which is based on the framework proposed in the earlier section and provides the logical linkage between various chapters of the thesis.

Chapter 2 presents an overview of e-Governance. The rationale for a discussion on good governance is to ensure that technology intervention in the cooperative sugar sector also factors the implications of the information technology paradox. As several authors have highlighted the information technology paradox, it is in this context that good governance becomes an important aspect that must be studied side-by-side with technology initiatives. Since the Indian sugar industry provides employment to a large rural population and since sugar is an important item in the Indian food basket, efficiencies in the sugar supply chain cannot be addressed by technology intervention alone. Change in mindsets amongst the officials of the various state and central government departments as well as officials of the sugar cooperatives, and good governance are also required if any technology intervention is to be successful. Hence, a chapter on good governance is an essential component of this discussion on improvements in the Indian sugar supply chain.

Chapter 3 provides the theoretical framework for optimal supplier selection in the sugar supply chain. Different optimization models are formulated to provide optimal supplier selection. A heuristic is also developed for the derivation of a penalty structure that defines penalties that can be imposed on suppliers who exhibit delays in the execution of their activities.

This model, when deployed on previous season's bids of the selected suppliers, provides an *a priori* penalty indication which is one of the significant contributions of this thesis.

In Chapter 4 a mobile-phone based decision support system (DSS) for optimal supplier selection is developed for use as a negotiation tool by the supply chain managers. The DSS leverages XForms technology for the deployment of electronic forms that can be rendered on a variety of mobile devices in a device-independent manner. While this DSS has been developed for supply chain managers in a single sugar factory, the framework can be further extended to cover the entire cooperative sugar sector with multiple factories.

In Chapter 5 crusher scheduling is modeled on the lines of a single-server multiple-queues model with server vacation to handle sugar cane lots that arrive at the sugar factory from different locations. A tabular policy is suggested instead of cyclic policies for optimal cost. Since the arrival of sugar cane lots deviates from the pre-determined arrival schedules there would be multiple queues formed at the crusher to await their turn for the raw material to be crushed. The quantity, quality, time of arrival and wait time of the arriving sugar-cane lots have an impact on the yield, quality and crushing time, besides the crusher usage. This situation is quite typical of a single-server multiple queues scenario in a manufacturing environment and it is applied to crusher scheduling because of the perishable nature of sugarcane.

Chapter 6 provides a description of the Public Distribution System and the problems inherent in it. A mobile technology based smart PDS system, which is essentially citizen-centric, is proposed as an alternative to the current system in place. A smart public distribution system which comprises mobile-enabled consumers, mobile-enabled retail PDS outlets, and a back-end system for managing the interactions between different entities and stake-holders, has been developed for improved service delivery and for ensuring that consumer entitlements reach the end consumers in a recorded manner. This solution addresses several of the problems in the public distribution system for targeted delivery of food to the rural and urban poor.

Chapter 7 provides a summary of the work done in the thesis along with conclusions, including limitations of the research work, and then provides suggestions on the future scope of work in this area.

1.8 Conclusions

This chapter has provided the background of the Indian sugar industry and the problems faced by the sugar cooperative sector post globalization. While Brazil, the top ranked producer has steadily increased production and market share over the last decade, India's production has remained virtually stagnant in the same period during which the local sugar industry was exposed to globalization. So, even though India has managed to retain its second rank in the world's sugar industry rankings, it has performed relatively poorly compared to the top sugar producer as well as several of the other lower ranked producers who have diversified. A disturbing cyclic trend of a few years of growth followed by a few years of decline has also been observed.

While the literature provides several examples of technology intervention in the agriculture sector there are many gaps, some of which have been addressed in this thesis in the context of the Indian cooperative sugar sector since the Indian sugar industry is a large component of the Indian agriculture sector which essentially operates through a cooperative structure.

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2. E-Governance: Addressing the Information Technology Paradox

2.1 Overview

The exposure of the Indian sugar sector to global competition due to the opening up of the Indian sugar sector in the last decade has highlighted inefficiencies in the existing system and its inability to compete effectively. Since the sugar sector, in particular the cooperative sugar sector forms an important component of India's agriculture industry and sugar distribution is a critical component in the nation's food security initiatives, technology interventions are required to improve productivity and competitiveness in this sector. However, technology intervention is not sufficient to improve productivity. While technology can normally be expected to provide improvements in the functioning of existing service structures, an information technology paradox affects any potential productivity gains of a technology intervention (Solow, 1987). The information paradox states that productivity increases do not necessarily occur with the intervention of information technology in any activity. Other factors must also be considered to obtain an overall gain in productivity.

In the context of the Indian sugar industry, this thesis suggests that governance issues should also receive adequate emphasis since the sugar industry is based on a cooperative model which engages more than 45 million farmers directly and provides indirect employment to a very large rural base. As the sugar industry is the second largest agro products industry in India, operating largely within the sugar cooperative framework, good governance in the cooperative sector must also be considered if improvements in productivity are sought to be achieved through technology intervention in the sugar supply chain.

This chapter provides the basic argument for the importance of good governance to address the information technology paradox.

2.2 Governance and E-Governance - a literature survey

2.2.1 The information technology paradox

Often, technology is not sufficient to cause a significant improvement in productivity of large systems. “The information technology paradox”, also known as the Solow paradox, highlights the slow growth experienced in service productivity in several large systems despite significant investment in IT infrastructure (Solow, 1987). Extensive discussion on the Solow paradox and especially the study of the relationship of IT spending in services and manufacturing demonstrates that IT spending does not directly lead to productivity gains and that other factors such as change of mindset also need to be addressed (Crafts, 2002; Triplett, 1999; Brynjolfsso, 1993; Sandulli et al., 2008). This observation is true even in the context of E-Governance initiatives taken up by various state and federal governmental agencies in the United States of America. A report by a committee of the US National Academy of Science offers several possible explanations of why the productivity gains are not commensurate with IT spending in governmental programmes and some of the reasons provided to explain the occurrence of this information paradox are:

- Wasteful and inefficient use of IT
- Impact of other problems may need to be considered
- Outdated methods of productivity measures may often be used
- Time lag due to learning and adjustment may lead to poor short-term results
- Level of aggregation

Methods of productivity measures often do not include measures for quality, responsiveness, speed, customer service and variety of service offerings. Learning and adjustment required when a technology intervention occurs may also result in time lag for improved results, making short-term results appear to be poor whereas long-term payoffs may not be considered (Brynjolfsson, 1993).

Many arguments in support of the productivity shortfall have been provided in the literature when questions are raised about whether big spending on computers guarantees higher profitability (Roach, 1991; Strassmann, 1997).

The concept of information technology paradox is introduced here with specific relevance to improvements in governance of the Public Distribution System which are essential and therefore, must be studied side by side with technology interventions to improve productivity in the sugar cooperative sector. To attempt a change in mindsets it is important to understand good governance so that the effects of the information technology paradox can be reduced to some extent.

2.2.2 Definition of Good Governance

Good governance is an abstract concept that constitutes a minimal set of expectations and indicators that citizens or members of civil society can reasonably expect from the government of their nation. While there are many definitions for "Good Governance" that reflect the experiences and expectations that each person has as a member of civil society, there is a universal theme that almost everyone seems to agree upon. The universal theme is generally to do with citizen participation in democratic institutions of government, encouragement to pluralism of ideas, encouragement to multi-culturalism, transparency, accountability, equitable opportunity, access, partnership, and efficiency. The rule of law and the protection of universal rights to freedom are implied in any definition. The role of any democratic institution is to use the principles of good governance to design the most appropriate structures and policies for that institution and implement the internal processes and mechanisms that will fulfill the stated mission (Backus, 2001; Cheema, 2005; Gorla, 2008; Palvia & Sharma, 2008). However, there is often a gap between the stated ideal of good governance and the implementation of it and developing countries have more than their fare share of poor governance. Accordingly, for any public administration to qualify as a reasonable democratic institution that claims to deliver good governance, it must have the following minimum characteristics:

- Provide accountability and transparency in all institutions of government
- Provide decentralization of governance to the smallest possible governance unit so that people's basic problems are addressed at the local level
- Ensure free, fair and legitimate elections
- Provide a system of adequate checks and balances between the executive and legislative branches
- Provide an environment of equal access to economic opportunity for its citizens
- Protect the rights of minorities and disadvantaged groups through inclusive efforts
- Provide access to justice that is speedy and cost-effective, and appears fair
- Provide protection of public and private goods and property
- Enable the enjoyment of personal freedom and religious beliefs
- Provide a facilitating environment for the active engagement and role of civil society and the private sector
- Utilize the power of information and communication technology to promote citizen's access and participation in development process through education of the citizen to his rights and responsibilities
- Promote and strengthen partnerships of various types to achieve policy and programme objectives

While different authors provide their own definitions of good governance (Backus, 2001; Cheema, 2005; Gorla, 2008; Palvia & Sharma, 2008), the United Nations has attempted to standardize a broad definition of good governance in many of its documents which is widely accepted. Specifically, the Office of the United Nations High Commissioner for Human Rights

(OHCHR) has published a report titled, "Good Governance Practices for the Protection of Human Rights" which provides a very comprehensive definition for "good governance", and a portion of the definition is reproduced verbatim here (OHCHR, 2007):

> "Depending on the context and the overriding objective sought, good governance has been said at various times to encompass: full respect of human rights, the rule of law, effective participation, multi-actor partnerships, political pluralism, transparent and accountable processes and institutions, an efficient and effective public sector, legitimacy, access to knowledge, information and education, political empowerment of people, equity, sustainability, and attitudes and values that foster responsibility, solidarity and tolerance."

The above-mentioned report emphasizes that "good governance and human rights are mutually reinforcing" and that good governance is in fact a precondition for the realization of human rights. The United Nations Economic and Social Commission for Asia and the Pacific (UN-ESCAP) also provides a comprehensive overview of the characteristics of good governance (UN-ESCAP, 2009), from which a figure is reproduced below as it encapsulates all the major attributes of good governance that have already been mentioned above:

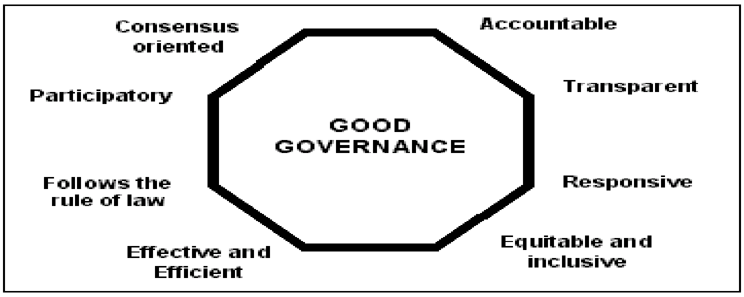

Figure 2-1: Governance and E-Governance
Source: UN-ESCAP: Characteristics of Good Governance (UN-ESCAP, 2009)

2.2.3 Definition of E-Governance

Like good governance, it is equally important to understand the concept of E-Government since the term "E-Government" is frequently used in many different forms. In the literature, discussion on e-Governance in developing countries often considers democracy as an integral part of an e-Governance definition since democracy provides a participatory component for the citizens (Cheema, 2005; Gorla, 2008; Curtin, 2007; Palvia & Sharma, 2008). Also, since democracy and e-governance are converging in a common achievable framework, a risk-assessment framework for e-services in public administration must also be considered (Backus, 2001; Chadwick, 2003; Eddowes (2004)

The World Bank provides a particularly instructive and comprehensive definition available online and titled, Definition for E-Government which is often quoted in the literature and is reproduced verbatim, below (World Bank, 2009):

> "E-Government refers to the use by government agencies of information technologies (such as Wide Area Networks, the Internet, and mobile computing) that have the ability to transform relations with citizens, businesses, and other arms of government. These technologies can serve a variety of different ends: better delivery of government services to citizens, improved interactions with business and industry, citizen empowerment through access to information, or more efficient government management. The resulting benefits can be less corruption, increased transparency, greater convenience, revenue growth, and/or cost reductions."

Just as e-commerce enables interaction between businesses and customers (B2C), or businesses and other businesses (B2B), e-government enables interaction between government and citizens (G2C), government and business enterprises (G2B), and inter-agency relationships (G2G) in more friendly, convenient, transparent, and inexpensive ways.

Citizens or businesses have traditionally interacted with governmental agencies in government offices. But the availability of cost-effective information and communication technologies has made it possible to change this interface through virtual interaction in citizen service centres or information kiosks. This interaction is further facilitated through the increasing availability of web based government services whereby a citizen or business entity could interact with government agencies directly through the Internet. This requires that government services be presented in the context of the participating entities. Businesses require a different contextual interface than citizens, since services required by these entities are quite different. Hence, various domains of interaction need to be defined so that services can be customized specific to the context of the relationship. Once again, the World Bank definition classifies E-Government interactions into several contextual relationship domains to provide a common vocabulary:

- Government-to-Citizen (G2C) domain which encompasses interaction between the Government agencies and Citizens
- Government-Government (G2G) domain which encompasses interaction between various intra-governmental agencies within the central or state government, interaction between central government and state, district, municipal and other local government agencies
- Government-to-Employee (G2E) domain which encompasses interaction between the Government as an Employer and Government officials as Employees
- Government-to-Business (G2B) domain which encompasses interaction between Government and the private sector such as contractors, service providers, non-governmental organizations etc

Since each interaction domain has different needs, system designers of e-government services must understand the contextual environment for which these services are to be designed so that different user interfaces can be designed for the different contexts within which electronically delivered services are to be presented.

2.2.4 E-Governance and ICT for rural markets

The “digital divide” refers to the gap that exists between a group of citizens who have access to the benefits of digital computing and communications technologies and those citizen groups that do not have access to these technologies. This results in an imbalance that is created in the skills required for participation in the modern economy which leverage on the digital revolution.

Several developed countries have deployed information technology (IT) enabled services to effectively reduce the digital divide and provide good governance to their citizens in geographically dispersed regions. In developing countries like India, it is imperative that for governance to be effective, the cost of delivery should be minimized so that the scarce resources can be deployed for actual developmental projects to enhance the quality of life of citizens rather than being expended in the process of delivery itself. Hence it is essential to use IT as an enabling platform for service delivery and control costs.

There is also a paradigm shift between Governance and E-Governance because India is now moving from a regime of control over policy and information to a more inclusive regime of participation in policy discussion with citizens, information dissemination, transparency and accountability. Keywords and key processes associated with Governance need to be adapted to accommodate a new set of concepts that arise from E-Governance. New keywords and key processes are required to define the transition from governance to e-governance, and new frameworks for e-Governance in the context of urban local bodies need to be developed (Sundar & Garg, 2002; Sundar & Garg, 2005). Whereas in the earlier paradigm of governance the major keywords reflected policy administration and control, the primary drivers in e-governance are now service delivery, response times, transaction costs and accountability. Hence, it is imperative that to move from Governance to E-Governance, and to avoid falling into the trap identified in the "Information Technology Paradox", there must also be a leap of faith and change of mind-sets amongst the various stake-holders. This paradigm shift from governance to e-governance which was discussed above and in some of the above-mentioned literature is shown in the diagram below:

Governance and E-Governance

Key words
- Society, policy administration, control, organizing

Key processes
- Making & administering policy
- Controlling
- Operationalysing policy for individual/society welfare
- Organizing for achieving the above

Key words
- Society, quality, delivery, services, accountable, policy, technology

Key processes
- Create, maintain and use knowledge
- Create secure systems
- Establish direct citizen interface and delivery
- Provide infrastructural support

Figure 2-2: Governance and E-Governance

Source: (*Sundar & Garg, 2005)*

According to the published figures for the 2001 Indian Census conducted by the Census Commissioner, Government of India, and data extracted for the rural population, it is estimated that in excess of 70% of India's population still lives in its rural hamlets. The figures for the recently concluded 2011 Census will not be available for some time, but it is expected that the percentage of the rural population will be quite high. Hence the E-Governance paradigm must specifically address the needs of this large body of citizens which is placed relatively lower on the literacy scale, is culturally diverse and is geographically dispersed.

In order to empower rural communities, various attributes such as local governance, political activity, primary health-care, basic education and sustainable economic opportunity, must all be available before rural communities can feel truly empowered. While e-governance and ICT are frequently linked, not enough emphasis is actually placed on holistic integration of these services and technologies in the context of the rural environment. Several previous initiatives in the rural environment have failed because of inadequate understanding of the rural context.

Based on case studies of several rural e-government projects implemented in India, several short-comings have been classified under the following categories (Gorla, 2008):

- Operational problems
    - Connectivity problems
    - Power failures
    - Non-standard processes
    - Lack of infrastructure in rural kiosks
    - Lack of availability of data for the rural sector
    - Non-availability of local language support
- Economic problems
    - Lack of funding for infrastructure
    - Insufficient financial assistance to the rural poor to set up and run village kiosks
    - Inadequate development of kiosk technology
- Personnel problems
    - Slow adoption of technology by rural folk
    - Environment not conducive for trainers to visit remote villages
    - Lack of skills at the village level

Improvements in the productivity of government officials are necessary but not sufficient. Delivery mechanisms must take these services to the doorstep of the rural citizens because the reality is that a large population of India resides in remote rural hamlets. Also, Rural India is quite different from Urban India in that there is a real digital divide due to reasons such as lower literacy levels, inadequate exposure to technology, and lower indicators on socio-economic measures. Therefore, it is important to approach infrastructure upgrade with an understanding of the appropriate context. The “last mile” of connectivity will have to be wireless based since villages can often be quite remote and isolated and wireless technology is likely to provide the only affordable communication option when measured against wire-line communication. In this scenario, it is essential to consider the role of mobile and ICT technologies as enabling and force-multiplier tools to change the way government services are provided.

Garg & Sundar (2011) provide a detailed discussion on the role of mobile technologies in mobile governance. Quality and cost of e-government services is discussed in detail by Aichholzer (2004) and they also discuss the innovation risks and sustainability of e-government strategies. Models and metrics for evaluating e-government applications and services are discussed in a paper by Carbo & Williams (2004). Alasem (2009) provides an overview of the importance of metadata standards in e-government initiatives, to enable services to interwork across different service providers. Eddowes (2004) discusses the adoption of modeling and methodologies in developing e-Government applications which enable staged and manageable introduction of technology in the public sector.

A balanced score-card methodology has been applied in a Bulgarian e-Government initiative as a way for measuring the potential for promotion of e-Governance applications (Gueorguiev et al., 2005). Exhaustive longitudinal surveys for the assessment of municipal government websites world-wide to determine the success of e-Governance initiatives have been used to provide a measure for the success of digital democracy and citizen participation in governance (Holzer & Rhee, 2005a; Holzer & Kim, 2006; and Holzer & Kim, 2008).

Generic services can be re-used and shared across participating government agencies to avoid development of similar functionality by different agencies and to improve the technical viability of services if such generic services can be properly identified across the participating government departments (Janssen & Wagenaar, 2004). For there to be sustainable development, there is definitely a need for good governance which perhaps explains the difficulty in keeping the two goals in sync in many African countries (Kabumba, 2005). The factors that impede the successful adoption e-Governance applications in different municipalities or local governments have been examined and it is found that while e-Government adoption is a function of financial, technical, and human resources, the key to success in local governments is often dependent on the political will within local governments (Schwester, 2009).

Again, as in the context of generic services that can be shared across participating departments to improve viability of such initiatives, the use of open international standards also provides many benefits such as wider choice of products and vendors, lower dependence on a single supplier, freedom from vendor lock-in, stability and reduction in costs, and flexibility in feature enhancement (Backus, 2001). Knowledge sharing between governments and non-governmental organizations using open-source platforms and the need for standard document formats for e-Governance applications for legal knowledge models are equally important in improving viability (Gordon, 2003; Butler et al., 2004). The path of open technology standards is also endorsed by the author of this thesis and, in fact the mobile framework for e-Governance applications in the Public Distribution System proposed in Chapter 6 of this thesis uses open standards for the development of the various components of the mobile framework.

2.3 Conclusions

The focus of this chapter was on addressing the issue of good governance. Since there is enough evidence in the literature to suggest that investment on information technology is not enough to improve productivity in large public sector programmes, other interventions are also required to ensure gains in productivity. This paradox is known as the information technology paradox which states that increases in information technology intervention in large programmes do not necessarily result in gains in productivity in such programmes. Since the Indian sugar industry impacts the lives of millions of farmers and families on a daily basis and sugar forms an integral part of the food security programmes of the Indian Government, it can be considered a large public sector initiative which is ongoing. This is a gap that needs to be addressed through good governance.

The thrust of this chapter was on highlighting this information technology paradox and explore ways to fill this gap. One way to address this gap is through good governance and by providing government services at the door-step of the citizen in a participative, interactive manner. With the rapid progress in wireless telephony, the communication infrastructure is now in a position to deliver services at the door-step, provided e-Governance makes a paradigm shift to m-Governance, i.e., mobile Governance, and it must include e-Democracy. Mobile communication technologies have a critical role as enabling technologies in the rural environment because it is desirable that governance services be provided at the doorstep of the rural citizen to bring greater inclusiveness to rural communities. So in the context of this discussion, the term "electronic government" also means "mobile government" or service delivery at the rural doorstep. Hence, the term "e-Government" must be extended to the context of "m-Government" when specific services are delivered at the rural door-step.

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3. Optimal Supplier Selection in the Sugar Supply Chain

3.1 Introduction to the sugar supply chain

In this chapter the sugar supply chain is studied as a network of activities and models are developed for the optimization of costs and selection of suppliers for all activities in the sugar supply chain. A heuristic formulation for a penalty structure is also developed for handling delays that may be incurred by the selected suppliers.

The introductory chapter described the Indian sugar sector which is a critical component of the Indian agro industry and also highlighted some of the problems it faces. Management of an efficient supply chain in the agro-products market requires that procurement of raw materials, production and supply of finished goods be done at minimum cost and within time constraints since the raw materials are of perishable nature. Dealing with agricultural products is a complex challenge because procurement of raw materials is often seasonal; production is partly seasonal whereas the demand for the finished product demand is steady throughout the year. The set of service providers and suppliers also changes periodically, which results in fresh negotiations and contracts every time. Hence a project, which is often defined as consisting of specific sets of activities to be executed as a one-time set of activities, can be used to model an agro-products supply chain. Since in an agro-products supply chain a re-assessment of a potentially new set of suppliers for a specified set of services is required every year or at some other periodic interval, the task of optimal supplier selection can be treated as a fresh set of activities every time. It is for this reason that an activity network approach has been used for time-cost optimization.

The sugar supply chain typically consists of a range of activities, primarily comprising, procurement of raw material which is sugar-cane in this case, in-bound logistics to ship sugar-cane and other raw materials to the sugar factory, sugar production and packaging, warehousing, out-bound logistics of shipping sugar to the retail markets and delivering to the citizens through public distribution system (PDS).

At each stage of the process, there are a host of suppliers or service providers who provide widely varying bids for their products or services. The value of the bid is dependent on the time of execution for that service. In general, if a particular service is to be executed in a shorter time then the cost for that service will be higher than if the time is relaxed by the purchaser of that service. Suppliers specify a certain unit cost for a specific service and the time required for delivery of the service which is related to that cost. At every stage the decision-maker has to choose the most optimal supplier bid which will give the lowest cost for a given time for completion of service. Since the supply chain network involves a chain of activities based on precedence relationships, the cost of each activity in the chain cannot be considered in isolation. In addition, it is also important to factor in the perishable nature of sugar-cane since it must be crushed within 24 hours of its arrival at the crushing station to provide maximum juice yield. Hence, this is a complex decision which can only be taken if the appropriate tools are available for modeling the entire sugar-cane supply chain.

This chapter presents an activity network model for the sugar supply chain and provides a set of optimization models that can be applied to help select the most optimal set of suppliers for various products and services in the supply-chain. This can be a powerful tool for the Sugar Cooperative in developing the most cost-effective vendors for the services required in the sugar supply chain. While the literature review suggests that linear programming (LP) based optimizations have been used in similar scenarios in the agro-production supply chain, this chapter additionally proposes a binary integer programming (IP) model with stochastic time constraints, along with a penalty structure that can help guide the purchaser in defining penalties for time overruns by the selected suppliers.

The remainder of this chapter is organized as follows: Section 3.2 of this chapter provides a survey of the literature on activity networks, project management, supplier selection and supply chain optimization. Section 3.3 provides an introduction to the activity network approach and Section 3.3.1 models the sugar supply chain as a network of multiple activities. Section 3.3.2 discusses the broad objectives of the optimization models for supplier selection. Section 3.4 provides a formulation for a baseline optimization model based on Market Intelligence Curves. Section 3.5 provides a formulation for an optimization model based on linear programming and Section 3.6 provides a formulation for an optimization model for supplier selection based on a binary integer programming model which is then extended to stochastic time constraints. Section 3.7 provides a heuristic for the derivation of a penalty structure. Section 3.8 describes two sugar supply chains of different size for which results are provided with a discussion of the results. Section 3.9 presents the results of the simulation for a small-sized sugar supply chain network and Section 3.10 presents results of the simulation for a medium-sized sugar supply chain network. Finally, Section 3.11 presents the conclusions for the optimization models proposed in this chapter along with limitations. Section 3.12 provides a list of the references that were used in the literature survey for this chapter.

3.2 Literature survey

A typical sugar supply chain handles a diverse range of activities starting from crop planning to harvesting, shipment of sugar-cane to the factory for crushing, production of sugar, packaging and warehousing. While every season these activities are repeated, for each of these activities there can be multiple suppliers with varying service costs. Completing these activities on time is critical due to the perishable nature of sugar-cane which will result in lower yields. In general, supply chain optimization involves diverse strategies and techniques which have been used in the modelling of multi-stage supply-chains and analysis of performance (Beamon, 1998), vendor selection using fuzzy goal programming approaches (Kumar et al., 2004), centralized strategy with decentralized operations for Internet-based supply chains for mass markets (Ghiassi et al., 2003), minimization of costs in a logistics supply chain network (Costa et al., 2010), optimization of multiple objectives for multiple products in supply chain networks using genetic algorithms (Altiparmak et al., 2006, Altiparmak et al., 2009), and for integrated logistics using a hybrid evolutionary algorithm (Lin et al., 2009).

Modelling and analysis are used for efficient management of manufacturing supply chains (Gunasekaren et al., 2000), for measurement of efficiency in the supply chain (Baiman et al., 2001), for inventory replacement to obtain competitive advantage in the supply chain (Borgman et al., 2007) and for collaborative project management between the project team and its suppliers to reduce project schedules (Wang et al., 2008). The literature on optimization in the agriculture sector provides extensive coverage in a number of areas such as harvesting, transportation, production and land-use management. For example, farm planning using integer programming (Butterworth, 1972), linear programming models for farm planning and profit maximization in Scottish agriculture, especially in dairy farming (Balm, 1980), and more recent studies on sugar production in Australia provide coverage for optimization of production in an Australian sugar mill (Jiao et al., 2005), production scheduling and shipping in a sugar supply chain (Higgins et al., 2006a), scheduling of vehicles for transport of sugar at an Australian sugar mill (Higgins, 2006), improvements in harvesting and logistics in the sugar supply chain (Higgins et al., 2006b) and a discussion on transaction cost economics in the Australian sugar supply chain (Banarjee et al., 2004). Despite the Australian sugar industry being relatively more advanced compared to other agro industries in Australia, there are indications of the inadequacy and failure of current efficiency and productivity thinking in the Australian sugar industry (Banarjee et al., 2004). Strategies have also been developed for the optimal management of land utilization in sugar production and to prevent land overuse using mathematical programming models (Colin, 2008).

Since sugarcane is a perishable raw material which must be converted to sugar in a short time after harvesting to maintain high yields, the logistics for sugarcane arrival at the sugar mill has a critical impact on sugar production for which there is a need for efficient scheduling of transportation that brings raw material to the sugar factory from farms of varying sizes and varying levels of capability (Le Gal et al., 2008). The conversion of raw sugar cane into sugar is done by a crusher and crusher scheduling is a complex problem in which the crusher can be modelled as a single-server multiple-queues model with server vacation. Cyclic policies have traditionally been used in such production systems' scheduling but a static tabular policy is better than cyclic policies when server utilization is high (Garg et. al., 2012). Since farm produce is perishable and has short shelf life, farmers and food processing units have to often make short-term decisions during harvesting to maximize their profits. 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 (Ahumada et al., 2011).

While an agro products supply chain is a network of suppliers/ stages or phases working together on different processes and such activities may be treated like activities in any other product supply chain, the important differentiating factors are weather related variability, food quality and safety which require special attention (Ahumada et. al., 2009). Even socio-economic interactions between the various stakeholders such as growers, harvesters and millers create complex situations where fair or equitable outcomes for all stakeholders are difficult to achieve through a super model of the entire sugar supply chain (Higgins et. al., 2006b). Hence a modelling framework has to be broken down into several sets of smaller components to be handled with different models. Crop planning, a complex task because of weather variability and land conditions, has been done using various mathematical programming models, viz., LP, IP, MILP and GP techniques with variations. The declining agricultural labour pool and shrinking margins due to globalization induced competition have resulted in excessive responsibility on the farmer and agro-processing unit owner to play multiple specialized roles of farmer, production manager, R&D manager, sales manager and financial expert which necessitate the use of tools that can assist in decision making during various stages of agro-products supply chains (Sargent, 1980).

In the context of an agro supply chain, since there may be a number of suppliers for the execution of any activity within the supply-chain, the managers need to decide on an optimal supplier set at minimal cost that will result in completion of all activities in the specified time frame. Delays in upstream or downstream stages of the agro supply chain result in losses due to lower yields and (or) poor quality end product since the raw materials are perishable. In this chapter optimization models for supplier selection are developed and in the next chapter these are used with a mobile-phone based decision support system. This tool will enable the supply chain manager to have access to the relevant information on a real-time basis.

In this chapter, the sugar supply chain is depicted as a network of activities with precedence relationships as in a project network. With multiple suppliers/service providers bidding for various activities of the supply chain network, the supply chain manager is expected to select suppliers in such a way to minimize the total cost of the supply chain operations. A typical project is defined as an undertaking that is typically executed once and it consists of a range of activities that consume various types of resources (Elmaghraby, 1964; Elmaghraby, 1970; Elmaghraby, 1977) and project management involves critical-path planning and scheduling (Kelley et al., 1959; Kelley, 1960; Kelley, 1961), optimization of resources in activity networks (Parikh et al., 1965; Golenko-Ginzburg, 1989; Drexl 1991; Demeulemeester, 1995; Golenko-Ginzburg et al., 1997; Herroelen, 2005). In project management, methodologies have been developed for solving the problems of optimal supplier selection (Ding et al., 2005), supplier selection in a built-to-order production supply chain (Kannan et al., 2007) and multi-criteria supplier selection models incorporating supplier risk (Ravindran et al., 2010). A more recent and comprehensive tutorial on project management through a theory of constraints on project networks is provided by Blackstone, Cox et al. (2009).

Different techniques such as collaborative project management between the project team and its suppliers have been used to reduce project schedules (Wang, Ming et al., 2008). A strategy of providing of incentives to facilitate collaboration between the buyer and the supplier has been used in the management of a supply chain that handles fresh products (Cai, Chen et al., 2010). A supply chain that produces time-sensitive products with large variations, a short shelf-life and with a short selling season requires problems to be solved in order assignment and in scheduling (Chen & Pundoor, 2006). Kreipl & Pinedo (2004) provides an overview of the practical issues in the planning and scheduling of supply chains.

Samaranayake & Toncich (2007) present an integrated framework for planning and execution of workflows in a production supply chain and the distribution of products from distributors to customers. Herroelen (2005) provides a theoretical overview of scheduling in a project of activities with precedence relationships and resource constraints. A model for development of strategic sourcing and optimal supplier selection in a supply chain is provided by Ding, Benyoucef et al. (2005). Kim & Boo (2010) provide a study on supplier selection criteria in the tourism and hospitality industry. An overview of market intelligence curves and a linear programming model for optimal supplier selection in an agro supply-chain is provided by Garg & Sundar (2011).

Saeed (2009) discusses trend forecasting techniques in policy design to control stability of ordering policies in supply chains. Reverse logistics in a supply chain requires detailed network design to determine the optimal location of repairs and service facilities for servicing consumer products (Srivastava, 2008). Sandulli, Fernandez-Menendez et al. (2008) analyze the information technology paradox in the supply chain.

As can be seen from the review of the literature presented above, while there is extensive literature on optimization of various aspects in the supply chain there is a significant gap in the area of optimization of supplier selection in a supply chain, more specifically in an agro-products supply chain where the perishable nature of the raw material is an important consideration. It is this gap that this chapter of the thesis addresses by proposing a supply chain network approach to optimization of supplier selection in the sugar supply chain. While some papers have described an incentive scheme for improved collaboration between a buyer and supplier (Cai, Chen et al., 2010), there is another significant research gap when selected suppliers cause delays in network execution. This research gap is addressed in this chapter by developing a heuristic model for a penalty structure that may be imposed on the selected suppliers who delay their activities. The penalty derivation model which provides an *a priori* indication of the penalty structure represents a more comprehensive approach to supply chain network management because it addresses all the selected suppliers in the critical paths of the supply chain.

3.3 An activity network approach

In this section the basic attributes of an activity network are defined as the foundation on which to build on in subsequent sections of this chapter. Every project can be viewed as a graph or an "activity network" consisting of nodes and edges representing events and activities (Elmaghraby, 1977; Kelley, 1961). There are two particular aspects of a project:

- The precedence relationship among the activities, and
- The duration of each activity

Precedence is a binary relation which is transitive (i.e. if u precedes v and v precedes w then u precedes w), non-reflexive (i.e. u doesn't precede u) and finally non-symmetric (i.e. if u precedes v then v doesn't precede u). Precedence comes out from technological and other considerations because in practice certain events must occur before others can occur. For example, one cannot harvest sugar-cane without first planting. In a network representation, the nodes are usually taken to depict 'events', which are considered as well-defined occurrences in time. The roles of nodes and edges can be interchanged in which nodes would represent activities and edges would represent events.

In a set E containing a partially ordered set of n+1 elements called events, in which a distinguished event (called *origin*) precedes every event in E and another distinguished event (called *terminus*) follows every event (Kelly, 1961). The events are labeled as non-negative integers such that if event i precedes another event j, then $i < j$. Associated with each event i is a property t_i representing the time of occurrence of the event, starting with $t_0 = 0$ for the *origin* and $t_i \leq t_j$ if event i precedes event j. An ***activity*** is defined as an element (i, j) of the set $E \times E$ such that $i < j$ and associated with each activity a property y_{ij}, called duration, a non-negative integer such that $y_{ij} + t_i - t_j \leq 0$. A ***project*** P is defined as a set of events and activities with the property that if events $i, j,$ and k exist in P, then activities (i, k) and (k, j) are both in P (Kelly, 1961).

In physical terms, an activity usually consumes resources such as materials, manpower, energy, skills, money, machinery etc. and it usually takes some non-zero, finite time to accomplish. In this context, a 'dummy' activity is the one which consumes no resources and is of time duration zero. An edge leading from one node to another is 'directed' (represented by an arrow) and represents the activity which must take place after the realization of the node at the tail of the arrow in order for the node at the head of the arrow to be realized. Thus the direction of the arrow determines the precedence relation between the two nodes. On the other hand, precedence between two activities is represented by having the terminal node of the preceding activity as the initial node of the succeeding activity. By virtue of the properties of the precedence relationship the resulting network is a directed, acyclic network. The network has only one origin (start node) and only one terminal node (last node). Each node must have at least one edge leading into it and one edge going out of it except the origin (which has only edges going out of it) and terminal node (which has only edges leading into it). Any two nodes must be connected by at the most, one edge. Since the precedence relationship is transitive, the realization of any node necessitates the realization of all the preceding events and activities to that node.

3.3.1 Modelling a sugar supply chain as an activity network

In this section, a sugar supply chain is modelled as an activity network in which multiple time-cost bids have been provided by multiple suppliers for each stage or node in the network. For each stage of the network there are multiple suppliers or service providers who may provide widely varying bids for their products or services. The value of a bid is typically dependent on the time of execution for that service. In general, if a particular service is to be executed in a shorter time then the cost for that service will be higher than the cost of the same service if it is performed at a slower pace. Therefore, each supplier can be expected to provide multiple time-cost bids for the same service. Since procurement of services for the sugar supply chain network involves multiple inter-related activities, arriving at an optimal selection of suppliers is a non-trivial task that has to be executed every season. When the sugar supply chain can be modeled as an activity network involving tasks that have to be done in a particular sequence, then it should be feasible to determine all the critical paths and the optimal supplier set.

Each activity in the activity network model represents a defined quantum of work to be done for which there are multiple suppliers who can supply materials, resources or skills. Suppliers bid for each activity individually and each supplier may offer multiple time-cost bids for each activity. These supplier bids generally fall into a convex curve such that cost of service decreases as time increases. While discrete time-cost bids are offered, in reality the suppliers' bids can be treated as stochastic because suppliers can deviate from their time bids with a Gaussian probability distribution which has mean time equal to the time bid specified and some standard deviation. This standard deviation is typically derived based on past experience with this particular supplier in earlier seasons. The standard deviation is different for different bids of a supplier and it generally decreases as the time bid increases. This is logical because the tendency for deviations from the specified execution time decreases if the initial amount of time given to a supplier increases. When the number of activities and the number of suppliers increases, going with the lowest bidding supplier for each activity may not result in the most optimal solution.

3.3.2 The objective of optimization in the sugar supply chain

Since the objective of the proposed network model is to enable the supply chain manager to choose the set of suppliers that is most optimal for the entire supply chain network, the main objective of the manager can be divided further into multiple sub-objectives which may or may not be independent of each other. These sub-objectives are:

- To calculate the minimum possible time of completion of the supply chain network (with no constraint on cost) and also to come up with a selection of suppliers whose bids will achieve this minimum time. This eventually gives an idea of the maximum cost that the complete supply chain network can incur with the given bids.
- To calculate the minimum possible cost of completion of the supply chain network (with no constraint on time) with given bids and also the corresponding selection of suppliers which results in the minimum cost for the activity network. This gives an idea of the maximum time a supply chain network can take, based on the current bids.
- To choose a supplier for each activity in such a way that the cost of the complete supply chain network is minimized given that the network is completed in a given amount of time (obviously, greater than the minimum time calculated in para one above).
- To derive a legitimate penalty structure for selected suppliers which can be imposed upon them if they deviate from their bids (usually in time) on the assumption that a selected supplier completing his activity in a longer period of time than the time assigned to him must attract a penalty for that delay.
- To apply the derived penalty structure based on different scenarios of a network to evaluate its performance.

In the context of the Sugar supply-chain, each activity in the network model represents some quantum of work to be done for which there are multiple suppliers who may supply materials, resources or skills. Suppliers bid for each activity individually and each supplier offers multiple time-cost bids for each activity. As the number of activities and the number of suppliers increases, going with the lowest bidding supplier for each activity may not be the most optimal solution. Hence optimal supplier selection in the sugar supply chain is a complex task that has to be executed every season.

3.3.3 Common steps in the formulation of all the optimization models

The following steps are common in the implementation of the market intelligence curves (MIC), linear programming (LP) and integer programming (IP) models. These common steps are used to convert the supply chain to an activity network.

1) For each activity, the individual supplier bids for that activity in the 3-tuple format representing (activity time, cost, variance of activity time) are arranged in an ascending order of time such that the lowest time bid is the first entry in the sequence and the highest time bid is the last entry in the sequence;

2) An activity_on_arrow network is derived as a set of activities with start_node and end_node in the form of a tuple $(a_i, s_{i,} e_i)$, where

a_i represents the activity for the i^{th} node

s_i represents the start node of activity a_i

e_i represents the end node of activity a_i

and i varies from 0 to n-1 nodes.

3) Using a depth-first search algorithm, path array P_{ij} is derived whose elements are the activity numbers of all paths in the network where i represents the index of the path number and j is the index of the j[th] activity on the i[th] path.

Table 3-1: List of variables used in MIC & LP models

Variable	Description
s_i	Start node for activity i
e_i	End node for activity i
t_{ij}	Completion time for an activity with starting node i and ending node j
Z_i	Time for completion of i^{th} end-node
m_i	Minimum value of time bid for activity i
M_i	Maximum value of time bid for activity i
S_i	Time for completion of starting node of activity i
E_i	Time for completion of ending node of activity i
$time(\mathrm{s}_i, \mathrm{e}_i)$	Time for completion of an activity i, between start-node s_i and end-node e_i
y_i	Cost incurred by activity i
T	Expected time for completion of activity network (input)
$c_i(t)$	Cost function for activity i on the time variable t which is the time taken for the activity i with a starting node s_i and ending node e_i
TC	Total Cost of all activities in the activity network

3.4 Market intelligence curves (MIC) for the sugar supply chain

A best-fit curve based on all the time-cost bid values of all suppliers for a particular activity is defined as a "*market intelligence curve* (MIC)" in this thesis. The formulation of a model for market intelligence curves is developed in this section. The market intelligence curves based approach provides a base-line time-cost solution for a given set of supplier bids for each activity in the supply chain network but does not provide an indication of the selected suppliers.

All suppliers submit discrete bids for each activity in a 3-tuple format (activity time, cost, variance of activity time) where discrete integer time values are given in terms of days, or weeks, or months and the cost bid can be a real number. Often, there are situations in which a supplier for an activity does not provide a bid for a specific discrete time value, whereas some other supplier may have bid for that particular time value for the same activity. However, over the entire range of bids by all suppliers for a particular activity, there is always a minimum time bid and a maximum time bid. In the MIC model, the time-cost curve of each supplier is first extrapolated by joining that supplier's bid points in time-cost space. In case a cost bid does not exist at the minimum-time value or at the maximum-time value, then an assumption of a very high cost bid value is made at these points.

Table 3-1 provides a list of the variables used in the formulation of the MIC model. The objective function for minimizing the total cost using the MIC model on the supply chain network is formulated below.

3.4.1 The objective function for MIC

Let

$i =$ activity index, where $i = 0, 1, .., n-1$

$j =$ supplier index, where $j = 0, 1, .., m-1$

$k =$ supplier bid index, where $k = 0, 1, .., p-1$

The objective function is determined as

$$\text{minimize TC} = \sum_{i=0}^{n-1} y_i \tag{3.1}$$

where TC, the total cost of the supply chain, is the sum of all the costs associated with all the activities; and y_i defines the cost incurred by activity i.

The function $Ae^{-\lambda t}$ has been used as a close approximation (based on extensive testing of the available industry data) and is applied to all supplier bids for each activity i in order to obtain market intelligence parameters (A_i, λ_i). Thus the expression $c_i(t) = A_i e^{-\lambda_i t}$ represents the cost function for activity i on the time variable t which is the time taken for the activity i with a starting node s_i and ending node e_i. Then $y_i = c_i(t)$ is the cost incurred by activity i.

3.4.2 The constraints

If no activity exists between a start node i and an end node j, then the time variable (t_{ij}), representing the time for an activity starting at node i and ending at node j, is made zero. Thus,

$$t_{ij} = \begin{cases} 0, \text{ if no activity exists starting at node } i \text{ and ending at node } j \\ \text{otherwise the value needs to be found} \end{cases} \tag{3.2}$$

The time for completion of an activity i between start-node s_i and end-node e_i i, denoted by $time(\mathrm{s}_i, \mathrm{e}_i)$ will always lie between the minimum time m_i and the maximum time M_i available for that bid, i.e.,

$$m_i \le time(\mathrm{s}_i, \mathrm{e}_i) \le M_i, \ \forall \ i \tag{3.3}$$

Time for completion of starting node (S_i), of an activity i plus its activity time $time(\mathrm{s}_i, \mathrm{e}_i)$ should be less than or equal to time of completion (E_i), of ending node of that activity, i.e.,

$$S_i + time(\mathrm{s}_i, \mathrm{e}_i) \le E_i \ , \ \forall \ i \tag{3.4}$$

Time for completion of terminal node ($Z_{i=n-1}$), should be less than or equal to the expected time for completion (T) of the entire network. This constraint is expressed as

$$Z_{i=n-1} \leq T \tag{3.5}$$

In the market intelligence curves model, best-fit curves are generated for all activities by plotting the time-cost bids for all suppliers for each activity. The cost for each activity falls on the best-fit curve for that activity and therefore, the list of suppliers cannot be determined. So market intelligence curves only provide the base-line time-cost solution for a given set of supplier bids for each activity in the supply chain network. Once the lower and upper limits on time have been obtained from the model, these values will be used in the subsequent optimization model for supplier selection to define the range of externally specified time constraints between these limits.

A linear programming model is proposed for obtaining an optimal list of suppliers in the next section, to overcome the shortcomings of market intelligence curves.

3.5 Linear programming model for optimal supplier selection

Since the model for market intelligence curves only provides the base-line time-cost solution for a given set of supplier bids for each activity in the supply chain network and provides no indication of the optimal set of suppliers, another model that provides this optimal supplier set needs to be developed. Hence, in this section the sugar supply-chain will be modeled as an activity network with a linear programming model being used for obtaining the optimal supplier set for the given supply chain network.

Over the entire range of bids provided by all suppliers for a particular activity, there is a minimum time bid and a maximum time bid. In the linear programming (LP) approach, the time-cost curve of each supplier is first extrapolated by joining that supplier's bid points in time-cost space. In case a cost bid doesn't exist at the minimum-time value or at the maximum-time value, then an assumption of a very high cost bid value is made at these points. Once extrapolated time-cost curves are available for each supplier, another time-cost curve is obtained as an "envelope curve" such that for each time bid, starting with the minimum-time value to the maximum-time value, the minimum-cost bid is selected out of all cost bids available at that particular time value from extrapolated curves of all suppliers for that particular activity. This gives rise to a new time-cost curve which is used in selecting the suppliers.

Table 3-1 provides a list of the variables used in the formulation of the LP model. The objective function for minimizing the total cost using the LP model on the supply chain network is formulated below.

3.5.1 The objective function for LP

Let

$i =$ activity index, where $i = 0,1,..,n-1$

$j =$ supplier index, where $j = 0,1,..,m-1$

$k =$ supplier bid index, where $k = 0,1,..,p-1$

The objective function is determined as

$$\text{minimize TC} = \sum_{i=0}^{n-1} y_i \tag{3.6}$$

where TC, the total cost of the supply chain, is the sum of all the costs associated with all the activities; and y_i defines the cost incurred by activity i.

This cost y_i will fall on the piecewise linear curve derived from lower-most envelope of extrapolated time-cost curves of suppliers for each activity i. Thus, the total cost of the activity network is the sum of the costs for all the associated activities, which has to be minimized, subject to the constraints specified below.

3.5.2 The constraints

If no activity exists between a start node i and an end node j, then the time variable (t_{ij}), representing the time for an activity starting at node i and ending at node j, is made zero. Thus,

$$t_{ij} = \begin{cases} 0, \text{ if no activity exists starting at node } i \text{ and ending at node } j \\ \text{otherwise the value needs to be found} \end{cases} \tag{3.7}$$

The time for completion of an activity i between start-node s_i and end-node e_i, denoted by $time(\mathrm{s}_i, \mathrm{e}_i)$ will always lie between the minimum time m_i and the maximum time M_i available for that bid, i.e.,

$$m_i \le time(\mathrm{s}_i, \mathrm{e}_i) \le M_i, \ \forall \ i \tag{3.8}$$

Time for completion of starting node (S_i), of an activity i plus its activity time $time(\mathrm{s}_i, \mathrm{e}_i)$ should be less than or equal to time of completion (E_i), of ending node of that activity, i.e.,

$$S_i + time(\mathrm{s}_i, \mathrm{e}_i) \le E_i \ , \ \forall \ i \tag{3.9}$$

Time for completion of terminal node ($Z_{i=n-1}$), should be less than or equal to the expected time for completion (T) of the entire network. This constraint is expressed as

$$Z_{i=n-1} \le T \tag{3.10}$$

In the implementation of the linear programming model, the following steps are followed:

For each supplier of each activity, extract a piece-wise linear extrapolated time-cost curve, given the discrete time-cost bids. Let this extrapolated time-cost curve $y_{ij}(t)$ be defined as the time-cost function of the supplier j for the activity i.

Then, at $t = 0$ and $t = M_i$, assign arbitrarily high values to cost. This results in bids in the first and last segments not being selected. Due to the extrapolation, new bids are generated where actual discrete bids do not exist for the supplier j for activity i. Once extrapolated time-cost curves have been generated for all the suppliers for activity i, another time-cost curve is extracted which is the lowest cost envelope for all suppliers $j \in i$. This gives the cost function $c_i(t)$ as

$$c_i\left(t\right) = \min(y_{ij}(t)), \ \forall\, j \in i$$

This lower-most envelope represents the time-cost, piece-wise linear function for activity i. Then $y_i = c_i(t)$ is the cost incurred by activity i which has to be minimized in equation (3.6), subject to the constraints specified in equations (3.7), (3.8), (3.9) and (3.10).

This lower-most envelope represents the time-cost, piece-wise linear function for activity i. The cost bid is chosen as the lowest value on this curve even though the selected supplier has not actually provided that bid. Since the selected supplier has not provided the extrapolated bid, this is a limitation of the linear programming model and hence, an integer programming model is developed in the next section.

3.6 Binary integer programming model for optimal supplier selection

While the LP model provides an optimal list of suppliers, some of the selected suppliers may not have given valid bids due to the extrapolation step that is used in implementation of the LP model. Hence, it is necessary to use a binary integer programming (IP) model for optimal supplier selection, which is formulated in this section.

The IP model requires a few more variables to be defined, in addition to those already defined in Table 3-1 of section 3.3.3. These additional variables are defined in Table 3-2 below:

Table 3-2: List of additional variables required by IP model

Variable	Description
I_{ijk}	An array of binary integers that contains only those bids that are selected
C_{ijk}	An array which holds the cost bids taken from the individual bids of all the suppliers
δ	Acceptable value of delay in the activity network (input)
ε	The probability that the delay ε will occur (input)

3.6.1 The objective function for IP with non-stochastic time constraints

Let

$i =$ activity index, where $i = 0,1,..,n-1$

$j =$ supplier index, where $j = 0,1,..,m-1$

$k =$ supplier bid index, where $k = 0,1,..,p-1$

The objective function is determined as follows:

The array I_{ijk} of binary integers contains only those bids that are selected. Thus,

$$I_{ijk} = \begin{cases} 1, \text{ if } k^{th} \text{ bid of } j^{th} \text{ supplier of activity } i \text{ is selected} \\ 0, \text{otherwise} \end{cases}$$

The array C_{ijk} holds the cost bids taken from the individual bids from all the suppliers. Then, the total cost TC of the supply chain network, which is the sum of the costs for all its associated activities, can be expressed as TC= $\sum_i \sum_j \sum_k \left(I_{ijk} * C_{ijk}\right)$

Hence, the Objective function is

$$\text{minimize TC} = \sum_i^{n-1} \sum_j^{m-1} \sum_k^{p-1} \left(I_{ijk} * C_{ijk}\right) \tag{3.11}$$

3.6.2 The constraints for IP with non-stochastic time constraints

Since only one bid can be selected for each activity i, this constraint is represented by the equation

$$\sum_j \sum_k I_{ijk} = 1 \ \forall i = 0,1,...(n-1), \ \forall j \text{ and } \forall \ k \tag{3.12}$$

Time for completion (S_i), of starting node of an activity i , plus its activity time should be less than or equal to time of completion (E_i), of ending node of that activity. Hence,

$$S_i + time(\mathrm{s}_i, \mathrm{e}_i) \le E_i, \ \forall i \tag{3.13}$$

Time for completion ($Z_{i=n-1}$), of the terminal node ($n-1$), should be less than or equal to the expected time for completion (T), of the entire supply chain network. This constraint is expressed as

$$Z_{i=n-1} \le T \tag{3.14}$$

For a basic integer programming model for time-cost optimization with non-stochastic time constraints, the objective function in equation (3.11) is subject only to the three constraints represented by equations (3.12), (3.13) and (3.14) shown above.

3.6.3 Additional constraint for the stochastic IP model

In practical situations, delays in the execution of activities are quite common and therefore a model with more realistic constraints is required. An integer programming model with stochastic time constraints addresses uncertainties in network delays. In this model it is assumed that a delay δ can be an acceptable delay in the entire network and that ε represents the probability that this delay will occur. Then, the probability that the actual time of completion of the network leads to a delay beyond the specified acceptable delay δ should be less than or equal to the specified input for the probability ε. This introduces an additional constraint for the minimization of the objective function. The formulation of the additional constraint for this model of optimization is given in the steps below.

The probability that the actual time of completion of the network leads to a delay beyond the specified input for the delay δ should be less than or equal to the specified input for the probability ε. Hence, this constraint is expressed by the expression

$$\Pr\left[\left(t_a - T\right) > \delta\right] \leq \varepsilon \tag{3.15}$$

where, t_a is the actual time for completion of the activity network;

T is an input variable that holds the expected time for completion of the network;

δ is an input variable that holds a value that is acceptable as delay in the entire network;

ε is an input variable that holds the acceptable probability for the delay.

This constraint is applied on every path in the network to handle stochastic time constraints.

In the integer programming model for time-cost optimization with stochastic time constraints, the objective function in (3.11) is subject the four constraints represented by equations (3.12), (3.13), (3.14) and (3.15).

In this model it is assumed that for any path in the network, the completion time for any activity along the selected path follows a normal distribution $N(\mu, \sigma^2)$. Since for any path P in the activity network the completion time for any activity along the selected path follows a normal distribution $N(\mu, \sigma^2)$, then the sum of completion times of all activities on this particular path P also follows a normal distribution $N(\sum_i \mu, \sum_i \sigma^2)$. This property is used here in the subsequent derivation.

If I_{ijk} is an array of binary integers which hold the k^{th} bid of the j^{th} supplier of activity i which lies in the path P , it is described by the expression

$$I_{ijk} = \begin{cases} 1 \text{ if this bid is selected} \\ 0 \text{ otherwise} \end{cases} \tag{3.16}$$

Let X_{ij} be a variable that denotes the activity duration for supplier j of the i^{th} activity in path P which has N activities, and let I_{ij} be a variable that holds the i^{th} supplier of i^{th} activity on path P . Then,

$$I_{ij} = \begin{cases} 1, \text{ if } j^{\text{th}} \text{ supplier of } i^{\text{th}} \text{ activity on path P is selected} \\ 0 \text{ otherwise} \end{cases} \tag{3.17}$$

Let the array σ_{ijk} hold the k^{th} bid's variance value of the j^{th} supplier of activity i which lies in the path P .

Now, for any random variable W with an expected value ω and variance θ, if $\Pr\left(|W-\omega|>\delta\right)\leq\varepsilon$ then, applying Chebychev’s inequality gives the expression

$$\Pr\left(|W-\omega|>\delta\right)\leq\frac{\theta^2}{\theta^2+\delta^2}$$

Then, the stochastic time constraint given in equation (3.15) for the probability that the total duration along a path P exceeds its expected value is rewritten as

$$\Pr\left[\sum_{i=1}^{N}\sum_{j} I_{ij} * \left(X_{ij}-\mu_{ij}\right) > \delta\right] \leq \frac{\sum_{i=1}^{N}\sum_{j} I_{ij} * \left(\sigma_{ij}\right)^2}{\sum_{i=1}^{N}\sum_{j} I_{ij} * \left(\sigma_{ij}\right)^2 + \delta^2} \leq \varepsilon \tag{3.18}$$

Applying Chebychev's inequality from equation (3.16), and using the original variables and parameters of the network model, this expression for the stochastic time constraint of equation (3.15) is rewritten as

$$\frac{\sum_{i=1}^{N}\sum_{j}\sum_{k} I_{ijk} * \left(\sigma_{ijk}\right)^{2}}{\sum_{i=1}^{N}\sum_{j}\sum_{k} I_{ijk} * \left(\sigma_{ijk}\right)^{2} + \delta^{2}} \leq \varepsilon \tag{3.19}$$

Equation (3.19) represents the stochastic time constraint on the objective function (3.11) for minimizing cost in our IP model. This integer programming model with stochastic time constrains is used to obtain an optimal cost for the supply chain network, along with the list of selected suppliers.

3.7 Heuristic for the penalty structure (PENSTRUCT)

The stochastic integer programming model for optimal supplier selection, implemented above, provides a list of selected suppliers but in real-world situations the execution of an activity by a selected supplier or service provider may often deviate from the stated time for completion of the given activity, which may result in losses in the supply chain network. This provides a motivation in this thesis for the development of a penalty structure which defines how the loss due to delays incurred on specific activities will expect to be compensated to the managers of the supply chain.

The development of a heuristic for such a penalty structure (**PENSTRUCT)** is described in a sequence of steps given below. Table 3-3 shows the list of additional variables that are required by the penalty simulation model.

Table 3-3: List of additional variables required by the PENSTRUCT model

Variable	Description
ED	Expected delay in the network
LPD	Loss per Day (input parameter)
EL	Expected Loss
(μ_i, c_i, σ_i)	Bid for activity i,
MS	Maximum Available Path Slack
m	Percentage of cost per day (c_i / μ_i), for activity *i*, that will be charged
D	Delay varying from 1 day to maximum path slack, MS , i.e. $D = (1, 2, ...MS)$
$MIP(p, D)$	Maximum increase in probability of delay D in path p

As the first step, the list of selected supplier bids for each activity is obtained using the stochastic binary integer programming model presented earlier. This implies that for any activity i, the value of the supplier $j = \text{J}$ and the selected supplier-bid $k = \text{K}$ have been found such that

$$I_{ijk} = \begin{cases} 1, & \text{for } j\text{=J, } k\text{=K} \\ 0, & \text{for } j \neq \text{J, } k \neq \text{K} \end{cases}$$

Based on the selected bids, a large number of iterations are used to obtain random realizations of activity times for those activities, assuming that a Gaussian distribution is used. If λ is the selected bid for activity i, then generate 10,000 random realizations based on $N(\mu_i, \sigma^2)$ for all activities, $i = 1, 2....N$.

Compute the critical paths (C_r) and actual completion times (T_r) for every random realization, i.e., for $r = 0, 1, 2, ...9999$.

Next, compute the most probable critical path MC, as the path that turns out to be critical the maximum number of times in the 10,000 iterations, post steady state. If c_i activities lie on the critical path MC, then the standard deviation for the most critical path is $(\theta)^2 = \sum_{i=1}^{N} (\sigma_i)^2$, where

σ_i is the sigma value of the selected bid for activity i which lies on the path P.

Using a 6-σ approximation compute the number of times a particular completion-time realization, out of the total of 10,000 iterations, occurred within a specified window of the expected network completion time M, as

$$(T - 6\theta) \le t \le (T + 6\theta) \tag{3.20}$$

where t is the network completion time.

Let $n(t)$ be defined as the number of times the actual network completion time is t.

Then,

ED, the expected delay in the network in number of days from T to $T + 6\theta$ is calculated as

$$ED = \frac{n(T+1)*1}{Total} + \frac{n(T+1)*2}{Total} + ... + \frac{n(T+6\theta)*6\theta}{Total} \tag{3.21}$$

where $Total = n(T+1) + n(T+2) + ...n(T+6\theta)$

A Gaussian distribution has been used with a large number of iterations which in this case is taken as 10,000 iterations after reaching steady state, though other distributions could have been considered. The iterations in which $t \le T$, i.e., the actual completion time is less than or equal to expected completion time, have been ignored because only network delays will attract a penalty.

Now compute the Expected Loss using the expression $EL = ED * LPD$, where LPD is a variable that represents Loss per Day which is an input parameter to the penalty simulation model.

Compute the completion time $CTP(p_i)$ for path p_i for all paths in the network from which the Maximum Available Path Slack (MS) is derived. If p_c is the critical path, then this path has the maximum completion time. Consequently, all other paths have a slack.

Let $PS(p_i)$ be defined as the available path slack on path p_i, which is the difference between the completion time of the critical path and the completion time of that specific path. So,

$$PS(p_0) = CTP(p_c) - CTP(p_0) \tag{3.22}$$

Thus, the generalized expression for the path slack for path p_i is

$$PS(p_i) = CTP(p_c) - CTP(p_i) \tag{3.23}$$

Now compute the Maximum Available Path Slack (MS) as

$$MS = \max\left(APS\left(path_i\right)\right) \forall \text{paths} \tag{3.24}$$

Now derive the penalty structure for each activity, by making use of all the paths in which the specific activity lies.

Let Ψ_i be the set of all paths in which activity i lies. Thus, if the paths m, n, q all have the activity i in them, then the set $\Psi_i = \{m, n, q\}$. Now, consider a path p in which activity i lies. Hence, $p \in \Psi_i$.

Let $D \equiv$ delay varying from 1 to maximum path slack, MS i.e. $D = (1, 2, \ldots MS)$.

Let $P_{\text{bd}}\left(i, p\right)$ be defined as the probability of the network getting delayed beyond the expected time m_k, without any delay in the activity i itself, where i is the activity which lies in the path p.

Let $P_{\text{ad}}(i,p,D)$ be the probability of the network getting delayed beyond the expected time T, when a delay $i = 1,2,..,N$ has occurred in the activity i which lies in the path p. Then,

$$P_{\text{bd}}(i,p) = 1 - P\left[(t_1 + t_2 + t_3) \le T - \mu_i\right] \tag{3.25}$$

and

$$P_{\text{ad}}(i,p,D) = 1 - P\left[(t_1 + t_2 + t_3) \le T - \mu_i - D\right] \tag{3.26}$$

Let $IP(i,p,D)$ be the increase in the probability of i^{th} activity in path p being delayed by D. Then

$$IP(i,p,D) = P_{\text{ad}}(i,p,D) - P_{\text{bd}}(i,p) \tag{3.27}$$

The maximum increase in probability of delay $MIP(p,D)$ is

$$MIP(p,D) = \max\left(IP(i,p,D)\right) \ \forall\, p \in \Psi, \text{ for delay } D \tag{3.28}$$

The final penalty structure can now be derived as a percentage of the per-day cost computed from the selected supplier's cost bid for activity i, per day of delay. Consider the selected supplier for activity i whose selected bid is (μ_i, c_i, σ_i). The daily charge for that activity is $\left(\frac{c_i}{\mu_i}\right)$, and if m is the percentage that will be charged as penalty then,

$$MIP(p,D) * EL = \left(\frac{m}{100}\right) * \left(\frac{c_i}{\mu_i}\right) * D \tag{3.29}$$

Hence

$$m = \frac{MIP(p,D) * EL * 100 * \mu_i}{c_i * D} \tag{3.30}$$

Thus, using the equation (3.30) compute the penalty that the selected supplier may be charged per unit of delay, and declare an *a priori* penalty structure for all selected suppliers for all activities.

In this section a heuristic for a penalty structure derivation has been developed which is applied after the selected supplier bids have been extracted from the integer programming model for stochastic constraints. Random realizations of activity times, based on a Gaussian distribution, are obtained by running 10,000 iterations of the simulation and critical paths and actual completion times are then computed. The penalty structure could be improved if some other random distribution is chosen but that is within the scope of future work.

3.8 Results and discussion

In the previous sections of this chapter, the theoretical ground-work for the activity network model and the formulations for various models of time-cost optimization were developed. In the remaining sections of this chapter, two activity networks are presented along with results and a discussion, followed by conclusions.

The first network represents a small-sized sugar supply chain comprising nine activities and the second network represents a medium-sized sugar supply chain with sixteen activities. Activities have been selected to reflect the requirements in a typical sugar factory within a sugar cooperative. For each activity there is a set of suppliers who provide multiple bids for each task. Each supplier gives a sequence of bids consisting of 3-tuples that represent (activity time, cost, variance of activity time) arranged in increasing order of time. The experiments provide a basis for analysis between the various optimization models that have been formulated earlier.

3.9 A small-sized activity network model for the sugar supply chain

In this section a small-sized activity network consisting of nine activities representing a typical supply chain for sugar production has been presented. The Table 3-4 shows all activities in sorted order, with a 3-tuple comprising (activity, start_node, end_node) given against each activity.

Table 3-4: List of activities in a small-sized sugar supply chain

List of Activities	Activity Tuple (activity, start_node, end_node)
a0: Purchase Sugar-cane	(0,0,2)
a1: Purchase Chemicals	(1,0,1)
a2: Purchase Bags	(2,0,3)
a3: Ship Sugar-cane to Crusher	(3,2,4)
a4: Ship Chemicals to Factory	(4,1,5)
a5: Crush Sugar-cane	(5,4,5)
a6: Ship Empty Bags to Factory	(6,3,6)
a7: Refine Sugar	(7,5,6)
a8: Package Sugar & Ship-out	(8,6,7)

Based on the activity tuples listed in the above table, a supply chain activity network shown in Figure 3-1 below has been constructed. This figure shows the connectivity for this network in an activity-on-arrow (AOA) network mode in which an activity is represented by an arc and an event is represented by a node (Kelley, 1961; Elmaghraby, 1977).

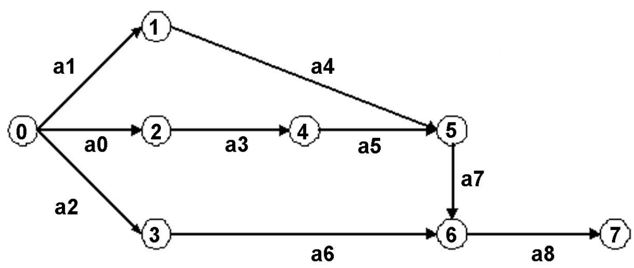


Figure 3-1: An activity network model of a small-sized sugar supply chain

Table 3-5 provides the supplier bids as inputs for all activities in this sugar supply chain (SSC) network. Suppliers provide multiple time-cost bids for each activity for each activity and each supplier bid is a 3-tuple representing (activity time, cost, variance of activity time). Individual supplier bids are sorted in ascending order of the time component in the bid.

Table 3-5: Supplier bids for a small-sized sugar supply chain

		Supplier Bids (completion time, cost, variance of completion time) (time in days, cost in INR 1000)			
Activity	**Suppliers**	**Bid 1**	**Bid 2**	**Bid 3**	**Bid 4**
a0: Purchase Sugar-cane	S00	90,10000,5	100,9000,4	120,8000,3	-
	S01	90,11000,6	110,8800,5	120,7700,4	130,6600,2
	S02	100,11000,6	110,10000,4	120,8500,3	130,8000,1
	S03	95,11800,5	110,10500,4	125,8800,3	-
	S04	100,11200,5	110,10200,3	120,9700,2	130,8500,1
a1: Purchase Chemicals	S10	5,2010,2	7,1985,1	9,1776,1	12,1560,0
	S11	4,2210,1	6,2085,1	10,1976,1	12,1530,0
	S12	6,2010,2	8,1985,1	10,1906,1	12,1570,0
	S13	7,2000,2	10,1885,1	12,1806,1	14,1470,0
a2: Purchase Bags	S20	40,1400,5	50,1300,4	60,1250,3	80,1150,0
	S21	45,1400,3	60,1200,2	90,1100,1	100,1000,0
	S22	40,1550,6	60,1350,4	80,1200,3	90,1050,1
	S23	52,1450,5	77,1240,3	92,1080,2	102,1000,0
a3: Ship Sugar-cane to Crusher	S30	2,2900,1	4,2200,0	5,1850,0	-
	S31	2,3200,1	4,2500,0	6,1950,0	-
	S32	3,2900,1	5,2400,1	6,2050,0	-
a4: Ship Chemicals to Factory	S40	2,2900,1	4,2200,0	5,1850,0	-
	S41	2,3200,1	4,2500,0	6,1950,0	-
	S42	3,2900,1	5,2400,1	6,2050,0	-
a5: Crush Sugar-cane	S50	16,8000,3	22,7200,2	26,6700,2	30,6100,1
	S51	19,7800,3	24,7500,2	29,7100,2	33,6600,1
	S52	16,8100,2	23,7700,2	28,7350,2	34,6950,1
	S53	15,8600,3	21,7950,2	27,7450,2	32,7050,1
	S54	17,8050,3	22,7930,2	27,7450,2	32,7050,1
a6: Ship Empty Bags to Factory	S60	2,2900,1	4,2200,0	5,1850,0	-
	S61	2,3200,1	4,2500,0	6,1950,0	-
	S62	3,2900,1	5,2400,1	6,2050,0	-
a7: Refine Sugar	S70	5,803,2	6,728,2	7,675,2	8,612,1
	S71	5,774,2	6,748,2	7,713,2	8,676,1
	S72	5,830,2	7,785,1	9,732,1	-
	S73	7,875,3	8,805,2	9,756,2	10,715,1

	S74	5,865,2	6,807,2	7,751,2	8,727,1
a8: Package Sugar & Ship Out	S80	2,2900,1	4,2200,0	5,1850,0	-
	S81	2,3200,1	4,2500,0	6,1950,0	-
	S82	3,2900,1	5,2400,1	6,2050,0	-

3.9.1 Market intelligence curves for the small-sized SSC network

According to the sequence of steps described in section 3.4 for the formulation of market intelligence curves, the (A_i, λ_i) pairs are first computed for each activity and a market intelligence curve is generated. Once all (A_i, λ_i) pairs have been computed for all activities, these values are used in the MIC model. The market intelligence curves are generated by using a best-fitting curve function $c_i(t) = A_i e^{-\lambda_i t}$ as the cost function for each activity i.

In the market intelligence curves model, best-fit curves are generated for all activities by plotting the time-cost bids for all suppliers for each activity. The time-cost curve of each supplier is extrapolated by joining that supplier's bid points in time-cost space. Over the entire range of bids by all suppliers for a particular activity, there is a minimum time bid and similarly there is a maximum time bid. The cost for each activity falls on the best-fit curve for that activity and therefore, the list of suppliers cannot be determined. Thus model for market intelligence curves only gives the base-line time-cost solution for a given set of supplier bids for each activity in the supply chain network, but it does not provide any indication of the optimal set of suppliers. Once the lower and upper limits on time have been obtained from the model, these values will be used in the subsequent optimization model for supplier selection to define the range of externally specified time constraints between these limits.

3.9.2 Results for the small-sized network of the sugar supply chain

The market intelligence curves provide the base-line time-cost solution for a given set of supplier bids for each activity in the supply chain network, and are shown in Figure 3-2 to Figure

3-10 below for all the activities. Since the market intelligence curves use a best-fit curve function, it is not possible to select a supplier for any of the bids. But they are useful in providing baseline time minima and maxima for use in the LP and IP models.

Figure 3-2: MIC for Activity a0

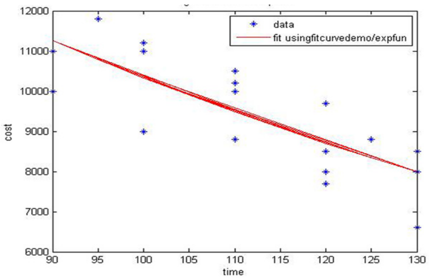


Figure 3-3: MIC for Activity a1

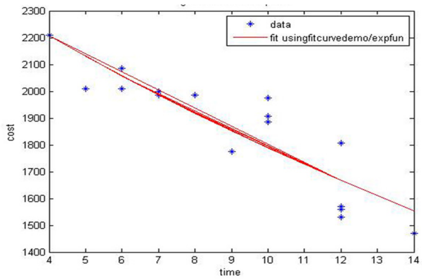


Figure 3-4: MIC for Activity a2

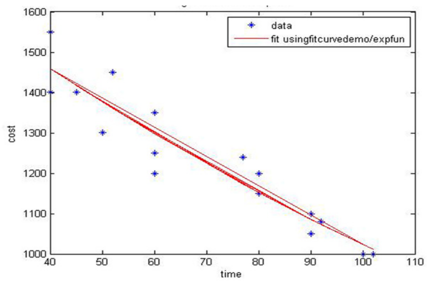


Figure 3-5: MIC for Activity a3

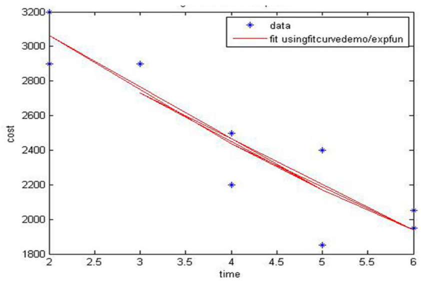


Figure 3-6: MIC for Activity a4

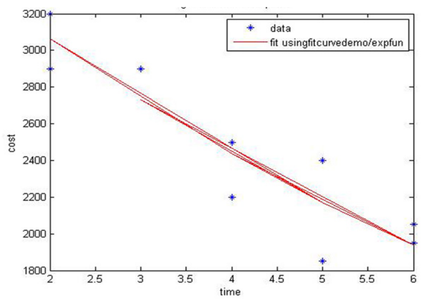


Figure 3-7: MIC for Activity a5

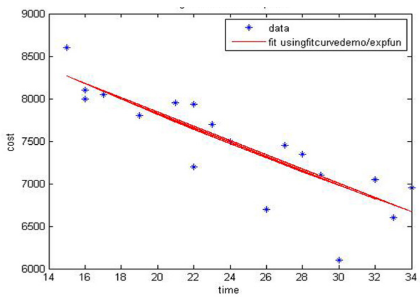


Figure 3-8: MIC for Activity a6

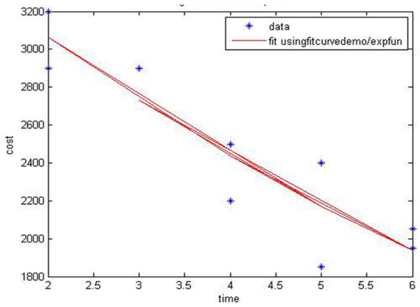


Figure 3-9: MIC for Activity a7

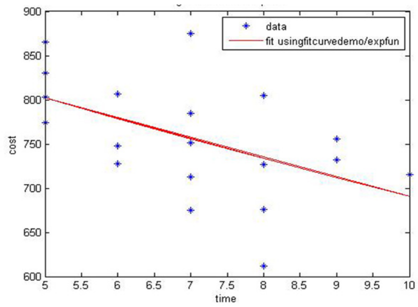
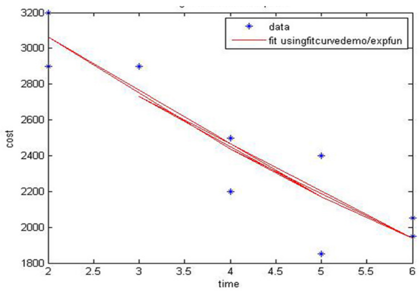


Figure 3-10: MIC for Activity a8



The simulation results of the MIC model applied to bids for the small-sized sugar supply chain network are shown in Table 3-6.

Table 3-6: Results for MIC

Results for MIC (for small-sized activity network)		
Model	**Time (in Days)**	**Total Cost (INR 1000's)**
MIC minimize Time	114	35838
MIC minimize Cost with no Time constraints	186	25658
MIC minimize Cost with Time constraints	120	31112
	130	29891
	140	28996
	150	28144
	160	27333
	170	26560
	180	25838

Table 3-7 shows the results for LP and IP for minimizing time with no cost constraints, minimizing cost with no time constraints, and minimizing cost with time constraints. It is observed that both the LP and IP models result in the same minimal time of execution for the supply chain network but the LP model delivers a lower cost. The list of the selected suppliers, from amongst the list of all suppliers for all activities, is also shown. While the LP and IP models show the same time and cost values, note that the LP model has a list of suppliers which is marginally different from that of the IP model. For example, note that for the activity a2, supplier 3 has been chosen in the LP model whereas supplier 1 is selected in the IP model.

Table 3-7: Results for LP & IP

Results for LP & IP (for small-sized activity network)			
Model	**Time (in Days)**	**Total Cost (in INR 1000s)**	**Selected Suppliers**
LP minimize Time	114	33893	0,0,1,0,0,3,0,1,0
IP minimize Time	114	36575	1,1,0,1,1,3,1,4,0
LP minimize Cost with no Time constraints	178	23182	1,3,3,0,0,0,0,0,0
IP minimize Cost with no Time constraints	178	23182	1,3,1,0,0,0,0,0,0

Table 3-8 provides the results for the LP and IP models for optimal supplier selection with time constraints. As can be seen, both models result in the same minimal time of execution for the supply chain network but the LP model delivers a lower cost. The list of selected suppliers, from amongst the list of all suppliers for all activities is also shown. Once again, there are marginal differences in the list of selected suppliers which is due to the way LP has extrapolated bids to find a supplier who may not have made a discrete, valid bid. So the IP model may be considered more useful and appropriate for this case.

Table 3-8: Results for minimizing cost with time constraints using LP & IP

Minimizing Cost with time constraints using LP & IP (for small-sized activity network)				
	LP model		IP model	
Time Constraint (in Days)	**Total Cost (in INR 1000s)**	**Selected Suppliers**	**Total Cost (in INR 1000s)**	**Selected Suppliers**
120	28994	0,3,3,0,0,0,0,1,0	28994	0,3,1,0,0,0,0,1,0
130	27469	0,3,3,0,0,0,0,1,0	27682	0,3,1,0,0,0,0,0,0
140	26244	0,3,3,0,0,0,0,1,0	26582	0,3,1,0,0,0,0,0,0
150	25482	0,3,3,0,0,0,0,0,0	25582	0,3,1,0,0,0,0,0,0
160	24982	0,3,3,0,0,0,0,0,0	25382	1,3,1,0,0,0,0,0,0
170	23894	1,3,3,0,0,0,0,1,0	24282	3,1,0,0,0,0,0,0,0
178	23182	1,3,3,0,0,0,0,0,0	23182	1,3,1,0,0,0,0,0,0

3.10 A medium-sized network model for the sugar supply chain

In this section the results for a medium-sized network consisting of sixteen activities representing a typical supply chain for sugar production are presented. Table 3-9 shows all activities in sorted order, with a 3-tuple comprising (activity, start_node, end_node) given against each activity. These tuples are subsequently used to construct an activity network for this supply chain.

Table 3-9: List of activities in a medium-sized model of a sugar supply chain

List of Activities	**Activity Tuple** (activity, start_node, end_node)
a0: Purchase of Sugar-cane Acreage	(0,0,1)
a1: Purchase Seeds & Fertilizer	(1,0,2)
a2: Ship S&F to Farms	(2,2,1)
a3: Plant Sugar-cane Crop	(3,1,3)
a4: Purchase Bags	(4,3,4)
a5: Cut Sugar-cane	(5,3,5)
a6: Purchase Chemicals	(6,3,6)
a7: Ship Sugar-cane to Factories	(7,5,7)

a8: Ship Empty Bags to Factories	(8,4,8)
a9: Grade Sugar-cane	(9,7,8)
a10: Ship Chemicals to Factories	(10,6,8)
a11: Process High-grade Sugar	(11,8,9)
a12: Process Low-grade Sugar	(12,8,10)
a13: Package High-grade Sugar	(13,9,11)
a14: Package High-grade Sugar	(14,10,11)
a15: Ship Sugar to Warehouses	(15,11,12)

Based on the activity tuples listed in the above table, an activity network shown in Figure 3-11 below is constructed.

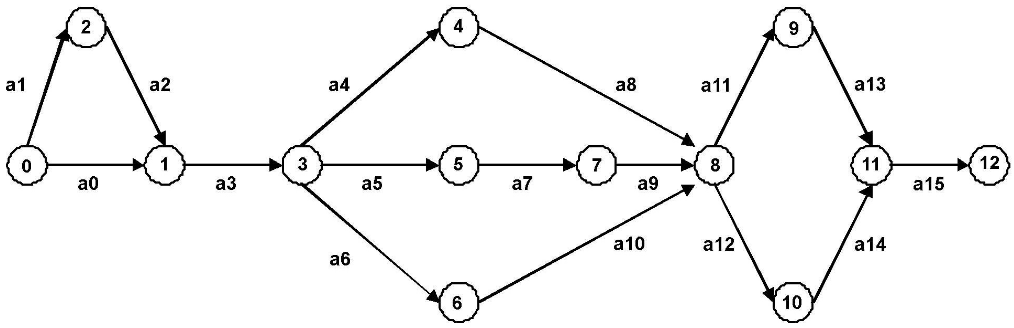


Figure 3-11: An activity network for a medium-sized sugar supply chain

Table 3-10 provides the supplier bids for all activities in this medium-sized sugar supply chain (SSC) network. Suppliers provide multiple time-cost bids for each activity for each activity and each supplier bid is a 3-tuple representing (time, cost, variance). Individual supplier bids are sorted in ascending order of the time component in the bid.

Table 3-10: Supplier bids for a medium-sized sugar supply chain

		Supplier Bids (completion time, cost, variance of completion time) (time in days, cost in INR 1000)			
Activity	**Suppliers**	**Bid 1**	**Bid 2**	**Bid 3**	**Bid 4**
a0: Purchase Sugar-cane Acreage	S00	40,14000,5	50,13000,4	60,12500,3	70,12000,2
	S01	45,14000,3	60,12000,2	90,11000,1	100,10000,0

	S02	40,15500,6	60,13500,4	80,12000,3	90,10500,1
	S03	52,14500,5	77,12400,3	92,10800,2	102,10000,1
	S04	44,15200,4	66,13200,3	84,12300,2	90,10700,0
a1: Purchase Seeds & Fertilizer	S10	20,5000,2	25,4800,1	30,4500,0	
	S11	18,5200,3	23,5000,2	28,4800,0	
	S12	15,5500,3	20,5200,2	25,5000,0	
	S13	19,5000,2	24,4800,1	29,4700,1	
	S14	20,5100,2	24,4900,1	29,4700,0	
a2: Ship S&F to Farms	S20	2,2900,1	4,2200,0	5,1850,0	
	S21	2,3200,1	4,2500,0	6,1950,0	
	S22	3,2900,1	5,2400,1	6,2050,0	
a3: Plant Sugar-cane Crop	S30	40,1400,5	50,1300,4	60,1250,3	80,1150,0
	S31	45,1400,3	60,1200,2	90,1100,1	100,1000,0
	S32	40,1450,6	60,1300,4	80,1205,3	90,1050,1
	S33	52,1350,5	77,1210,3	92,1020,2	
	S34	44,1400,4	66,1300,3	84,1210,2	90,1040,0
a4: Purchase Bags	S40	40,1400,5	50,1300,4	60,1250,3	80,1150,0
	S41	45,1400,3	60,1200,2	90,1100,1	100,1000,0
	S42	40,1550,6	60,1350,4	80,1200,3	90,1050,1
	S43	52,1450,5	77,1240,3	92,1080,2	102,1000,0
	S44	44,1520,4	66,1320,2	90,1070,0	
a5: Cut Sugar-cane	S50	16,5000,2	20,4800,1	25,4500,0	
	S51	18,5200,3	23,5000,2	28,4800,0	
	S52	15,5500,3	20,5200,2	25,5000,0	
	S53	19,5000,2	24,4800,1	29,4700,1	
	S54	20,5100,2	24,4900,1	29,4700,0	
a6: Purchase Chemicals	S60	5,2010,2	7,1985,1	9,1776,1	12,1560,0
	S61	4,2210,1	6,2085,1	10,1976,1	12,1530,0
	S62	6,2010,2	8,1985,1	10,1906,1	12,1570,0
	S63	7,2000,2	10,1885,1	12,1806,1	14,1470,0
	S64	6,2090,2	9,1985,1	12,1836,1	15,1400,0
a7: Ship Sugar-cane to Factories	S70	2,2900,1	4,2200,0	5,1850,0	
	S71	2,3200,1	4,2500,0	6,1950,0	
	S72	3,2900,1	5,2400,1	6,2050,0	
a8: Ship Empty Bags to Factories	S80	2,2900,1	4,2200,0	5,1850,0	
	S81	2,3200,1	4,2500,0	6,1950,0	
	S82	3,2900,1	5,2400,1	6,2050,0	
a9: Grade Sugar-cane	S90	5,2010,2	7,1980,1	9,1770,1	12,1560,0
	S91	4,2210,1	6,2070,1	10,1900,1	12,1400,0

	S92	6,2000,2	8,1850,1	10,1760,1	12,1510,0
a10: Ship Chemicals to Factories	S10_0	16,1200,3	22,1000,2	26,920,2	30,870,1
	S10_1	19,1100,3	24,960,2	29,880,2	33,610,1
	S10_2	15,1240,3	21,1130,2	27,1010,2	32,960,1
	S10_3	29,1449,7	42,603,4	49,433,2	
	S10_4	17,995,3	22,830,2	27,740,2	32,650,1
a11: Process High Grade Sugar	S11_0	16,8000,3	22,7200,2	26,6700,2	30,6100,1
	S11_1	19,7800,3	24,7500,2	29,7100,2	33,6600,1
	S11_2	16,8100,2	23,7700,2	28,7350,2	34,6950,1
	S11_3	15,8600,3	27,7450,2	27,7450,2	32,7050,1
	S11_4	17,8050,3	22,7930,2	27,7450,2	32,7050,1
a12: Process Low Grade Sugar	S12_0	16,4000,3	22,3600,2	26,3350,2	30,3050,1
	S12_1	19,3800,3	24,3600,2	29,2950,2	33,2800,1
	S12_2	16,4000,2	23,3600,2	28,3150,2	34,2750,1
	S12_3	15,4400,3	21,3950,2	27,3450,2	32,3050,1
	S12_4	17,4050,3	22,3830,2	27,3150,2	32,2750,1
a13: Package High Grade Sugar	S13_0	16,800,3	22,750,2	26,700,2	30,650,1
	S13_1	19,775,3	24,750,2	29,725,2	33,700,1
	S13_2	16,830,2	23,785,2	28,730,2	34,695,1
	S13_3	15,875,3	21,805,2	27,750,2	32,715,1
	S13_4	17,865,3	22,810,2	27,750,2	32,725,1
a14: Package Low Grade Sugar	S14_0	16,300,3	22,240,2	26,195,2	30,160,1
	S14_1	19,255,3	24,220,2	29,195,2	33,175,1
	S14_2	16,310,2	23,285,2	28,200,2	34,195,1
	S14_3	15,415,3	21,365,2	27,305,2	32,295,1
	S14_4	17,365,3	22,305,2	27,250,2	32,225,1
a15: Ship Sugar to Warehouses	S15_0	2,2900,1	4,2200,0	5,1850,0	
	S15_1	2,3200,1	4,2500,0	6,1950,0	
	S15_2	3,2900,1	5,2400,1	6,2050,0	

3.10.1 Market intelligence curves for the medium-sized SSC network

Once again, the (A_i, λ_i) pairs are computed for each activity and a market intelligence curve is generated for each activity using the best-fitting curve function $c_i(t) = A_i e^{-\lambda_i t}$ as the cost function for each activity i. On computation of (A_i, λ_i) pairs for all the activities, these values are used in the MIC model. Figure 3-12 to Figure 3-27 show these curves for each activity:

Figure 3-12: MIC for Activity a0

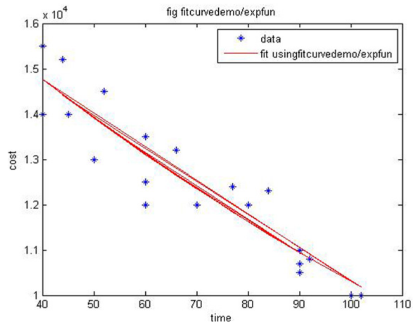


Figure 3-13: MIC for Activity a1

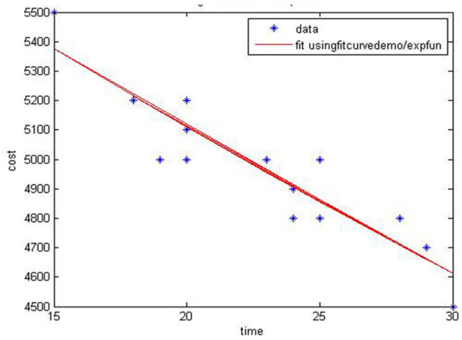


Figure 3-14: MIC for Activity a2

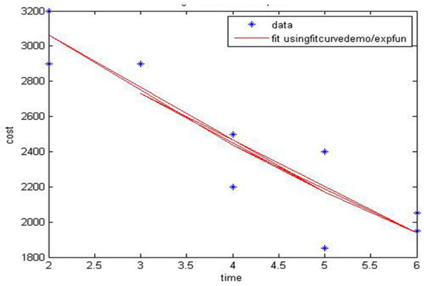


Figure 3-15: MIC for Activity a3

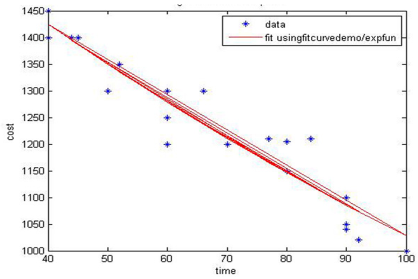


Figure 3-16: MIC for Activity a4

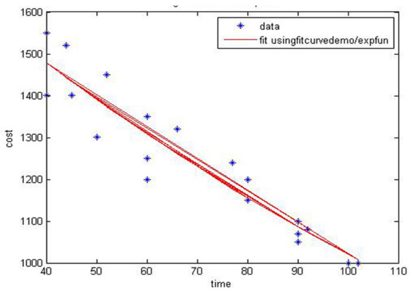


Figure 3-17: MIC for Activity a5

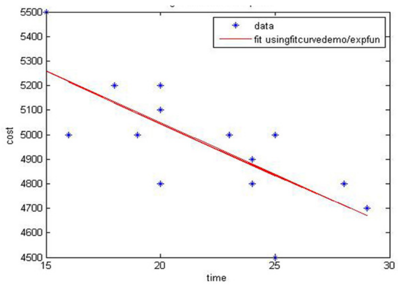


Figure 3-18: MIC for Activity a6

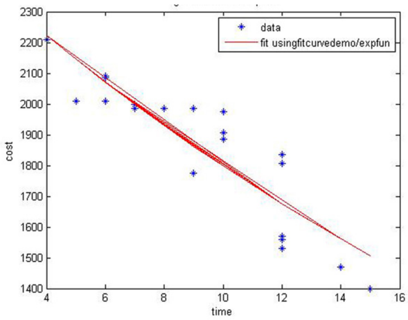


Figure 3-19: MIC for Activity a7

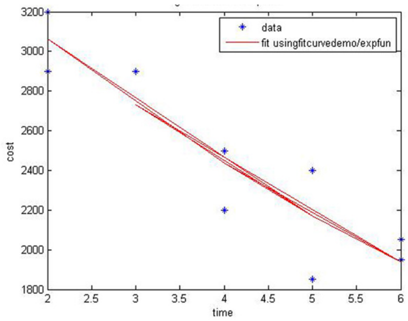


Figure 3-20: MIC for Activity a8

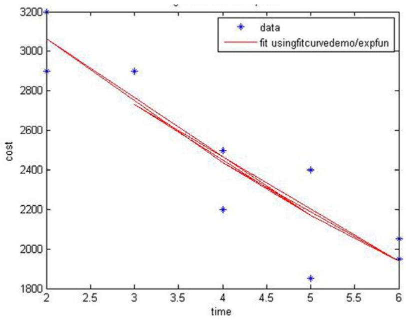


Figure 3-21: MIC for Activity a9

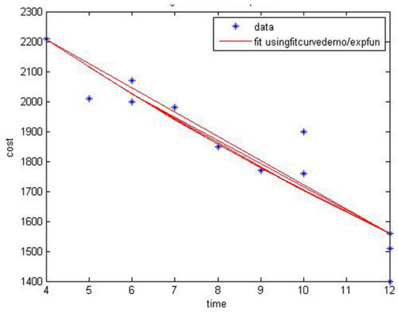


Figure 3-22: MIC for Activity a10

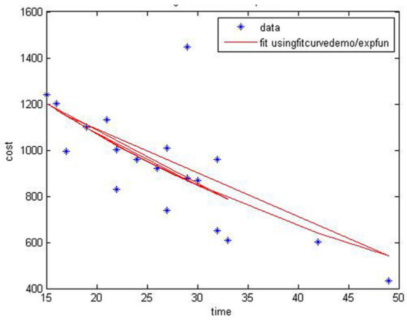


Figure 3-23: MIC for Activity a11

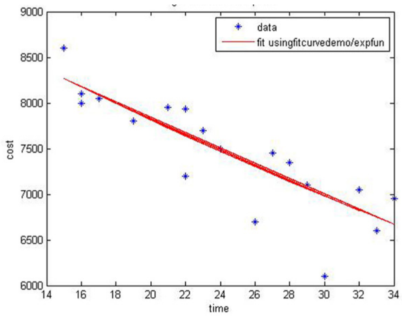


Figure 3-24: MIC for Activity a12

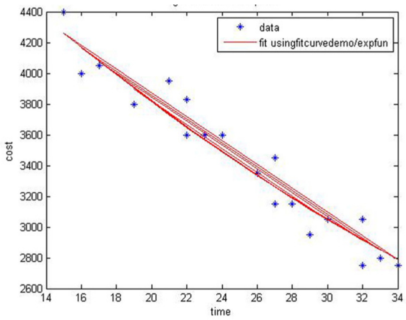


Figure 3-25: MIC for Activity a13

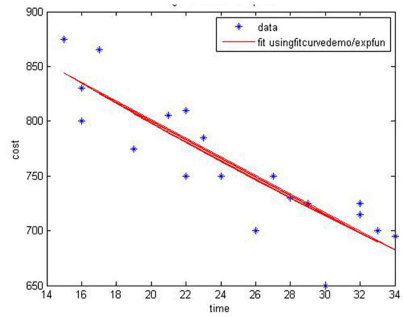


Figure 3-26: MIC for Activity a14

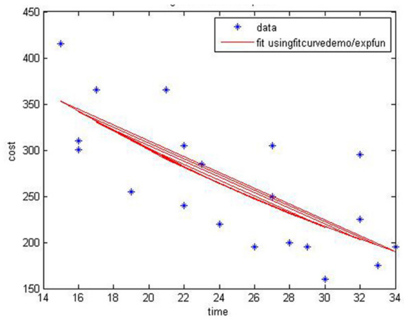
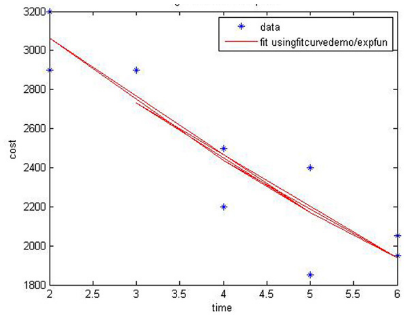


Figure 3-27: MIC for Activity a15



3.10.2 Results for medium-sized model of the sugar supply chain

In this section the simulation results of the IP models that were implemented for the medium-sized sugar supply chain network are given. Results for LP have not been shown since this model resulted in selecting some suppliers with no valid bids and was of no further interest. Table 3-11 lists the results of simulation for the IP model for optimal supplier selection by minimizing cost with non-stochastic time constraints, where the time constraints are specified as input parameters to the simulation.

Table 3-11: Optimal cost and list of selected suppliers in medium-sized SSC

Externally Supplied Time Constraint (in Days)	Total Cost (in INR 1000s)	Selected Suppliers
140	51035	0,3,4,0,4,3,1,0,0,0,0,0,4,0,0,1
160	48020	0,0,0,4,3,1,0,0,0,0,0,4,0,0,0,0
180	45590	1,0,4,0,4,3,1,0,0,0,0,0,4,0,0,0
200	44455	1,0,1,0,4,1,1,0,0,0,0,0,4,0,0,1
220	43123	2,0,3,0,4,0,0,0,0,0,0,0,4,0,0,1
240	42228	1,0,3,0,4,0,0,0,0,0,0,0,4,0,0,1
260	41828	1,0,3,0,4,0,0,0,0,0,1,0,4,0,0,1
280	41678	1,0,3,0,4,0,0,0,0,1,0,0,4,0,0,1
300	41348	1,0,3,0,4,0,0,0,0,3,1,0,4,0,0,1

Table 3-12 lists the results of simulation for the IP model with stochastic time constraints, where the time constraints are specified as input parameters to the simulation. These external parameters were specified in the range obtained from the MIC model.

Table 3-12: Minimizing cost with stochastic time constraints in medium-sized SSC

Externally Supplied Time Constraint (in Days)	Total Cost (in INR 1000s)	Selected Suppliers
140	52805	1,0,2,2,4,3,0,0,0,0,0,0,1,0,0,1
160	48220	0,0,4,0,4,4,0,0,0,0,1,0,4,0,0,1
180	45590	1,0,4,0,4,3,1,0,0,0,0,0,4,0,0,0
200	44455	1,0,1,0,4,1,1,0,0,0,0,0,4,0,0,1
220	43123	2,0,3,0,4,0,0,0,0,0,0,0,4,0,0,1
240	42228	1,0,3,0,4,0,0,0,0,0,0,0,4,0,0,1
260	41828	1,0,3,0,4,0,0,0,0,0,1,0,4,0,0,1
280	41678	1,0,3,0,4,0,0,0,0,1,0,0,4,0,0,1
300	41348	1,0,3,0,4,0,0,0,0,3,1,0,4,0,0,1

The objective of the stochastic IP model was to determine the list of suppliers while minimizing cost for an externally specified time constraint. For each time constraint specified, the optimal cost obtained from simulation has been shown along with the list of the selected suppliers for each of the activities.

3.10.3 Results for penalty structure derived from PENSTRUCT

This section provides the results for the derivation of the penalty structure and a discussion on those results. The final objective of the simulation was to obtain a penalty structure that could be applied on the list of selected suppliers obtained from the stochastic integer programming model. To determine the number of iterations required to achieve a steady-state after the transient phase, the penalty derivation was first run multiple times, each with an externally specified number of iterations. The number of iterations was varied in the range from

100 to 9500 in order to attain the steady state in which the penalty for a specific activity was within a specified range. The steady state was empirically obtained at around 8,000 iterations. The Figure 3-28 below depicts steady state simulation output after crossing the transient phase around 8000 iterations for all activities. The same behaviour was observed for all activities.

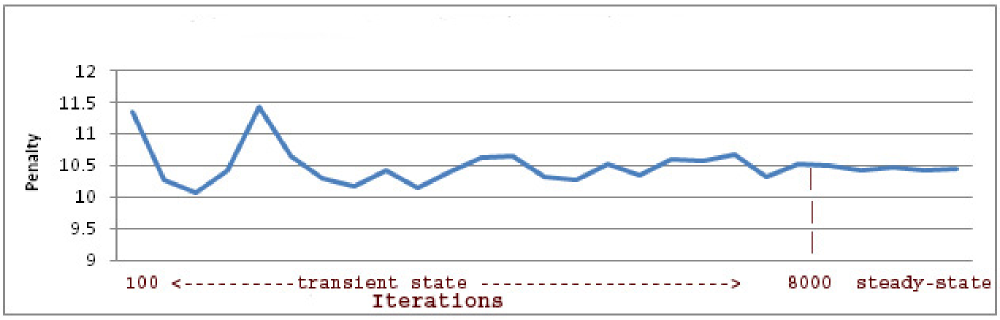


Figure 3-28: Steady-state simulation output from PENSTRUCT

Once a steady state was empirically attained at around 8,000 iterations, the penalty structure derivation has been run once again using another 10,000 iterations, to obtain delays in the execution of the network for each activity. The expected completion time was specified as an external input to the simulation model for each cycle of each penalty derivation sequence along with a value of 10% for the acceptable probability of delay ε and the value of 10 days for the acceptable delay δ in the network.

Since the probability for an acceptable delay and the value of that delay were also given as input parameters in the formulation of the simulation model, the acceptable values for these parameters also had to be determined empirically. For this purpose, the penalty structure derivation was run repeatedly with varying values of acceptable probability for delay (ε) and the acceptable delay (δ). Figure 3-29 shows the results obtained for the relationship between ε and δ on three different data-sets. It is seen that as the probability for acceptable delay is reduced, the value of the minimum delay rises. When the probability of the acceptable delay increases, the value of the minimum acceptable delay reduces. From this experiment, the value of ε was chosen as ten percent and the corresponding delay δ was chosen for the computation of a penalty structure for all the activities.

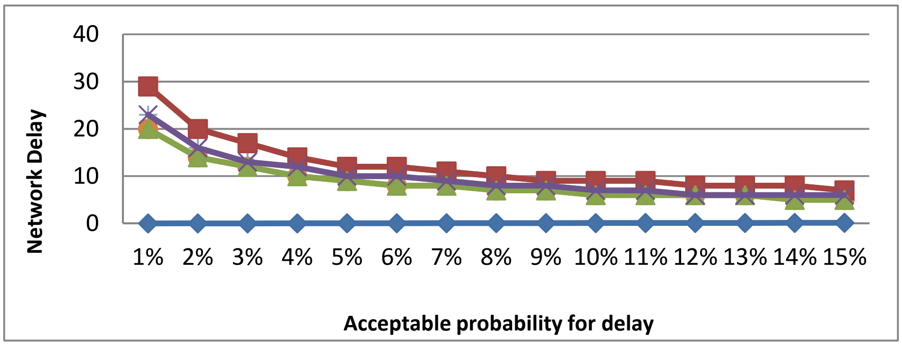


Figure 3-29: Acceptable probability (ε) v/s minimum acceptable delay (δ)

Table 3-13 shows the results of a simulation for the IP model with stochastic time constraints which was been run for 10,000 iterations to obtain delays in execution time for each activity, from which the penalty structure for each activity was derived. For the penalty structure shown, the following input parameters have been supplied to PENSTRUCT:

a) The expected completion time, $T = 140$ days;

b) The acceptable delay in the network, $\delta = 10$ days;

c) The acceptable probability of delay, $\varepsilon = 10\%$;

d) The expected loss per day, LPD = 100;

e) Maximum penalty to be charged (computed on per-day cost derived from supplier bid), $m = 20\%$;

f) The number of iterations = 10,000.

Table 3-13: Penalty structure computed on current season's data by PENSTRUCT

Execution Delay in time units	Activity															
	a0	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12	a13	a14	a15
1	0.72	1	1	0.43	0	1	1	0.14	0	1	1	0.66	1	0.14	0.56	0.37
2	0.72	1	1	0.43	0	1	1	0.14	0	1	1	0.66	1	0.14	0.56	0.38
3	0.69	1	1	0.4	0	1	1	0.14	0	1	1	0.63	1	0.13	0.53	0.36
4	0.66	1	1	0.39	0	1	1	0.12	0	1	1	0.57	1	0.12	0.52	0.35
5	0.6	1	1	0.36	0	1	1	0.11	0	1	1	0.5	1	0.11	0.48	0.32
6	0.54	1	1	0.32	0	1	1	0.09	0	1	1	0.43	1	0.09	0.43	0.29
7	0.47	0.94	1	0.28	0	1	1	0.09	0	1	1	0.38	1	0.08	0.38	0.26
8	0.42	0.83	1	0.25	0	1	1	0.07	0	1	1	0.33	0.98	0.07	0.34	0.23
9	0.37	0.74	1	0.22	0	1	1	0.06	0	1	1	0.3	0.88	0.06	0.3	0.2
10	0.33	0.67	1	0.2	0	1	1	0.05	0	1	1	0.27	0.79	0.06	0.27	0.18
11	0.39	0.61	1	0.2	0	1	1	0.07	0	1	1	0.33	0.72	0.07	0.25	0.18
12	0.49	0.74	1	0.27	0	1	1	0.09	0	1	1	0.43	0.87	0.09	0.3	0.24
13	0.58	0.94	1	0.32	0	1	1	0.11	0	1	1	0.52	1	0.11	0.38	0.3
14	0.65	1	1	0.37	0	1	1	0.13	0.07	1	1	0.6	1	0.13	0.45	0.34
15	0.71	1	1	0.41	0	1	1	0.14	0	1	1	0.67	1	0.14	0.51	0.38
16	0.77	1	1	0.45	0	1	1	0.16	0	1	1	0.72	1	0.16	0.56	0.41
17	0.82	1	1	0.48	0.02	1	1	0.17	0	1	1	0.78	1	0.17	0.61	0.44
18	0.86	1	1	0.51	0.07	1	1	0.19	0.02	1	1	0.82	1	0.18	0.65	0.46
19	0.9	1	1	0.53	0.19	1	1	0.19	0.04	1	1	0.86	1	0.19	0.69	0.49
20	0.94	1	1	0.56	0.36	1	1	0.2	0.08	1	1	0.9	1	0.19	0.72	0.51
21	0.97	1	1	0.58	0.52	1	1	0.2	0.12	1	1	0.93	1	0.2	0.75	0.53

The penalty structure for a given delay represents a value based on the cost per day computed by PENSTRUCT from that selected supplier bid which is capped at a maximum percentage specified as an input parameter. The penalty value is a cumulative number which, for a given delay of n days, is computed by multiplying the corresponding penalty structure for the delay n and the expected loss per day (LPD, an input parameter) and adding the penalty for the previous $(n-1)$ days of delay. From the results of the simulation shown above, graphs have been generated for the cumulative penalty structure for the selected suppliers of all activities in this medium-sized supply chain network. This gives a quick graphical overview of what the selected supplier should expect in case of delay in execution of the activity for which the supplier was selected. The graphs for the cumulative penalty for each of the activities are shown in Figure 3-30 to Figure 3-45. These graphs show that some activities exhibit behaviour that is different from the other activities. For example, the suppliers selected for the activities a4 and a8 initially exhibit a zero penalty for the initial few units of delay but then exhibit a steep rise in penalty beyond, which is a bit different from the penalty functions of the other activities. This can be explained since certain activities are non-critical at the start of network execution and therefore do not incur penalty for several initial units of delay but, as the network delay increases beyond the path slack, even non-critical activities begin to experience delay and will attract a penalty. Hence, it is observed that even non-critical activities can become critical as network delay increases beyond the path slack.

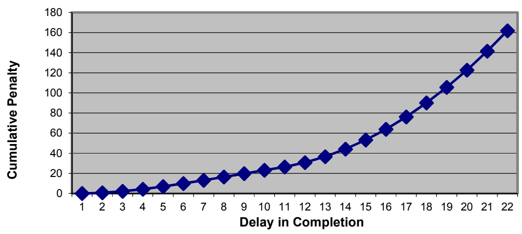


Figure 3-30: Cumulative penalty for activity a0

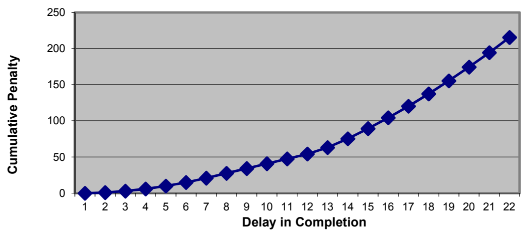


Figure 3-31: Cumulative penalty for activity a1

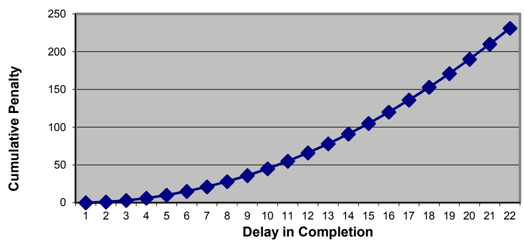


Figure 3-32: Cumulative penalty for activity a2

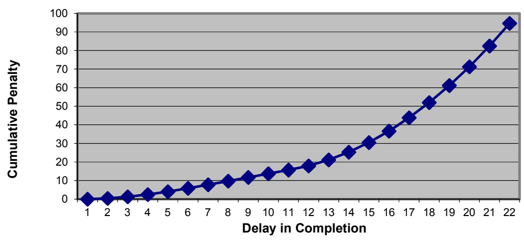


Figure 3-33: Cumulative penalty for activity a3

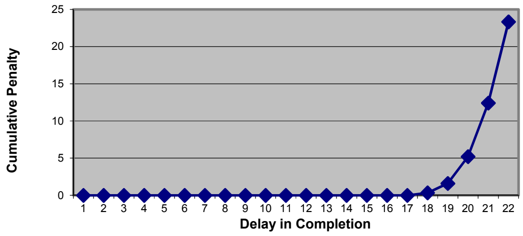


Figure 3-34: Cumulative penalty for activity a4

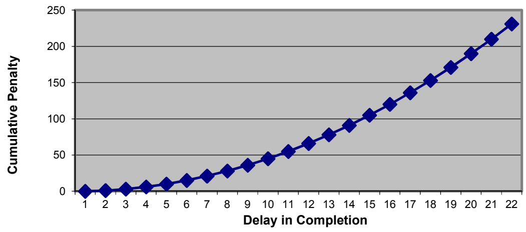


Figure 3-35: Cumulative penalty for activity a5

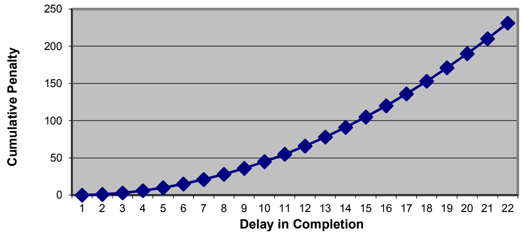


Figure 3-36: Cumulative penalty for activity a6

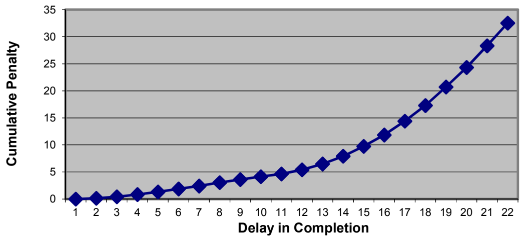


Figure 3-37: Cumulative penalty for activity a7

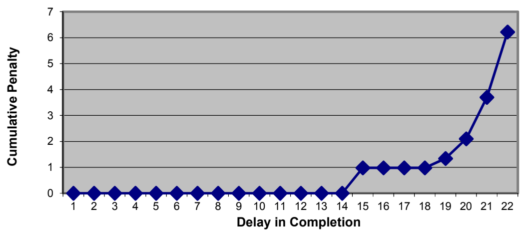


Figure 3-38: Cumulative penalty for activity a8

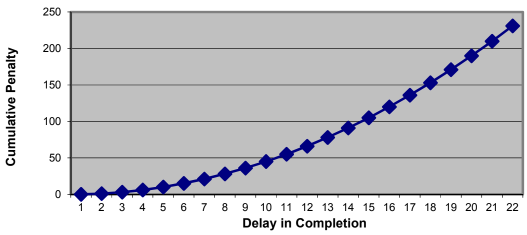


Figure 3-39: Cumulative penalty for activity a9

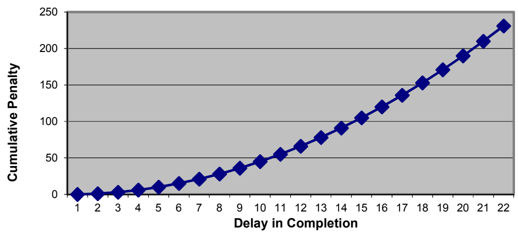


Figure 3-40: Cumulative penalty for activity a10

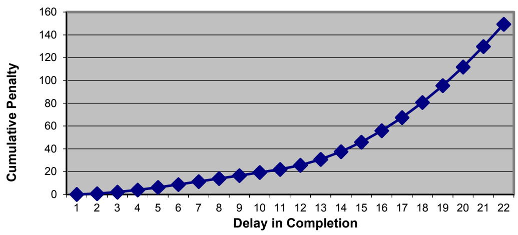
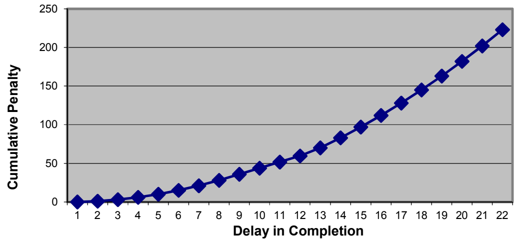


Figure 3-41: Cumulative penalty for activity a11



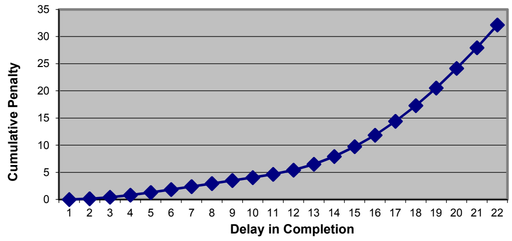
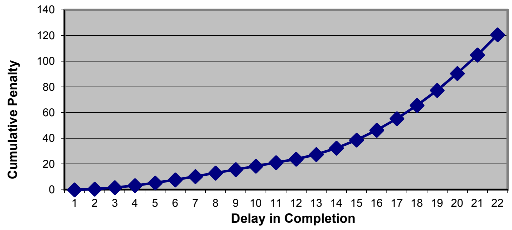


Figure 3-42: Cumulative penalty for activity a12

Figure 3-43: Cumulative penalty for activity a13



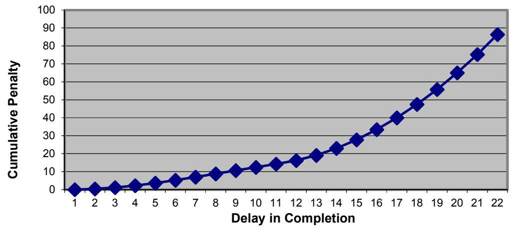


Figure 3-44: Cumulative penalty for activity a14

Figure 3-45: Cumulative penalty for activity a15

3.11 Conclusions

Due to the seasonal and perishable nature of agro products, the production supply chain needs to be efficiently and optimally managed. Since the set of service providers and conditions may change every season, every procurement cycle essentially presents a new set of activities in the sugar supply chain for which optimal decisions need to be taken by the supply chain managers. Since this can pose enormous challenges for the supply chain managers in choosing the most optimal supplier set for a given set of objectives, in this chapter several optimization models have been developed. Market intelligence curves have been developed to provide a baseline overview of the minimum cost and time estimates but since MIC does not assist in supplier selection, a linear programming model has been formulated to provide an optimal set of suppliers for all activities in an activity network. Since an LP model often results in a set of suppliers who may not have provided valid bids, a binary integer programming model with stochastic time constraints has been formulated to arrive at a more realistic model for supplier selection. The binary integer programming model has then been extended to develop a heuristic for deriving a penalty structure that can be used to specify *a priori*. This is the penalty that would apply in case of delays in the execution of activities by the selected suppliers. The penalty derivation is based on calculations of network completion times obtained through 10,000 random iterations on the selected suppliers obtained from the stochastic IP model.

Activities that lie in the critical path of an activity network cannot be delayed since these would delay the entire network, and hence it is only logical that the selected suppliers for those activities will attract a penalty for any delay. The penalty structure gives an *a priori* indication of what that penalty might be as a percentage of the quoted cost for that activity, for each unit of delay. This model with stochastic time constraints may be further improved by investigating other distributions for time constraints and delays.

In the next chapter, a mobile-phone based decision support system (DSS) framework and related tools are presented in which the optimal supplier selection models and the penalty structure heuristic formulated in this chapter are used. Since supply chain managers have to take complex decisions every season, the decision support tool enables negotiation with suppliers for the various activities on a real-time basis.

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4. A Mobile-phone enabled Decision Support System for Optimal Supplier Selection

4.1 Introduction

This chapter presents a mobile-phone based decision support system (DSS) that has been developed for the supply chain managers in the sugar supply chain. The DSS uses optimal supplier selection models and the simulation model for a penalty structure developed in Chapter 3. It enables the supply chain manager to access the supplier bids, initiate optimization for determining the set of suppliers that meet the optimal cost for the specified constraints, and presents this information on the mobile device of the supply chain manager in real-time. While the DSS tools helps the supply chain managers to take the appropriate supplier selection decisions in real-time, it also enables the Regulator to monitor bidding activity from multiple sugar factories in real-time, thereby ensuring a level of accountability and transparency in the process.

4.2 Literature survey

Since farm produce is perishable and has short shelf life, farmers and food processing units have to often make short-term decisions during harvesting to maximize their profits. 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 (Ahumada et al., 2011).

While an agro products supply chain is a network of suppliers/ stages or phases working together on different processes and such activities may be treated like activities in any other product supply chain, the important differentiating factors are weather related variability, food quality and safety which require special attention (Ahumada et. al., 2009). Even socio-economic interactions between the various stakeholders such as growers, harvesters and millers create complex situations where fair or equitable outcomes for all stakeholders are difficult to achieve through a super model of the entire sugar supply chain (Higgins et. al., 2006b). Hence a modelling framework has to be broken down into several sets of smaller components to be handled with different models. Crop planning, a complex task because of weather variability and land conditions, has been done using various mathematical programming models, viz., LP, IP, MILP and GP techniques with variations. The declining agricultural labour pool and shrinking margins due to globalization induced competition have resulted in excessive responsibility on the farmer and agro-processing unit owner to play multiple specialized roles of farmer, production manager, R&D manager, sales manager and financial expert which necessitate the use of tools that can assist in decision making during various stages of agro-products supply chains.

Decision support systems have also been implemented in various stages of an agro supply chain, covering different aspects such as farm management, supplier selection, crop planning, harvesting, post-harvest production, packaging and distribution. Decision support systems play an important role in situations where human participants may not have the necessary skills to interact with complex information systems. In multi-objective supplier selection systems optimization of cost is just one of the objectives and other tangible and intangible qualitative factors may be required in making a decision to choose the best suppliers and optimal ordering quantity for each supplier (Ghodsypour et al., 1998).

Decision support tools can also differ on the basis of techniques they employ. Different modelling techniques like object-oriented modelling in a supply chain network have been employed in decision support systems and tools have been implemented which can model different supply chains along with different optimization models using supply chain objects (Biswas and Narahari, 2004). A simulation tool within a decision support framework for cane growers and millers has helped to manage the supply of sugarcane as raw material to a sugar factory in order to maximize yield (Lejars et al., 2008). Decision processes have also been modelled for a farm information management system using a soft system methodology that enables farmers to understand the tools in a simple way as they would not otherwise understand formal models (Sorensen et. al., 2010 and Sorensen et. al., 2011). Soft system methodology is useful in modelling of systems which involve human interaction at various complex decision levels and is based on comparing a conceptual model with a real-world problem situation (Sorensen et. al., 2010). A decision support tool for the management of warehousing and distribution in the sugar supply chain has been used to improve decision making for the export of sugar from Thailand (Chiadamrong and Kawtummachai, 2008).

The decision support system described in this chapter defines process abstraction and interaction between different processes using a notation from the business process modelling notation (BPMN) standard (OMG, 2009). Abstraction of processes using the business process modelling notation has also been done at different levels in a demand-driven supply chain for the fruit industry (Verdouw et. al., 2010).

Several studies have described the use of handheld devices in many farm applications, especially in precision farming. Personal digital assistants have been used for record keeping and decision support for cucumber production at a farm production centre in China (Li, 2010). RFID tag-based tracking on mobile devices has been used for warehouse management in vineyards (Cunha et al., 2010). Precision agriculture uses advanced farm equipment which generates voluminous data coupled with real-time information from various sensors. Such systems require sophisticated farm management information systems and decision support since farms involved in precision agriculture have to conform to variance compliance standards (Nikkila et. al., 2010; Nikkila et. al., 2012). In a precision viticulture project the infrastructure of a distributed wireless sensor network has been managed remotely through smart-phones (Peres et al., 2011). Often, mobile devices used on a farm collect data from various sources and send it to other applications using XML documents for data exchange. However, writing XML code can be non-trivial for the user. A bi-directional exchange of data has been implemented between handheld devices used on a modern farm and a backend application, using a pre-defined set of rules encapsulated in a graphical user interface based on open source technologies to provide an easily usable tool for farmers, without requiring farmers to learn XML for data exchange (Iftikhar, 2011).

DECOSS (Decision support and Optimal Supplier Selection) also uses the same philosophy of making user interfaces simpler by incorporating an XForms interpreter within the mobile device to handle the complexity of inputting data on the mobile device. XForms technology (Boyer, 2009) which is an open standards specification is used to implement the electronic forms deployed in the bi-directional exchange of data between the mobile device in the field and a remote server. This enables the decision support system to be deployed on a range of mobile devices such as low-cost cell-phones, smart-phones and tablets for the front-end.

4.3 The decision support system (DECOSS)

The literature describes several decision support systems that have been implemented for various aspects of an agricultural supply chain such as crop planning, farm information management systems for precision farming, environmental impact assessment tools, RFID tag-based tracking and warehouse management. Several implementations have used mobile devices like personal digital assistants and cell-phones. However, there is a gap in that a mobile decision support system with an optimization model for supplier selection and supply chain management has not yet been studied. This provides a rationale for the development of a decision support system to augment the supplier selection model presented in the previous chapter.

4.3.1 DECOSS framework

In this section a mobile-phone based decision support system, DECOSS (Decision support for Optimal Supplier Selection), is presented. The front-end interface of DECOSS comprises an electronic forms interpreter that can run on a low-cost mobile-phone or smart-phone or an Android wireless tablet. The forms interpreter takes metadata embedded in an electronic form, interprets the metadata and renders the form on the mobile device. The use of xml and XForms technology (Boyer, 2009) for the form metadata enables data interchange with a wide variety of application back-ends. The advantage of this approach is the flexibility available to an application developer to concentrate on functionality and not have to worry about the user interface for input and presentation. DECOSS has been developed in the context of the Indian Sugar sector and its major components are:

- **mForms**, a mobile client application that resides on mobile phones and other mobile devices and interprets XForms metadata to enable electronic forms to be deployed on mobile devices
- **eCollect**, a back-end server which incorporates a set of platform services for the forms infrastructure
- **eWorkflow**, a workflow engine that manages the flow of work between various processes and users
- **OPMOD**, a module that implements the optimization models and a heuristic model for deriving the penalty structure which have been formulated in chapter 3

The mForms mobile client application enables suppliers to enter their bids on a mobile phone and send them to the server and a similar mobile web-based client application enables the supply chain manager to initiate bidding and monitor activities. A web-based client application also enables a Regulator to monitor the bidding process by requesting reports from the back-end server. The optimizer module is based on the optimal supplier selection formulations and the heuristic for the penalty structure that have been developed in Chapter 3.

Figure 4-1 provides a diagrammatic representation of the interactions between the various entities in DECOSS. It also shows the flow of xml/XForms data between the various entities in the DECOSS framework. Each of the user entities (the suppliers, the supply chain manager and the regulator) interacts with DECOSS through a set of pre-defined forms and interactions between the users are managed by a workflow engine. On the supplier's mobile device a form that enables the supplier to input his bids into the system is downloaded when he logs in. When the supplier has finished entering bids, the data in xml form is automatically uploaded to the server. The supply chain manager uses a different set of forms to interface with the system. Once all suppliers have uploaded bids in the system, the workflow engine generates a pre-filled form for the supply chain manager. The supply chain manager downloads this pre-filled form as a workflow item, examines the bids and uploads his response. The workflow engine drives the optimizer to obtain an optimal set of suppliers.

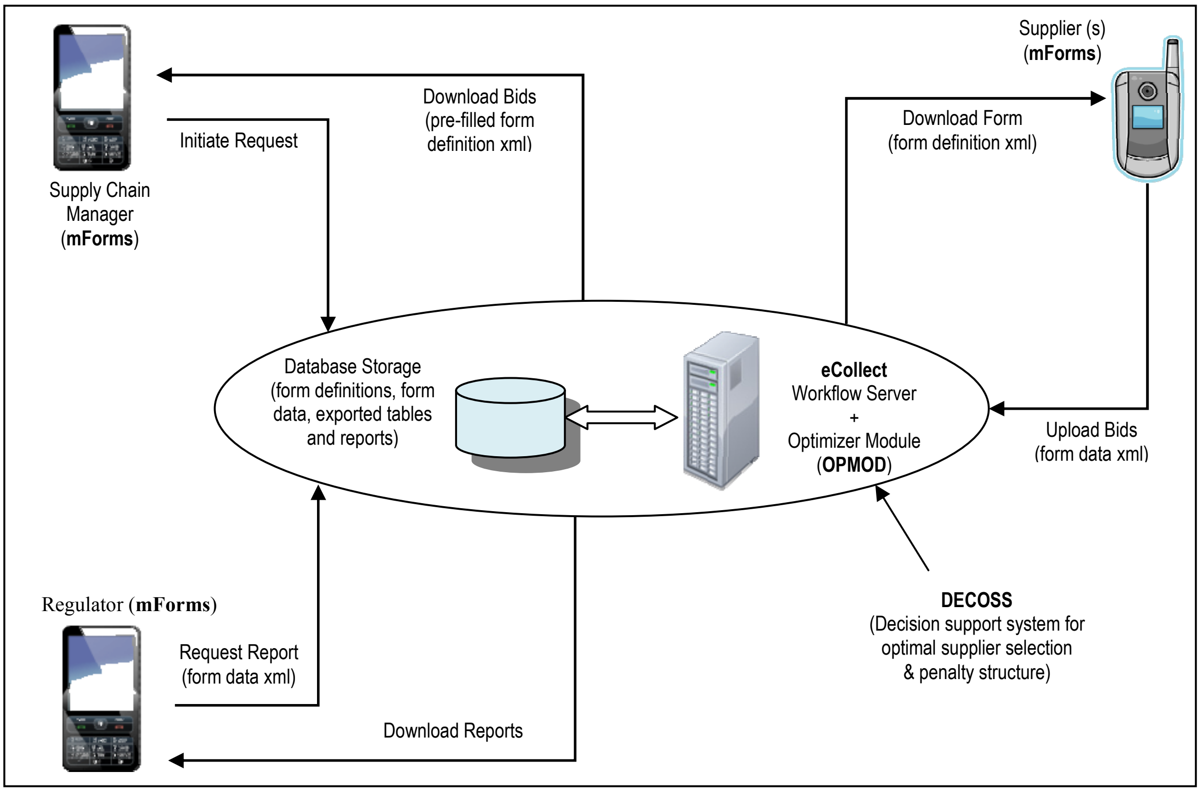


Figure 4-1: Interaction between various entities in DECOSS

4.3.2 XForms technology for electronic forms in DECOSS

The electronic forms which are used for all interaction between different user entities and the DECOSS are based on XForms technology which enables forms to be developed such that they can be rendered on any device which has an XForms interpreter (Boyer, 2009). This platform independence enables different users to choose the mobile device that is most appropriate to their needs. XForms is an open standard that enables this device independence by providing a separation between form design and form rendering. XForms is a language built on xml infrastructure which provides a specification for handling xml data, along with a user interface and incorporates constructs that are commonly required in data capture. It supports multiple data types and uses a *model-view-controller* approach in which the *model* provides the constructs for handling form data; the *view* provides a description of the way user interface controls would appear on a form; the *controller* orchestrates data manipulations, the interactions between the *model* and *view* layers and data submissions to a server, essentially providing the core of the business logic that goes into a data capture module. Electronic forms based on XForms technology can contain a rich set of data types, validation logic and skip rules to define the flow of input based on specified conditions. All of these features provide a framework for data collection that helps in minimising errors at the source of input.

An XForms engine is essentially an interpreter that interprets the XForms syntax and metadata to carry out the intent of an XForms document. The separation between the form definition and form rendering allows different mobile devices to render the form differently and yet perform the same set of functions for data collection. All that is required is an appropriate XForms engine on the target mobile device. Most contemporary web browsers already incorporate an XForms rendering engine and are therefore capable of rendering XForms on a web page. Rendering engines need to be developed for non-browser based devices. XForms supports many data types such as alpha, numeric, decimal, date, gps, image, audio, video etc. An input field in a form can be validated while data is being entered, to prevent erroneous or nonsensical values from being accepted at the source of input itself; fields can have range checks; fields can have calculations based on values in other fields; complex skip-logic can also be used to change the sequence of questions based on specified conditions generated due to the answers of previous questions.

4.3.3 The XForms model for the input form for supplier bids

The XForms form definition model for the input form for supplier bids, generated by the forms designer, is shown in Table 4-1 below:

Table 4-1: The form definition *model* for the input form for supplier bids

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<xforms xmlns:xsd="http://www.w3.org/2001/XMLSchema">
<model>
<instance id="input_form_for_supplier_bid">
<input_form_for_supplier_bid formKey="input_form_for_supplier_bid" id="6" name="Input form for supplier bid">
<activity/>
<supplier/>
<bid>
<time/>
<cost/>
<variance/>
</bid>
</input_form_for_supplier_bid>
</instance>
<bind id="activity" nodeset="/input_form_for_supplier_bid/activity" required="true()" type="xsd:string"/>
<bind id="supplier" nodeset="/input_form_for_supplier_bid/supplier" required="true()" type="xsd:string"/>
<bind id="bid" nodeset="/input_form_for_supplier_bid/bid"/>
<bind id="time" nodeset="/input_form_for_supplier_bid/bid/time" required="true()" type="xsd:int"/>
<bind id="cost" nodeset="/input_form_for_supplier_bid/bid/cost" required="true()" type="xsd:int"/>
<bind id="variance" nodeset="/input_form_for_supplier_bid/bid/variance" required="true()" type="xsd:int"/>
</model>
<group id="1">
<label>Page1</label>
<input bind="activity">  <label>Activity</label>  </input>
<input bind="supplier">  <label>Supplier</label>  </input>
<group id="bid">
<label>Bid</label>
<repeat bind="bid">
<input bind="time">  <label>Time</label>  </input>
<input bind="cost">  <label>Cost</label>  </input>
<input bind="variance">  <label>Variance</label>  </input>
</repeat>
</group>
</group>
</xforms>
```

Each supplier uses this input form to enter bids for each activity. Each bid is a 3-tuple of the form (activity completion time, cost, variance of activity completion time) as specified in Chapter 3 and multiple bids can be entered for each activity in the same form. Within the XForms *model* section there is an instance para which contains the name of the form, an index and the various fields of the form. A table is created in the database with the name specified in the *instance* para. Just below the *instance* para, a binding value and a data type value is specified for each of the fields. The binding value represents the name of the column that will be created within the table defined by the *instance* name and with the specified data type. The schema for the input forms for supplier bids is shown in Figure 4-2. The para below the *model* para specifies the input fields, using the same binding values defined in the *instance* para.

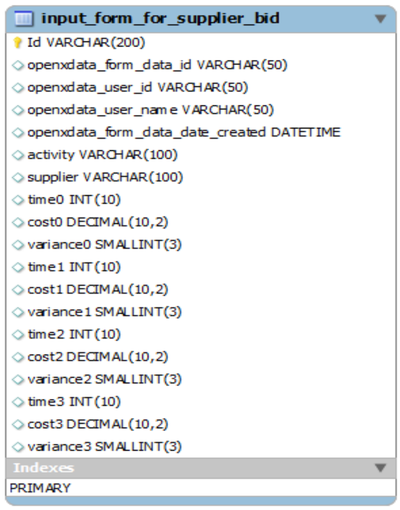


Figure 4-2: The database table for the input form for supplier bids

The field names defined in the schema are the binding variables that have been defined in the *instance* para of the form. Thus, the forms designer automatically creates the database schema which will be used when data is entered in the form and uploaded to the server. This is a useful feature since designing a database schema is no longer required to be done as a separate activity. The XForms syntax is quite simple and it is possible to design complex forms even without recourse to a forms designer, though in the decision support system that has been developed and presented here, a forms designer has been used to design all the forms.

4.3.4 The mobile client front-end for the DSS

The mobile client application, **mForms**, developed as a front-end for DECOSS, uses an XForms interpreter that interprets XForms metadata within the environment of an HTML5-compliant web browser, thereby making it possible to use this application on any platform with a web browser. Several variations of mForms have been developed. The **mForms-w** client application runs within an HTML5-compliant web browser in a tablet or on a smart-phone and **mForms-nw** runs on Java-enabled cell-phones in non-browser environments. Though the mForms-nw client application renders electronic forms on a low-cost Java-enabled cell-phone, the embedded interpreter engine does not support form layout on these phones. Therefore, on a low-cost cell-phone the mForms interpreter renders the form in a linear, vertical layout since the screen does not have adequate graphics capability and scrolling in both the horizontal and vertical directions is not considered comfortable for the user. On the other hand, the embedded interpreter in mForms-w renders any XForms-compliant electronic form with full layout capability, as if it were a paper form because of the quality and higher resolution of its graphics display. Thus the main difference between the browser-based version of the mForms client (mForms-w) and the non-browser based version of the mForms client (mForms-nw) is in the way the layout or display information embedded within the form definition xml document is handled by each interpreter. The other functionality that mForms provides remains the same across browser-based and non-browser based versions of mForms. This independence from the underlying hardware and software operating environment within mForms using the XForms approach, provides a unique, ubiquitous capability since device characteristics are not a limiting factor in using electronic forms on different types of mobile phones or other mobile devices.

Figure 4-3 shows the display of a web-based form that has been designed for collecting supplier bids from each of the suppliers. This form would be used by all suppliers to enter their multiple bids for each activity into the system, one activity at a time. It works within the environment of an HTML5 based web browser. Since browsers are available for a vast range of platforms from desktops to mobile devices, it can run on most such platforms. Figure 4-4 displays the same form for entering supplier bids on an Android tablet or smart-phone and Figure 4-5 shows the same input form for supplier bids, rendered on a low-cost Java-enabled cell-phone.

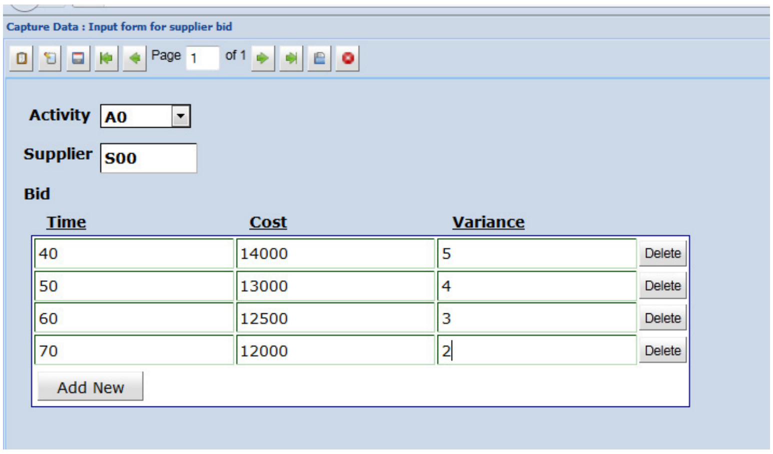


Figure 4-3: Web-based form for supplier bids

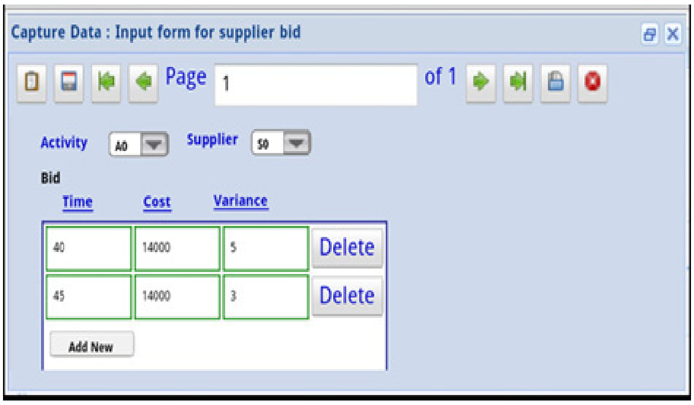


Figure 4-4: Form for supplier bids on an Android tablet or smart-phone

Figure 4-5: Form for supplier bids on a Java-enabled cell-phone

While the form looks different on each of these mobile client devices, because different mobile devices have different form-factors and graphics capabilities, the functionality is essentially the same. All the validation rules and skip rules remain the same. This platform independent approach to designing electronic forms based on XForms technology is used in DECOSS, the decision support system developed for optimal supplier selection.

Once the potential supplier selects an activity and enters the supplier code, multiple bids can be entered on the form where the fields for time, cost and variance are presented in a row form. The supplier can enter any number of bids by clicking on the "Add New" control button on the form to get an additional row for entering bid values. Each instance of a form contains data for only one activity, one supplier and multiple bids. After completing the entry of bid values for one activity, the potential supplier submits the bid and can create a new instance of the input form to enter bid data for additional activities. Once the supplier is ready with bids for all activities of interest, the data from all completed forms is uploaded to the server through a control button on the main screen of the mForms-w client application. The data is uploaded using the built-in GPRS/3G data connectivity on the mobile device.

Once the supplier's bid data is uploaded to the server and stored in a form data xml that is shown in Table 4-2, this form data xml document is available in the server's system tables for subsequent processing. It is also exported into a database table whose schema, designed at the form design stage shown in Figure 4-2 above. The form data xml and the exported tables are always maintained at the server since they are required for other functions such as viewing of data, pre-filling of forms and recovery from transaction failures. Since the entire form definition xml document is not uploaded to the server but only the form data xml is uploaded, it represents an efficient transport mechanism. This is an important consideration when data transfer bandwidth is limited or has to be conserved.

Table 4-2: The form data xml to hold the input data


```
<?xml version="1.0" encoding="UTF-8"?>
<input_form_for_supplier_bid formKey="input_form_for_supplier_bid" id="6" name="Input form for supplier bid"
xmlns:xsd="http://www.w3.org/2001/XMLSchema">
 <activity>a0</activity>
 <supplier>S00</supplier>
 <bid> <time>40</time> <cost>14000</cost> <variance>5</variance> </bid>
 <bid>
  <time new="true()">50</time> <cost new="true()">13000</cost> <variance new="true()">4</variance>
 </bid>
 <bid>
  <time new="true()">60</time> <cost new="true()">12500</cost> <variance new="true()">3</variance>
 </bid>
 <bid>
  <time new="true()">70</time> <cost new="true()">12000</cost> <variance new="true()">2</variance>
 </bid>
</input_form_for_supplier_bid>
```


4.3.5 Workflows in a disconnected environment

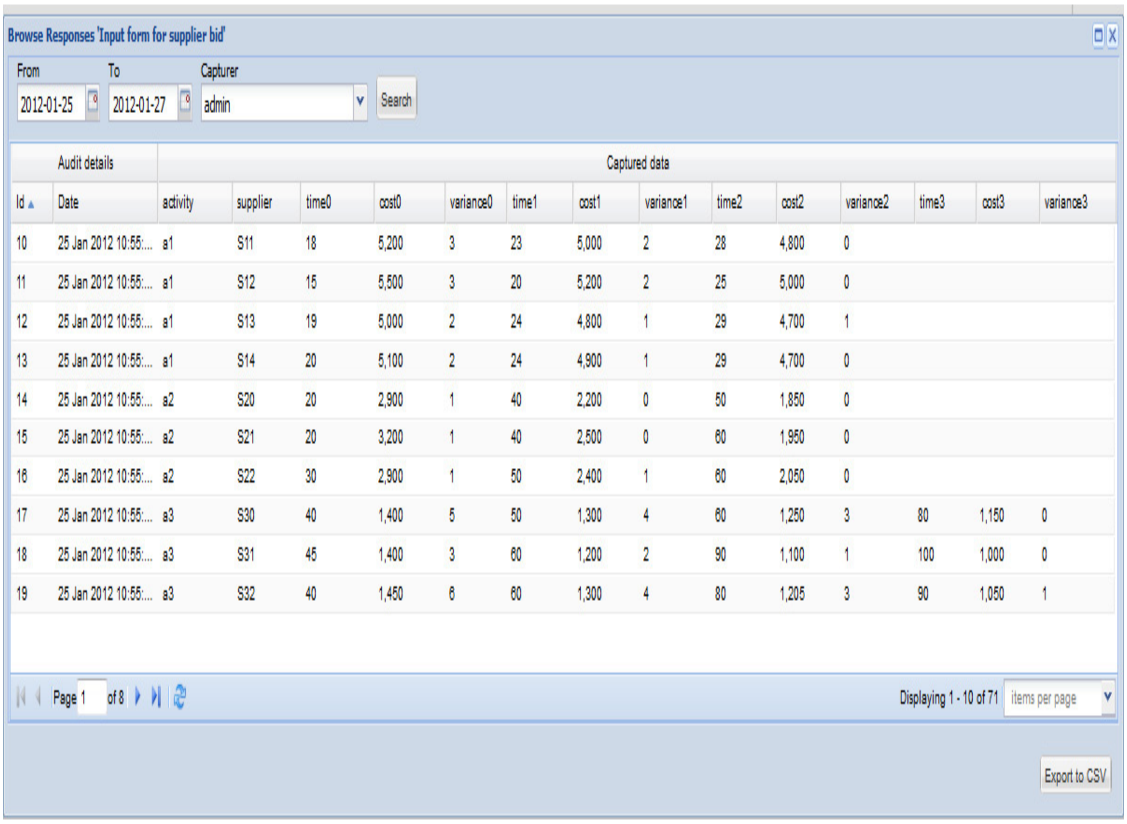
A unique feature of mForms, the mobile client application that has been presented in this chapter, is its ability to operate in off-line or disconnected mode so that the mobile user can collect data in the field without requiring connectivity to a back-end server once the appropriate set of electronic forms have been downloaded to the mobile phone. The offline client application (mForms) handles all the layout information embedded within the form itself which has been downloaded to the mobile device and renders it on the mobile device using device-specific capabilities. In addition, the web version of the client (mForms-w) also provides support for Java-scripting, a feature that can be deployed in complex forms that require functionality not implemented within the embedded XForms interpreter. This client-side Java-scripting enables forms to implement complex functions which may not be available in the basic set of XForms validation rules and compute functions. The mForms client application also has function control buttons for download of forms from a remote server, uploading of data and several other maintenance tasks. Once a form is downloaded to the mobile device, along with all its related resources, connectivity is no longer required even though a web interface is used for collection of data. Data collected through locally resident electronic forms is stored in a local object store till it can be uploaded to the back-end server.

The mobile client also supports workflow based data collection through the process of synchronization of workflows between the mobile device and a workflow engine running on the remote back-end server. This is an important feature since data collection is just one aspect of DECOSS, the developed decision support system.

A workflow provides an abstraction for the definition, execution and automation of business processes where tasks, information or documents are passed from one actor to another for action in accordance with a set of procedural rules (Sharp, 2009; Aalst, 2009). Workflows are important for implementing the business logic of interconnected processes. The workflow processes are defined through a workflow editor and forms are assigned to these processes at the server.

The mobile client application downloads workflow items, fills up the relevant data and submits it to the eCollect server as a completed workflow item and then picks up the next workflow item that may have been assigned to it. In this case, the workflow items for a supplier are a set of forms that he must fill up for the supplier bids and upload to the server. In the case of the supply chain manager, the workflow items are pre-filled forms which show all supplier bids which he verifies, approves and sends back to the server to initiate the optimizer workflow process. Hence, even though the mobile client may operate in offline mode, at the time of synchronization with the server the workflow engine intervenes and downloads workflow items assigned to that user so that the user can only perform those tasks that have been assigned to him. The workflow engine also provides alerts through email or sms so that the recipient can log into the server and reclaim the next workflow assigned to that user. This enables the user to stay in sync with the workflow system without being required to be continuously online.

Once all the supplier bids have been collected at the server, the eCollect workflow engine generates a workflow item for the supply chain manager who can now pull in all the supplier bids on his mobile client device. Figure 4-6 gives an overview of the supplier bids that are viewable by the supply chain manager on his mobile client device.


Browse Responses 'Input form for supplier bid'

From 2012-01-25 To 2012-01-27 Capturer admin Search

Audit details		Captured data													
Id	Date	activity	supplier	time0	cost0	variance0	time1	cost1	variance1	time2	cost2	variance2	time3	cost3	variance3
10	25 Jan 2012 10:55:...	a1	S11	18	5,200	3	23	5,000	2	28	4,800	0			
11	25 Jan 2012 10:55:...	a1	S12	15	5,500	3	20	5,200	2	25	5,000	0			
12	25 Jan 2012 10:55:...	a1	S13	19	5,000	2	24	4,800	1	29	4,700	1			
13	25 Jan 2012 10:55:...	a1	S14	20	5,100	2	24	4,900	1	29	4,700	0			
14	25 Jan 2012 10:55:...	a2	S20	20	2,900	1	40	2,200	0	50	1,850	0			
15	25 Jan 2012 10:55:...	a2	S21	20	3,200	1	40	2,500	0	60	1,950	0			
16	25 Jan 2012 10:55:...	a2	S22	30	2,900	1	50	2,400	1	60	2,050	0			
17	25 Jan 2012 10:55:...	a3	S30	40	1,400	5	50	1,300	4	60	1,250	3	80	1,150	0
18	25 Jan 2012 10:55:...	a3	S31	45	1,400	3	60	1,200	2	90	1,100	1	100	1,000	0
19	25 Jan 2012 10:55:...	a3	S32	40	1,450	6	60	1,300	4	80	1,205	3	90	1,050	1

Page 1 of 8 Displaying 1 - 10 of 71 items per page

Export to CSV

Figure 4-6: Supplier bids displayed on supply chain manager's mobile device

At the start of every season when suppliers have to be selected, the supply chain manager publishes the a *priori* penalty structure details which are based on the previous season's bids of the selected suppliers for each of the activities of the supply chain and initiates the process of requesting bids from suppliers. The suppliers use electronic forms on their own mobile devices (either mForms-w or mForms-nw) to send bids to DECOSS, the back-end system for decision support. Once the bids are collected from all suppliers, supply chain manager initiates optimization and the OPMOD, the optimizer module gives the selected bids/suppliers for that season. On receipt of results from the workflow engine, the supply chain manager informs the suppliers about the selected bidders and starts the specified set of supply chain activities. If any activities experience any delay beyond the activity time(s), the suppliers will be charged the penalty indicated *a priori.*

4.3.6 The workflow processes in DECOSS

Several entities are involved in DECOSS, the developed decision support system, with interactions between them shown in Figure 4-7 which provides a detailed view of the processes within the decision support system and the related workflows using a business process modelling notation (BPMN) defined in an open-standards specification (OMG, 2009). Various drawing tools are available for drawing BPMN diagrams.

The DECOSS decision support system comprises four major entities working in sync with each other:

- The supplier chain manager
- The suppliers
- The workflow engine
- The regulator.

Each process has been implemented in a separate pool in the BPMN diagram.

The role of the Regulator is particularly important in the context of the Indian sugar industry. Since the Indian sugar industry is organized into state/province-wise sugar cooperatives, all government support and subsidies to the farmers are provided through the cooperatives which are supervised by regulators. DECOSS takes this scenario into account by ensuring that a report of all bid data, the list of selected suppliers and the penalty structure is automatically sent to the Regulator who is informed through an email or sms alert. When the Regulator logs in, he can view the reports coming in from different sugar factories in near real-time and monitor the progress of the supply chains in each of the sugar factories under his supervision.

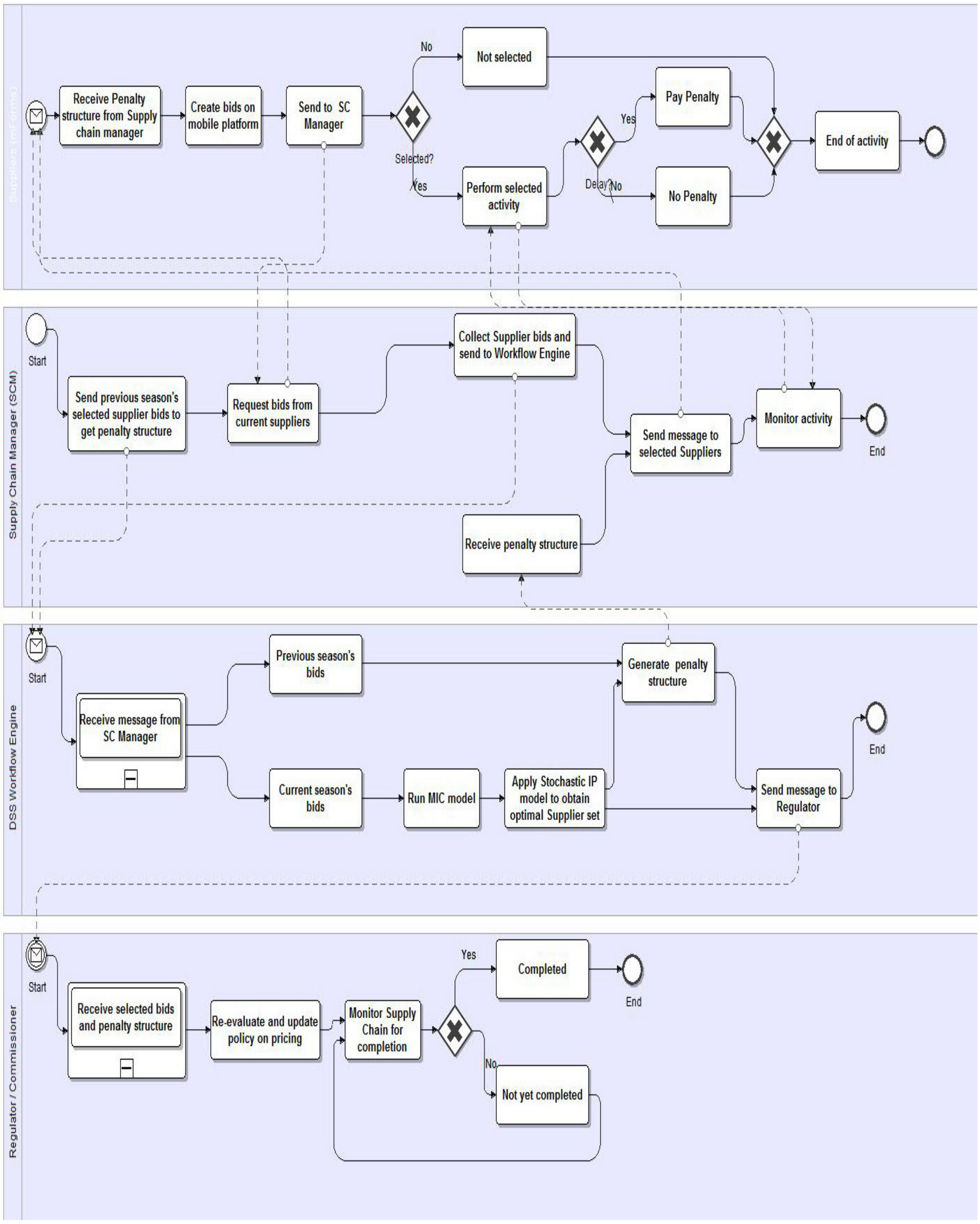


Figure 4-7: The workflow processes within DECOSS

As shown in the DECOSS workflow processes in Figure 4-7 above, the supply chain manager first initiates the generation of a penalty structure through the eCollect workflow engine by submitting the bids of the selected suppliers from the previous season's bid data. The simulation model for penalty derivation returns the penalty structure which is forwarded to potential suppliers of the current season's bidding cycle as an *a priori* indicator of the penalties they would attract in case of delays in the completion of their activities. After this process, the market intelligence curves (MIC) model is applied on historical data which gives the supply-chain managers an idea of the historical bidding patterns. When the MIC model is applied to the supplier bids of the current bidding cycle, it provides time and cost optima for the current cycle which is then used as inputs into the subsequent optimization models. After MIC, a stochastic integer programming model is applied on the current bids to generate an optimal set of suppliers for all activities. This information is used by the supply chain managers to inform the selected set of suppliers. The penalty heuristic is again run on current supplier bids for the selected set of suppliers obtained from the stochastic IP model to get the list of activities/suppliers that have the potential of getting delayed. This report is useful to the supply chain managers in monitoring, specifically, the activities/suppliers listed in the report. In case of delays in the completion of the supply chain network, the appropriate penalty is levied on those suppliers according to the indicated penalty structure. Since all information on supplier selection, the penalty structure and network execution is also shared with the Regulator, who is now able to perform his supervisory functions using the reports received in near real-time, thereby ensuring transparency in the supply chain.

4.4 The DECOSS software

The electronic data capture system which is part of the DECOSS is called eCollect. It comprises a server and mobile client software and the eCollect protocols and stack are based on the OpenXdata platform, (OpenXdata, 2011). The eCollect server stack runs in a java servelet container (Tomcat) and uses a MySQL database server. It uses a hibernate-compliant persistent storage repository that provides an abstract layer over the database engine, thereby providing a degree of database independence. Hence, a different database server like PostgresSQL or Oracle could be used instead of MySQL, if required. The eCollect server stack comprises a web-based forms designer that is used to design the electronic forms, a workflow engine, a web-based dashboard for remote administration and maintenance of the server, and a task scheduler for performing several administrative tasks such as export of data from xml format to relational tables in the persistent repository. Administrative tasks involve the management of users and assigning them roles and permissions to manage forms in the repository. Additional services can be added by using the plug-in architecture of the underlying system.

Figure 4-8 depicts the software architecture of the eCollect software that is part of DECOSS, the decision support system for optimal supplier selection.

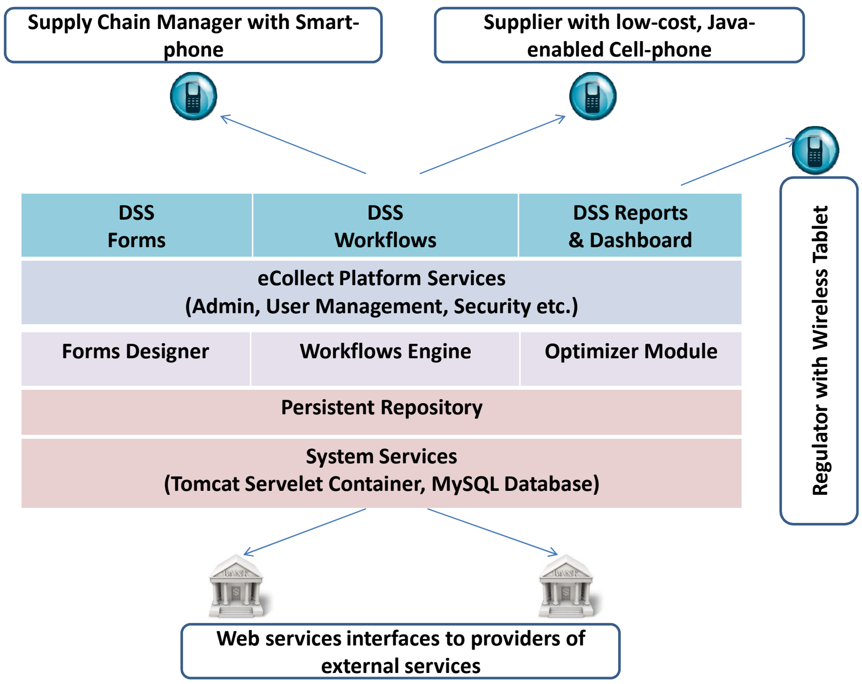


Figure 4-8: Software architecture of the eCollect system

The mobile workflows components and the workflow component within the eCollect platform services of DECOSS are developed on the Yawl workflow engine, a powerful workflow language for workflow management (Yawl, 2011). The workflow management tool is a simple way to specify and control processes involving data collection by different user entities and other tasks within DECOSS. The system provides the functionality to control workflow items on mobile devices even when the mobile devices operate in disconnected mode, i.e., asynchronously. This is possible because during synchronization with the application server, the scheduled workflow items are downloaded to the mobile device for data collection or data for completed workflow items is automatically uploaded to the application server and passed on to the workflow engine for further processing.

4.4.1 The optimizer module (OPMOD)

All suppliers enter their bids through the mobile-phone based data collection application and upload the bids to the back-end server. Each form contains multiple bids for one activity of a single supplier. If a supplier wishes to bid for other activities, for each such activity a separate form has to be filled up. Once the data has been uploaded to the back-end server it is available to the supply chain manager on his mobile-phone or tablet device as a workflow item. The supply chain manager can now initiate the optimizer to determine an optimal set of suppliers.

The optimizer module (OPMOD) comprises the following tasks:

- generation of an activity network for the supply chain
- deriving time and cost optima using market intelligence curves
- obtaining an optimal set of suppliers using a stochastic integer programming model for optimization
- developing a penalty structure for handling delays in execution of activities

Figure 4-9 shows a flowchart for OPMOD, the optimizer module which incorporates all the optimization models within the DECOSS decision support system.

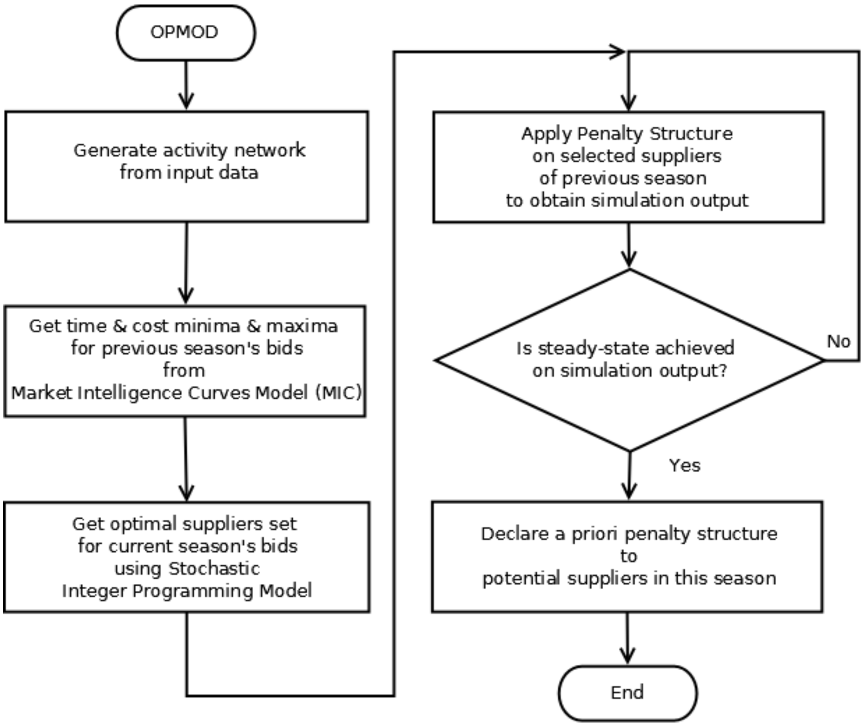


Figure 4-9: Flowchart of OPMOD, the Optimizer Module

As described in Chapter 3, the sugar supply chain is modelled as an activity network comprising multiple suppliers who have submitted multiple bids for each activity. The model for market intelligence curves (MIC), whose formulation is provided in Chapter 3, is then applied on bid data from the previous season to obtain the baseline information on time and cost optima for the supply chain network. In the MIC model, since the cost for each activity falls on the best-fit curve derived from bids for all suppliers for each activity, suppliers cannot be obtained using the model. Thus a stochastic integer programming model (STOIP) is used for obtaining an optimal supplier set. The minimum and maximum values of time obtained from the MIC model provide the range of values between which the external time constraints are specified as input to STOIP whose formulation is also described in Chapter 3. STOIP provides the supply chain manager with a list of suppliers while minimizing cost for a time constraint that is specified as an input parameter to the model. A heuristic based simulation model (**PENSTRUCT)**, whose formulation is provided in Chapter 3, computes penalty for delays incurred by the selected suppliers. Bid data from the previous season's selected suppliers is used to generate the *a priori* penalty structure. This information provided to the potential suppliers may moderate supplier behaviour during the current season's bids. The OPMOD optimization models which run at the back-end server are implemented as a set of java applications which internally uses ILOG CPLEX solver for solving the stochastic IP model.

4.5 Results and discussion

Figure 4-10 shows the activity network of one of the sugar factories where the developed DSS has been implemented.

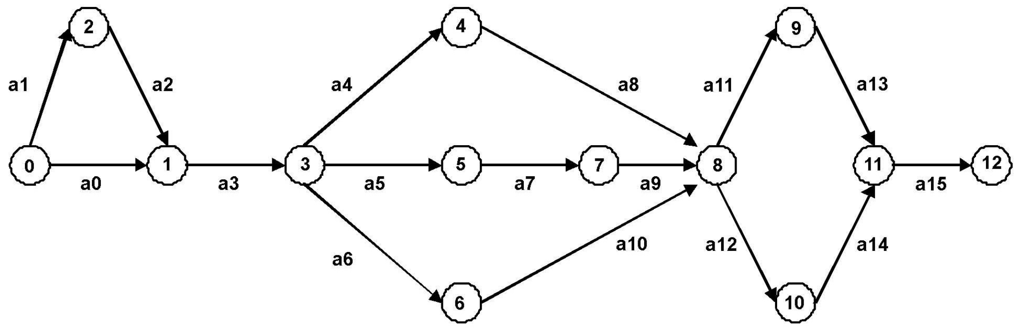


Figure 4-10: Sugar supply chain network for the decision support system

Table 4-3 provides the bid data as input for OPMOD, which comprises a list of supplier bids for all activities given in a 3-tuple format comprising (activity time, cost, variance of activity time). The data in this table represents the current season's bids. These bids have been entered by the various suppliers using electronic forms on their mobile-phones and uploaded to the eCollect server, as part of the workflow in the decision support system. The minimum values of time and cost have first been obtained from the MIC model by minimizing for time and then minimizing for cost with no time constraints.

Table 4-3: Bids of all suppliers for current season in the sugar supply-chain network

		Supplier Bids (completion time, cost, variance of completion time) (time in days, cost in INR 1000)			
Activity	**Suppliers**	**Bid 1**	**Bid 2**	**Bid 3**	**Bid 4**
Activity a0	S00	40,14000,5	50,13000,4	60,12500,3	70,12000,2
	S01	45,14000,3	60,12000,2	90,11000,1	100,10000,0
	S02	40,15500,6	60,13500,4	80,12000,3	90,10500,1
	S03	52,14500,5	77,12400,3	92,10800,2	102,10000,1
	S04	44,15200,4	66,13200,3	84,12300,2	90,10700,0
Activity a1	S10	20,5000,2	25,4800,1	30,4500,0	
	S11	18,5200,3	23,5000,2	28,4800,0	
	S12	15,5500,3	20,5200,2	25,5000,0	
	S13	19,5000,2	24,4800,1	29,4700,1	
	S14	20,5100,2	24,4900,1	29,4700,0	
Activity a2	S20	16,1200,3	22,1000,2	26,920,2	30,870,1
	S21	19,1100,3	24,960,2	29,880,2	33,610,1
	S22	15,1240,3	21,1130,2	27,1010,2	32,960,1
	S23	29,1449,7	42,603,4	49,433,2	
	S24	17,995,3	22,830,2	27,740,2	32,650,1
Activity a3	S30	16,8000,3	22,7200,2	26,6700,2	30,6100,1
	S31	19,7800,3	24,7500,2	29,7100,2	33,6600,1
	S32	16,8100,2	23,7700,2	28,7350,2	34,6950,1
	S33	15,8600,3	27,7450,2	27,7450,2	32,7050,1
	S34	17,8050,3	22,7930,2	27,7450,2	32,7050,1
Activity a4	S40	16,4000,3	22,3600,2	26,3350,2	30,3050,1
	S41	19,3800,3	24,3600,2	29,2950,2	33,2800,1
	S42	16,4000,2	23,3600,2	28,3150,2	34,2750,1
	S43	15,4400,3	21,3950,2	27,3450,2	32,3050,1
	S44	17,4050,3	22,3830,2	27,3150,2	32,2750,1
Activity a5	S50	16,800,3	22,750,2	26,700,2	30,650,1
	S51	19,775,3	24,750,2	29,725,2	33,700,1
	S52	16,830,2	23,785,2	28,730,2	34,695,1
	S53	15,875,3	21,805,2	27,750,2	32,715,1
	S54	17,865,3	22,810,2	27,750,2	32,725,1
Activity a6	S60	16,300,3	22,240,2	26,195,2	30,160,1
	S61	19,255,3	24,220,2	29,195,2	33,175,1
	S62	16,310,2	23,285,2	28,200,2	34,195,1
	S63	15,415,3	21,365,2	27,305,2	32,295,1

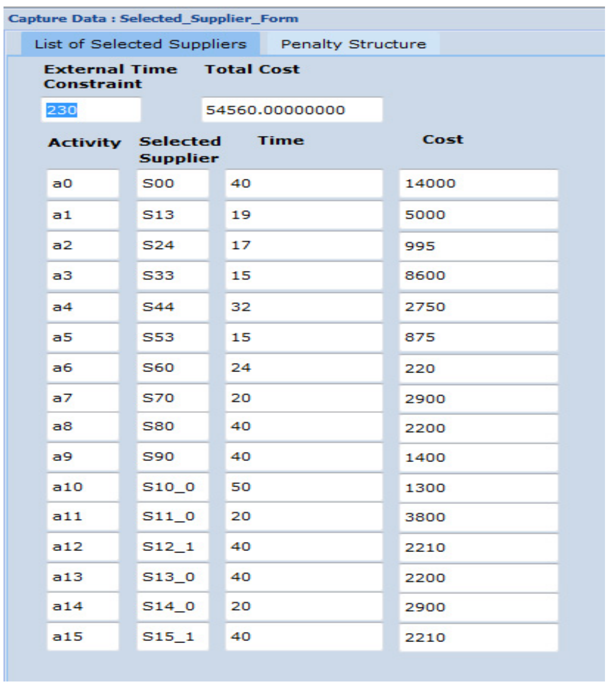
	S64	17,365,3	22,305,2	27,250,2	32,225,1
Activity a7	S70	20,2900,1	40,2200,0	50,1850,0	
	S71	20,3200,1	40,2500,0	60,1950,0	
	S72	30,2900,1	50,2400,1	60,2050,0	
Activity a8	S80	20,2900,1	40,2200,0	50,1850,0	
	S81	20,3200,1	40,2500,0	60,1950,0	
	S82	30,2900,1	50,2400,1	60,2050,0	
Activity a9	S90	40,1400,5	50,1300,4	60,1250,3	80,1150,0
	S91	45,1400,3	60,1200,2	90,1100,1	100,1000,0
	S92	40,1450,6	60,1300,4	80,1205,3	90,1050,1
	S93	52,1350,5	77,1210,3	92,1020,2	
	S94	44,1400,4	66,1300,3	84,1210,2	90,1040,0
Activity a10	S10_0	40,1400,5	50,1300,4	60,1250,3	80,1150,0
	S10_1	45,1400,3	60,1200,2	90,1100,1	100,1000,0
	S10_2	40,1550,6	60,1350,4	80,1200,3	90,1050,1
	S10_3	52,1450,5	77,1240,3	92,1080,2	102,1000,0
	S10_4	44,1520,4	66,1320,2	90,1070,0	
Activity a11	S11_0	16,5000,2	20,4800,1	25,4500,0	
	S11_1	18,5200,3	23,5000,2	28,4800,0	
	S11_2	15,5500,3	20,5200,2	25,5000,0	
	S11_3	19,5000,2	24,4800,1	29,4700,1	
	S11_4	20,5100,2	24,4900,1	29,4700,0	
Activity a12	S12_0	50,2010,2	70,1985,1	90,1776,1	120,1560,0
	S12_1	40,2210,1	60,2085,1	100,1976,1	120,1530,0
	S12_2	60,2010,2	80,1985,1	100,1906,1	120,1570,0
	S12_3	70,2000,2	100,1885,1	120,1806,1	140,1470,0
	S12_4	60,2090,2	90,1985,1	120,1836,1	15,1400,0
Activity a13	S13_0	20,2900,1	40,2200,0	50,1850,0	
	S13_1	20,3200,1	40,2500,0	60,1950,0	
	S13_2	30,2900,1	50,2400,1	60,2050,0	
Activity a14	S14_0	20,2900,1	40,2200,0	50,1850,0	
	S14_1	20,3200,1	40,2500,0	60,1950,0	
	S14_2	30,2900,1	50,2400,1	60,2050,0	
Activity a15	S15_0	50,2010,2	70,1980,1	90,1770,1	120,1560,0
	S15_1	40,2210,1	60,2070,1	100,1900,1	120,1400,0
	S15_2	60,2000,2	80,1850,1	100,1760,1	120,1510,0

Table 4-4 summarises the results of the MIC and STOIP models. It is seen that optimal cost obtained from STOIP is higher than that obtained from MIC. This happens because MIC uses best-fit curves on supplier bid values whereas the STOIP model uses the actual discrete cost bids for the selected suppliers.

Table 4-4: Results for MIC model and STOIP model

Objective	MIC Model		STOIP Model	
	Time (Days)	Cost (in INR 1000)	Time (Days)	Cost (in INR 1000)
Minimize Time	230	32103	230	61800
Minimize Cost with no Time Constraints	660	21030	632	41293

Figure 4-11 displays the list of selected suppliers on the mobile device of the supply chain manager. This list of suppliers for all activities is obtained for optimal cost from STOIP for the time constraint which has been specified by the supply chain manager as an input parameter to STOIP.


Capture Data : Selected_Supplier_Form

List of Selected Suppliers | Penalty Structure

External Time Constraint: 230

Total Cost: 54560.00000000

Activity	Selected Supplier	Time	Cost
a0	S00	40	14000
a1	S13	19	5000
a2	S24	17	995
a3	S33	15	8600
a4	S44	32	2750
a5	S53	15	875
a6	S60	24	220
a7	S70	20	2900
a8	S80	40	2200
a9	S90	40	1400
a10	S10_0	50	1300
a11	S11_0	20	3800
a12	S12_1	40	2210
a13	S13_0	40	2200
a14	S14_0	20	2900
a15	S15_1	40	2210

Figure 4-11: List of selected suppliers for all activities

Table 4-5 displays the penalty structure obtained from PENSTRUCT for the selected suppliers of all activities. The following parameters have been supplied to PENSTRUCT:

- the expected completion time, $T = 230$ days
- the acceptable delay in the network, $\delta = 9$ days
- the acceptable probability of delay, $\varepsilon = 10\%$
- the expected loss per day, LPD = 100
- maximum penalty to be charged (computed on the per-day cost derived from supplier bid), $m = 20\%$
- the number of iterations, 10000

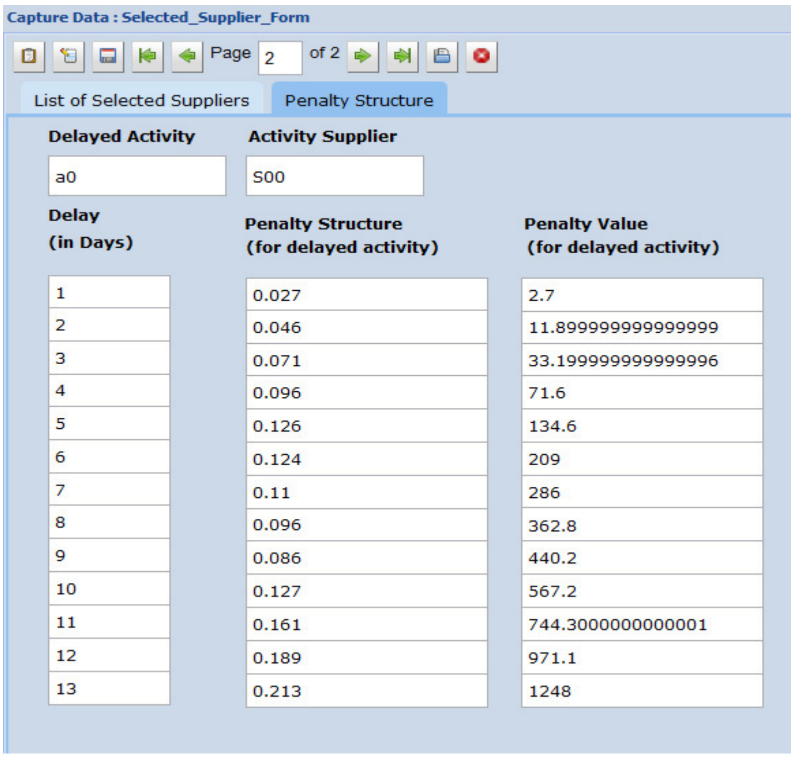
The choice of ε and δ were made on the basis of empirical data (see Chapter 3, Section 3.10.3 for an explanation).

Table 4-5: Penalty structure computed on previous season's data by PENSTRUCT

	Activity															
Delay	**a0**	**a1**	**a2**	**a3**	**a4**	**a5**	**a6**	**a7**	**a8**	**a9**	**a10**	**a11**	**a12**	**a13**	**a14**	**a15**
1	0.03	0.32	1	0.24	0	0.75	1	0.23	0	1	1	0	0.88	0	0.86	0.88
2	0.05	0.32	1	0.24	0	0.75	1	0.23	0	1	1	0	0.88	0.03	0.86	0.88
3	0.07	0.26	1	0.2	0	0.66	1	0.21	0.01	1	1	0.01	0.73	0.07	0.73	0.73
4	0.1	0.21	1	0.15	0.03	0.55	1	0.18	0.09	1	1	0.03	0.53	0.14	0.56	0.57
5	0.13	0.17	1	0.12	0.18	0.45	1	0.145	0.42	0.93	1	0.05	0.46	0.24	0.45	0.46
6	0.12	0.16	1	0.12	0.28	0.45	1	0.15	0.63	0.91	1	0.07	0.44	0.35	0.44	0.44
7	0.11	0.21	1	0.16	0.26	0.42	1	0.14	0.59	0.83	1	0.1	0.58	0.49	0.58	0.58
8	0.1	0.27	1	0.2	0.22	0.38	1	0.13	0.52	1	1	0.10	0.74	0.50	0.74	0.74
9	0.09	0.31	1	0.23	0.33	0.48	1	0.12	0.46	1	1	0.09	0.86	0.46	0.86	0.86
10	0.13	0.35	1	0.26	0.41	0.63	1	0.15	0.68	1	1	0.09	0.95	0.42	0.95	0.95
11	0.16	0.38	1	0.28	0.48	0.75	1	0.19	0.87	1	1	0.08	1	0.38	1	1
12	0.19	0.40	1	0.3	0.54	0.86	1	0.24	1	1	1	0.12	1	0.57	1	1
13	0.21	0.42	1	0.31	0.59	0.95	1	0.27	1	1	1	0.15	1	0.74	1	1

Table 4-5 indicates that some activities exhibit behaviour that is different from the other activities. For example, the suppliers selected for the activities a4, a8, a11 and a13 initially exhibit zero penalty for the initial few units of delay but then exhibit a steep rise in penalty beyond, which is a bit different from the penalty functions of the other activities. This can be explained since certain activities are non-critical at the start of network execution and therefore do not incur penalty for several initial units of delay but, as the network delay increases beyond the path slack, even non-critical activities begin to experience delay and will attract a penalty. Hence, it is observed that even non-critical activities can become critical as network delay increases beyond the path slack.

Figure 4-12 displays the penalty structure and penalty values for the activity a0, based on the previous season's bids that were input to PENSTRUCT. The information is also accessible on the supply chain manager's tablet as a report.


Capture Data : Selected_Supplier_Form

Page 2 of 2

List of Selected Suppliers | Penalty Structure

Delayed Activity: a0

Activity Supplier: S00

Delay (in Days)	Penalty Structure (for delayed activity)	Penalty Value (for delayed activity)
1	0.027	2.7
2	0.046	11.899999999999999
3	0.071	33.199999999999996
4	0.096	71.6
5	0.126	134.6
6	0.124	209
7	0.11	286
8	0.096	362.8
9	0.086	440.2
10	0.127	567.2
11	0.161	744.3000000000001
12	0.189	971.1
13	0.213	1248

Figure 4-12: Penalty structure for delays incurred by supplier for activity a0

Figure 4-12 shows one column for the penalty structure and another column for the penalty value. The penalty structure for a given delay represents a value based on the cost per day computed by PENSTRUCT from that selected supplier bid which is capped at a maximum percentage specified as an input parameter. The penalty value for a given delay of n days is computed by multiplying the corresponding penalty structure for the delay n and the expected loss per day (LPD, an input parameter) and adding the penalty for the previous $(n-1)$ days of delay. So the penalty column reflects a cumulative penalty value that is to be applied to the delaying supplier. For example, Figure 4-12 shows that the penalty structure for activity a0 is 0.11 for 7 days of delay with a penalty value of 286. The penalty value of 286 is computed by adding the penalty due to the 7th day's delay to the cumulative penalty for the previous 6 days.

The PENSTRUCT simulation output is given once the system ensures steady output after discounting the transient phase. Through a detailed experiment (see Chapter 3, Figure 3-28) it has been established that PENSTRUCT stabilizes after 8000 simulation runs. A built-in feature in PENSTRUCT enables the number of simulation runs required to determine steady state, to be changed for different business environments. By default, PENSTRUCT gives the output of the10,000th run to represent steady state performance.

In summary, PENSTRUCT is used to compute the penalty structures for all activities based on the previous season's bids, which are then announced to the potential bidders in the current season as *a priori* penalty structure for delays. These penalties are to be applied on the selected set of suppliers (obtained from STOIP) based on the current season's bid data in case of delays.

4.6 Conclusions

In this chapter DECOSS, a decision support system has been presented. DECOSS is a tool that enables the supply chain manager in negotiation with suppliers and subsequently for monitoring of activities in the sugar supply chain. Different stake-holders may use different mobile devices to interface with DECOSS. The sugar supply chain manager may access the decision support tools on an Android smart-phone or wireless tablet whereas suppliers may use low-cost Java-enabled cell-phones to enter bids for their activities into the system. The regulator of the cooperative sugar sector also has access to this information through web-based forms on a real-time basis. XForms technology has been used to implement electronic forms which can be rendered seamlessly across any of these mobile platforms. At the back-end, the eCollect server has been developed for designing forms, for serving forms to different client devices, collecting data and managing the data in persistent storage.

A workflow engine, running as a web service, provides the interface between different processes that make up the back-end of the decision support system. It interacts with the eCollect server to access the forms received from suppliers and provides this data as input to OPMOD, an optimizer module which generates a list of suppliers that meets optimal cost for specified time constraints. OPMOD also incorporates a simulation model (PENSTRUCT) for deriving a penalty structure for handling delays that might occur during the execution of activities in the supply chain network. The optimization models were formulated and developed in Chapter 3.

The sugar cooperative sector in India is significantly dependent on government subsidies due to which political patronage and other considerations bring in inefficient practices in supplier selection and sugar supply chain management. Through the use of the DECOSS package which comprises STOIP and PENSTRUCT, supplier selection and supply chain management is not only optimal but the PENSTRUCT module also takes care of delays with appropriate penalties which can be announced *a priori* to the potential suppliers. The penalty structure is developed taking the previous season's selected supplier bids in the PENSTRUCT module. Once the suppliers are selected, PENSTRUCT may also be used to determine the applicable penalties on the currently selected bids to facilitate negotiation with suppliers.

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5. Crusher Scheduling

5.1 Introduction

In this chapter sugar-cane procurement and crusher scheduling are modeled based on a single server, multi-channel queuing with server vacation. Sugar cane procured by the sugar factories from various farmers in different fields and locations arrives in lots at the sugar factory according to the pre-determined schedule in terms of quantity, quality and time. However, in reality, the arrival of sugar cane lots deviate from the pre-determined arrival schedule hence there would be multiple queues formed at the factory/crusher to await their turn to be crushed. The quantity, quality, time of arrival and wait time of the arriving sugar cane lots have an impact on the yield, quality and crushing time besides the crusher usage. This situation boils down to a typical single-server multiple queues scenario.

Due to the subjective approach of the logistics and crusher managers at the sugar factories, multiple queues form of the arriving sugar cane lots, and quite often the crushing of the arriving sugar cane lots would not take place on first-come-first-served (FCFS) basis by skipping the arrival sequence. This scenario is similar to the typical manufacturing scenario of multiple queues (products), single server with server vacation.

In a typical manufacturing setting, multiple items compete for the availability of a common production facility and production of units of individual items is initiated on the basis of outstanding orders for the item. In this chapter, the focus is on a setting where uncertainty prevails regarding the demand patterns and production times. Switching between different items incurs constant (random) sequence independent setup times and an explicit cost for setup as well. A variety of strategy classes have been proposed to govern these systems effectively with a view to minimize system-wide costs. These can be classified as i) *static* and ii) *dynamic* strategies. Dynamic strategies determine at any point in time which type of the items and the corresponding number of items, if any, is to be produced in the facility on the basis of *complete* state of the system which may include inventory levels of all items and the most recent assignment of the production facility. On the other hand, static policies use only the state information that pertains to the item currently being produced. Optimal policies for many common performance measures are often dynamic and can be obtained through solution of a dynamic program in multi-dimensional space. In many practical cases, such dynamic programs suffer from curse of dimensionality. Also, even in the cases where the optimal strategies could be computed in a reasonable amount of time, the policies have complex structure and can hardly be implemented in practice.

5.2 Literature survey

In contrast with the set of dynamic policies, the class of static policies offers a better co-ordination of various other inter-related activities such as raw material procurement; external setups *etc* and hence have a good practical appeal in manufacturing framework. Also, recent works stand as evidence to the fact that restriction to static policies in the context of scheduling of production-inventory systems comes with only a moderate loss of optimality. Among them is a comparative performance study of a dynamic cyclic base stock rules and a minor variant of a static cyclic base stock policy (Markowitz, Reiman et al., 2000). It has been demonstrated that significant improvement in performance is achievable by replacing the static cyclic rules in the above case by general periodic strategies which produce different items with different relative frequencies (Federgruen & Katalan, 1998). A loose lower bound on second moment for shortfall distribution was derived in terms of individual item frequencies and a convex program was formulated using these bounds to derive approximate values for these frequencies (Federgruen & Katalan, 1998).

To obviate difficulties arising out of fully dynamic policies, a class of semi-dynamic policies has been proposed in the literature (Browne & Yechiali, 1989; Duenyas & Van Oyen, 1995; Duenyas & Van Oyen, 1996; Zipkin, 1986; Leachman, Xiong et al., 1991; Bourland & Yano, 1991a; and Bourland & Yano, 1991b). While a detailed review of the policies is described in the literature there are no accurate analytical techniques that can evaluate this class of policies if the number of classes is more than two (Federgruen & Katalan, 1994; Federgruen & Katalan, 1996; Federgruen & Katalan (1998). The only class of policies which admits evaluation and optimization is the class of static base stock policies and an efficient methodology to evaluate any given base stock policy and to derive optimal base stock policies for a given periodic sequence of items, with a particular reference to the cyclic policy case has been developed (Federgruen & Katalan, 1994; Federgruen & Katalan, 1996) and subsequently, a methodology to arrive at an effective periodic sequence that outperforms cyclic base stock policy has also been developed (Federgruen & Katalan, 1998).

Another paper proposes a simulation based method to compute optimal base stock levels for a given cyclic sequence (Anupindi & Tayur, 1998). In communication networks scenario, several authors have derived polling table policies for various performance measures such as weighted average of steady state waiting times and workloads (Boxma, Levy et al., 1990; Boxma, Levy et al., 1991; Boxma, Hanoch et al., 1991; Bertsimas & Xu, 1993). The effect of product variety on inventory costs has been examined in a capacitated production-inventory system to show that inventory costs increase almost linearly in the number of products and that, the rate of increase is sensitive to demand variability, demand and capacity levels, and setup times (Benjaafar, Kim et al., 2004). Solving the tardiness problem in single-machine sequencing by using integer programming formulations has also been proposed (Baker and Keller, 2010). The scheduling problems that occur in multi-item production-inventory systems in the presence of random setup and production times have also been studied (Ravikumar et al., 2000).

Traditional inventory models such as the economic production quantity model (EPQ) and the economic order quantity model (EOQ) have been formulated to minimize the holding cost or the ordering cost, components of the inventory-related costs, under ideal conditions of no defective products. However, the occurrence of defective products will cause rework on the same production line. A batch production system may produce a few defective products which require rework and determining the optimal batch quantity under rework conditions poses additional challenges. Several studies have also been made to understand optimal lot sizing of EPQ and EOQ inventory models that include rework due to defective products on the same production line.

Two different operational policies have been proposed to determine the optimal batch size and minimize the total system cost in a single-stage production system on which rework is done (Jamal et al., 2004). Some numerical errors in the above operational policies have been pointed out and a simple improved algebraic derivation of the policies to determine the optimal batch size has been done (Cárdenas-Barrón, 2004; Cárdenas-Barrón, 2007). A further extension of the above single-stage production policies resulted in two different policies for an optimal batch quantity in a multi-stage production system (Sarker et al., 2008). The first policy proposed the rework of defective products within the same production cycle, whereas the second policy proposed the rework of defective products after N cycles, at the end of the last regular cycle, with the choice of rework policy to be determined by the work-in-process inventory costs. In a numerical correction to these policies, an EPQ inventory model of a single-stage production system in which all defective products are reworked in the same production cycle using planned backorders was provided (Cárdenas-Barrón, 2009a; Cárdenas-Barrón, 2009b).

The literature provides extensive coverage of flow-shop scheduling involving machine setup times and single-machine scheduling with learning to reduce processing times (Cheng et al., 2000; Wang and Wang, 2010; Cheng et al., 2011). The probabilistic safety stock n-item inventory system having varying ordering cost and zero lead-time that obtains the optimal maximum inventory levels has been studied using a geometric programming approach (Fergany, 2005). Winands et al. (2005) provides a comprehensive survey of research in production-inventory systems under stochastic economic lot scheduling.

5.3 Sugar-cane crushing – a scheduling model

In this chapter, the focus is on the class of static periodic policies for assignment of the facility and to present an approximation for the second moment of shortfall distribution using the analysis of queues with server vacations. With the aid of this approximation, an approximate convex program to minimize system wide costs has been developed. A discussion on two special cases for which the mathematical program admits solution without invoking any numerical techniques is provided. Since in many practical situations either of these two cases occurs, these solutions are used to construct a periodic sequence for production of items.

The chapter is organized as follows: In Section 5.4 a complete description of the problem is given and the procedure outlined in arriving at a periodic sequence. In Section 5.5 the details of the approximation procedure are discussed and a mathematical program is developed for system wide costs using distribution free procedures. Subsequently, two cases are isolated under which the mathematical program can be solved without invoking any numerical methods. Relative frequencies of production of individual items have been derived in the discussed cases. In Section 5.6 a table is constructed and a heuristic is developed to identify a sequence for production of items such that the items appear in the sequence according to their respective absolute frequencies and also such that inter-visit times between successive visits to each item type is uniform. Results of the numerical study are provided to demonstrate that tabular policies could be more cost-effective than simple exhaustive cyclic policies.

5.4 Description of the scheduling problem

Consider a production system with N distinct items, demands for which are generated by independent Poisson processes with λ_i as the rate at which demand arises for item i, $i = 1, 2, ..., N$. Let $\lambda = \sum_{i=1}^{N} \lambda_i$. With appropriate modifications, analysis to be presented here can be carried over to compound Poisson demand streams as well. The N items are produced at common processing facility that can produce a single unit of any item at a time. Production times for individual units of an item are assumed to be *i.i.d* random variables with *c.d.f* $F_i(.)$ and mean $\frac{1}{\mu_i}$ for $i = 1, 2, ..., N$. A possibly random setup time with cdf G_i and mean s_i is incurred when setting up the facility to produce item i. Consecutive setup times are independent. The utilization rate for item i is $\rho_i = \frac{\lambda_i}{\mu_i}$ and the utilization of the system equals $\rho = \sum_{i=1}^{N} \rho_i$. Assume that the system is stable *i.e.,* $\rho < 1$.

A demand which finds zero inventory is backlogged. The following costs are incurred:

- C_{h_i} = the inventory carrying cost rate for item i per unit of time ($i = 1, 2, ...N$);
- C_{b_i} = the backorder cost rate for item i per unit of time ($i = 1, 2, ..., N$);
- K_i = Sequence independent setup cost for item i, $i = 1, 2, ..., N$

The objective is to find a production sequence to minimize the long-run average total cost.

Let B_i denote the base stock level for item i, $i = 1, 2, ..., N$. An arriving demand which finds non-zero inventory will deplete the inventory level by a unit and each such depletion initiates a production order request at the facility. Also, a demand arriving into the system when the inventory level of the corresponding item is zero, will initiate a back order. It is assumed that no priority is assigned to the back logged demands. In such a scenario, one can model the production facility as a multi-class M/G/1 queue. Further, it is assumed that once production is initiated on a particular item, the facility continues to serve it *exhaustively*, that is, until its inventory level reaches its base stock level. A *periodic tabular policy* is specified by

- base-stock level vector **B** := ($B_1, B_2, \ldots B_N$)
- a table **T** := (T(1), T(2),…, T(M)) where $T(j) \in 1, 2, \ldots, N$ and M denotes the size of the table T.
- the idling policy specified by the vector of idle time $\delta := (\delta_1, \delta_2, \ldots, \delta_N)$.

($\mathbf{B}, \mathbf{T}, \delta$) is used to denote any such periodic tabular policy. Execution of the foregoing policy results in a cycle in which items are replenished according to the sequence specified by the table and production of units of a given item, i, is continued until the inventory level of the item hits its base-stock level B_i.

Define *shortfall* for item i at any time t as the amount by which inventory level of item i at time t, $I_i(t)$ falls below its base stock level B_i. Note that the shortfall is *not equal* to the number of back-orders. For stable policies such as periodic policies, using regenerative arguments, one can show that steady state values of $L_i(t)$ and $I_i(t)$, denoted by L_i and I_i respectively, exist and values are related by:

$$L_i = B_i - I_i \tag{5.1}$$

Further, let the steady state *cycle length* random variable be denoted by C. Its mean value is given by

$$E[C] = \frac{\sum_{i=1}^{M} s_{(T(i)} + \delta_i}{1 - \rho} \tag{5.2}$$

Now, one can represent the long run expected average cost for a given periodic policy $(\mathbf{B}, \mathbf{T}, \delta)$ as follows:

$$TC = \frac{\sum_{i=1}^{M} K_{T(i)}}{E[C]} + \limsup_{t\to\infty} \frac{1}{t} E\left[\int_0^t \sum_i C_{b_i} (L_i(t) - B_i)^+\right]$$

$$+\limsup_{t\to\infty} \frac{1}{t} E\left[\int_0^t \sum_i C_{h_i} (B_i - L_i(t))^+\right] \tag{5.3}$$

Since by construction the policy ($\mathbf{B}, \mathbf{T}, \delta$) imposes regenerative dynamics, the long run average terms in the equation (5.3) above converge to their respective steady state expected values (See Wolff, 1988). Thus, equation (5.3) can be re-written as

$$TC = \frac{\sum_{i=1}^{M} K_{T(i)}}{E[C]} + \sum_i C_{b_i} E(L_i - B_i)^+ + \sum_i C_{h_i} E(B_i - L_i)^+ \tag{5.4}$$

It is interesting to note that $\{L_i, i = 1,2,\ldots,N\}$ is independent of $\mathbf{B}$ but does depend on the table T and the vector of idle times δ. For a given table $\mathbf{T}$ and a given idle time vector δ, the optimal base stock levels, $B_i, i = 1,2,\ldots,N$ are obtained from the solution of a newsboy problem with L_i as the demand distribution which is given by

$$B_i^* = \min\{k : P[L_i \le k] \ge \frac{C_{b_i}}{C_{b_i} + C_{h_i}}\} \tag{5.5}$$

Note that B_i^* in equation (5.5) can be computed only when complete distribution of L_i is known. More often than not, it is difficult to find the distribution function of L_i even in a simplified framework. In our problem, L_i depends on the policy $(\mathbf{B}, \mathbf{T}, \delta)$ and for a given policy, regenerative arguments can be used to arrive at expressions for moments of L_i. This knowledge of moments will help us to approximate the objective value in (5.4) by the solution of the distribution free newsboy problem. A detailed account of the distribution free newsboy problem is provided in the literature by Gallego & Moon (1993). To make the discussion self-contained a brief account of the distribution free newsboy problem is given.

Consider the following component terms in (5.4):

$$nb_i := C_{b_i} E[L_i - B_i]^+ + C_{h_i} E[B_i - L_i]^+ \quad \forall\, i \tag{5.6}$$

(5.6) is the steady state average holding cost and back order cost incurred for item i and is equal to total cost incurred in the *newsboy* problem when the demand follows the law of L_i above. Scarf (1958) provided an upper-bound for (5.6) when only the mean and variance of the distribution of the demand L_i, rather than the complete distribution, are known. It is easy to show that

$$nb_i \le \frac{1}{2}(C_{b_i} + C_{h_i})\left[\sqrt{\sigma_{L_i}^2 + (B_i - E[L_i])^2} - (B_i - E[L_i])\right] + C_{h_i}(B_i - E[L_i]) \tag{5.7}$$

where $\sigma_{L_i}^2$ denotes the variance of L_i.

Since (5.7) is convex in $\hat{B}_i := B_i - E[L_i]$, its minimum value can be obtained from the first order conditions. The objective at the minimum value of B_i is given by

$$\min_{B_i} nb_i = \sqrt{C_{b_i} C_{h_i}}\, \sigma_{L_i} \tag{5.8}$$

Hence if an approximation for $\sigma_{L_i}^2$ can be obtained, then (5.8) provides a way to establish relationship between the policy ($\mathbf{B}, \mathbf{T}, \delta$) and the total cost given in (5.4). These are formalized in the following sections.

As mentioned earlier, under ($S-1, S$) replenishment for requests policy, the dynamics of the system can be analyzed using a multi-class $M/G/1$ queue model. Since demands for different items join different queues and server switches for service from one queue to another as specified by $(\mathbf{B}, \mathbf{T}, \delta)$, then it is possible to relate the time elapsed between two successive visits to a given queue with server's vacation. Since a periodic tabular policy ensures stability, vacation periods have finite moments. However it is difficult to arrive at exact expressions for the moments of vacation even in a special case of periodic policies, the cyclic base stock policy. In view of this, the variance of steady state queue length in an $M/G/1$ queue with server vacations is derived and this knowledge is used in deriving approximation to (5.8), and hence to (5.4).

5.5 Determination of production frequencies

The problem of determining production frequencies is analyzed in two phases. Firstly, the variance of numbers of customers is derived in a $M/G/1$ queue with server vacation under steady state conditions. The assumption is that if server goes on vacation at the end of each busy period and after return from a vacation, if the system is empty, then the server goes on a new vacation. Further, assume that the vacation periods are random and form an *i.i.d* sequence.

5.5.1 Variance of number of customers in an M/G/1 queue with server vacation

Consider an M/G/1 queue with Poisson arrival rate λ and *i.i.d* service times.

Lemma 1. Let L be the steady state number of customers in the system, and W the steady state waiting time of a customer in the system. Then,

$$Var(L) = \lambda^2 Var(W) + E[L] \tag{5.9}$$

Proof

Consider the moment generating function of L:

$$G_L(z) = \sum_{n=0}^{\infty} z^n P(L=n) \; = \sum_{n=0}^{\infty} z^n \int_0^{\infty} \frac{e^{-\lambda t}(\lambda t)^n f(t)dt}{n!}$$

where $f(t)$ is the *p.d.f* of the waiting time, W.

$$= \int_0^{\infty} e^{-\lambda t + \lambda z t} f(t)dt$$

$$\Rightarrow G_L(z) = G_W(\lambda - \lambda z)$$

where $G_W(z)$ is the moment generation function of the waiting time. Using this relation, the variance of L can be obtained as:

$$Var(L) = G_L^{(2)}(z)|_{z=1} - (G_L^{(1)}(z)|_{z=1})^2 + G_L^{(1)}(z)|_{z=1}$$

$$\Rightarrow Var(L) = \lambda^2 E[W^2] - \lambda^2 (E[W])^2 + \lambda E[W]$$

Using Little's formula and the definition of variance, $Var(L)$ is obtained as:

$$Var(L) = \lambda^2 Var(W) + E[L]$$

Hence proved. •

Now consider an M/G/1 queue when the server goes on vacations at the end of each busy period. A new arrival to an idle system, rather than going into service immediately, waits for the end of the ongoing vacation period. Also, if the system is empty at the end of a vacation, the server takes a new vacation. Assume the sequence of vacations, $\{V_n\}_{n\geq 1}$ is *i.i.d*. A new arrival into the system has to wait in the queue for the completion of the ongoing service or vacation and then for the service of all the customers ahead of it. Assume that the *i.i.d* vacation sequence $\{V_n\}$ has finite first and second moments $E[V]$ and $E[V^2]$ respectively. Further, let λ denote the Poisson arrival rate, and $\{X_n\}_{n\geq 1}$ denote the *i.i.d* sequence of service times with finite first, second and third moments. The residual time seen by i-th arrival can be either remaining time for completion of customer in service or remaining time in vacation in process when the arrival occurs.

Let $r(\tau)$ be the residual time at time τ. Let $N(t)$ be the number of services completed by time t and $N_v(t)$ the number of vacations completed by time t. At any time t when a service or vacation is just completed, it is easy to see that the following holds:

$$\frac{1}{t}\int_0^t r(\tau)d\tau = \frac{1}{t}\sum_{i=1}^{N(t)} \frac{1}{2} X_i^{\ 2} + \frac{1}{t}\sum_{i=1}^{N_v(t)} \frac{1}{2} V_i^{\ 2}$$

$$= \frac{N(t)}{t} \frac{\sum_{i=1}^{N(t)} \frac{1}{2} X_i^{\ 2}}{N(t)} + \frac{N_v(t)}{t} \frac{\sum_{i=1}^{N_v(t)} \frac{1}{2} V_i^{\ 2}}{N_v(t)} \tag{5.10}$$

Thus it follows that the steady state residual time R has its mean as:

$$E[R] = \frac{\lambda E[X^2]}{2} + \frac{(1-\rho)E[V^2]}{2E[V]} \tag{5.11}$$

Observe that $(1-\rho)$ is the fraction of server's time occupied in vacations. From (5.11), it can be re-interpreted that R has the following distribution

$$R = \begin{cases} X_e & \text{w.p. } \rho \\ V_e & \text{w.p. } (1-\rho) \end{cases}$$

where, X_e and V_e are the equilibrium excess distributions of the service time and the vacation period respectively. Thus,

$$E[R] = \rho E[X_e] + (1-\rho)E[V_e] \tag{5.12}$$

Now, variance of R can be written as

$$Var(R) = \rho E[X_e^2] + (1-\rho)E[V_e^2] - E[R]^2$$

$$= \frac{\rho}{3}\frac{E[X^3]}{E[X]} + \frac{1-\rho}{3}\frac{E[V^3]}{E[V]} - E[R]^2 \tag{5.13}$$

The waiting time of the i^{th} customer in the system can be expressed as:

$$W_i = R_i + \sum_{j=i-N_i}^{i-1} X_j \tag{5.14}$$

where, R_i and N_i are the residual time seen and the number of customers found in queue, respectively, by the i-th customer upon his arrival. Let Q be the steady state number of customers in the queue at a typical arrival epoch. Since occupation distribution upon arrival is typical, Q has the same distribution as the steady state number of customers in queue. Q is used to denote both and can be interpreted appropriately based on its context. It is easy to see that, R_i is independent of the sum appearing in (5.14). Also, since $\{X_j\}$'s are *i.i.d*, the steady state version of (4.14) is rewritten as

$$Var(W) = Var(R) + Var(\sum_{j=1}^{Q+1} X_j) \tag{5.15}$$

where W is the steady state waiting time in the system.

Also,

$$Var(\sum_{j=1}^{Q+1} X_j) = E[Var(\sum_{j=1}^{Q+1} X_j \mid Q)] + Var(E[\sum_{j=1}^{Q+1} X_j \mid Q])$$

$$= Var(X) + E[Q]Var(X) + E[X]^2 Var(Q) \tag{5.16}$$

Note that, if L is the number of customers in the system in the steady state, then $Q = L - 1$ during a service (that is, if a typical arrival observes that the server is busy) and $Q = L$, when the server is on vacation (that is, if a typical arrival notices that the server is on vacation). Thus,

$$Q=\begin{cases} L-1 & \text{w.p. } \rho \\ L & \text{w.p. } (1-\rho) \end{cases}$$

Also note that,

$$E[L]=\frac{\lambda E[R]}{1-\rho}+\rho \tag{5.17}$$

Thus,

$$E[Q]=E[L]-\rho \tag{5.18}$$

$$Var(Q)=\rho E[(L-1)^2]+(1-\rho)E[L^2]-E[Q]^2$$

$$=Var(L)+\rho(1-\rho) \tag{5.19}$$

Using Lemma (5.9) and (5.15), (5.16), (5.19) and (5.18) to obtain:

$$Var(L)=\frac{\lambda^2 Var(X)(E[L]-\rho+1)+\rho^3(1-\rho)+\lambda^2 Var(R)+E[L]}{1-\rho^2} \tag{5.20}$$

where $Var(R)$ and $E[L]$ are as given in (4.13) and (4.17) respectively.

Equation (5.20) is used to derive an approximation for the system wide costs for any given $(\mathbf{B},\mathbf{T},\delta)$.

5.5.2 An approximate mathematical program

Consider a policy ($\mathbf{B},\mathbf{T},\delta$). At time $t=0$, the facility starts production of item T(1) and continues production until the inventory level hits $B_{T(1)}$. Then the facility switches to item $T(2)$, after possibly idling for duration ta_1, incurring a random or non-random setup time, $s_{T(2)}$. The procedure is continued until item $T(M)$ is processed and then the policy is repeated.

For any policy ($\mathbf{B}, \mathbf{T}, \delta$), the expected long run average cost is given by (5.4). As mentioned in Section 5.3, for a given table, optimal base stock levels can be determined from (5.5) provided complete distribution of the shortfall for each item is known. Since such distribution is difficult to arrive at, the distribution free newsboy solution is invoked which requires only the knowledge of moments of shortfall. Assume that variance of shortfall for item i, $Var(L_i)$ is known. Then from (5.8) it follows that the total cost can be approximated by

$$TC = \sum_{i=1}^{n} [\sqrt{C_{b_i} C_{h_i} Var(L_i)} + K_i f_i] \tag{5.21}$$

where f_i is the long run average switching frequency.

Let $m_i, i = 1, 2, ..., N$ be the absolute frequencies with which items appear in the production sequence specified by the table $\mathbf{T}$. Note that $\sum_{i=1}^{N} m_i = M$. Also, note that, from the regenerative arguments, it can be shown that

$$f_i = \frac{m_i}{E[C]} \tag{5.22}$$

Also, under stable conditions, the following holds true:

$$E[C](1-\rho) = \sum_{i=1}^{n} m_i s_i + \sum_{i=1}^{M} \delta_i \tag{5.23}$$

$$\Rightarrow f_i = \frac{m_i(1-\rho)}{\sum_{i=1}^{n} m_i s_i + \sum_{i=1}^{M} \delta_i} \tag{5.24}$$

For, $j = 1, 2, ..., m_i$, let V_i^j be the inter-visit time between the ($j-1$) and j th visit to queue i for service. That is, V_i^j is the time between the end of busy period on the server's ($j-1$)$^{\text{th}}$ visit to the start of j-th visit to item i. Federgruen & Katalan (1996) prove that the steady state inter-visit time between two consecutive visits to i will converge to V_i, which has a mixed distribution of equilibrium excess distribution of individual inter-visit times $V_i^j, j = 1, 2, ..., m_i$.

Observe that,

$$\sum_{j=1}^{m_i} E[V_i(j)] = (1-\rho_i)E[C] \tag{5.25}$$

Using V_i instead of V_i^j in (5.21), to get

$$E[V_i] = \frac{1-\rho_i}{f_i} \tag{5.26}$$

Denoted by

$$g_i := \frac{m_i s_i}{\sum_{i=1}^{n} m_i s_i + \sum_{i=1}^{M} \delta_i} \tag{5.27}$$

If it is assumed that the variance of the vacations are negligible, then (5.21) reduces to the following *approximate* mathematical program:

$$Min \sum_{i=1}^{n} \left[\sqrt{a_i + \frac{b_i s_i}{g_i} + \frac{c_i s_i^2}{g_i^2}} + k_i g_i \right] \tag{5.28}$$

$$\text{subject to} \sum_{i=1}^{n} g_i = 1 \tag{5.29}$$

where,

$$a_i = \frac{\rho_i \lambda_i^3 Var(X_i)}{2(1-\rho_i)} \frac{E[X_i^2]}{E[X_i]} + \lambda_i^2 Var(X_i) + (1-\rho_i)\rho_i^3 + \frac{\lambda_i^2 \rho_i}{3} \frac{E[X_i^3]}{E[X_i]}$$

$$-\frac{\rho_i^2 \lambda_i^2}{4} \left(\frac{E[X_i^2]}{E[X_i]} \right)^2 + \frac{\lambda_i \rho_i}{2(1-\rho_i)} \frac{E[X_i^2]}{E[X_i]} + \rho_i$$

$$b_i = \left[\frac{\lambda_i^3 Var(X_i)}{2} + \frac{\lambda_i}{2} - \frac{\lambda_i^2 \rho_i (1-\rho_i)}{2} \frac{E[X_i^2]}{E[X_i]}\right] \frac{(1-\rho_i)}{(1-\rho)}$$

$$c_i = \left[\frac{\lambda_i^2 (1-\rho_i)}{3} - \frac{\lambda_i^2 (1-\rho_i)^2}{4}\right] \frac{(1-\rho_i)^2}{(1-\rho)^2}$$

$$k_i = \frac{K_i (1-\rho)}{s_i}$$

Now, using the Lagrangean multiplier approach it is possible to solve (5.28). That is, there is need to choose an appropriate λ such that the following hold:

$$\frac{b_i s_i g_i + 2c_i s_i^2}{2g_i^2 \sqrt{a_i g_i^2 + b_i s_i g_i + c_i s_i^2}} - \frac{k_i}{s_i} = \lambda \quad \forall i \tag{5.30}$$

$$\text{and,} \sum_{i=1}^{n} g_i = 1 \tag{5.31}$$

(5.30) is a sixth degree equation and any numerical technique can be used to find a solution.

However, by restricting to the following cases, one can arrive at a simplified program which can be easily solved.

Case 1

Assume that $a_i \ll c_i s_i^2$ and $b_i s_i \ll c_i s_i^2$. Then

$$\frac{c_i s_i^2}{g_i^2 \sqrt{c_i s_i^2}} = \frac{k_i}{s_i} + \lambda$$

$$\Rightarrow g_i = s_i \sqrt{\frac{\sqrt{c_i}}{k_i + \lambda s_i}} \text{, and} \tag{5.32}$$

$$\sum_{i=1}^{n} s_i \sqrt{\frac{\sqrt{c_i}}{k_i + \lambda s_i}} = 1 \tag{5.33}$$

Case 2

Consider the case when $a_i g_i^2 \gg b_i s_i g_i \gg c_i s_i^2$. It follows that

$$\frac{b_i s_i g_i}{g_i^2 \sqrt{a_i g_i}} = \frac{k_i}{s_i} + \lambda$$

$$\Rightarrow g_i = s_i \sqrt{\frac{b_i}{2\sqrt{a_i}(k_i + \lambda s_i)}} \text{, and} \tag{5.34}$$

$$\sum_{i=1}^{n} s_i \sqrt{\frac{b_i}{2\sqrt{a_i}(k_i + \lambda s_i)}} = 1 \tag{5.35}$$

In both the above cases, the problem reduces to choosing an appropriate λ that satisfies (5.33) or (5.35) as appropriate and finding the corresponding g_i 's and thus, the relative frequencies, f_i 's for $i = 1, 2, ..., N$.

5.5.3 Computation of production frequencies

Based on the results presented in the foregoing, the procedure to compute production frequencies is summarized as follows:

1. Compute a_i , b_i , c_i and k_i in (5.28)
2. Check if any of the cases presented in the previous are satisfied.
3. Compute g_i s from (5.32) or (5.34) varying λ such that $\sum_i g_i = 1$.

In the next section, a method to construct an appropriate production sequence for items is provided which conforms to the underlying assumptions in deriving the mathematical program (5.21).

5.5.4 Generation of item sequence for production

This procedure for sequence construction is along the lines of Federgruen & Katalan (1998). For a table size M and the corresponding absolute frequencies of items m_i, the relative positioning of items can be treated as a scheduling problem with M jobs, with m_i as the number of items of type i, $i = 1, 2, ..., N$ and $\sum_{i=1}^{N} m_i = M$. Different heuristics have been proposed for this problem in various related contexts. The Golden ratio heuristic and Dobson's makespan heuristic are some examples and are widely used in the scheduling literature. In the Golden ratio rule, the items are positioned such that the number of entries between two consecutive appearances of an item in the table is equalized. This construction is based on the Fibonacci sequence. The Dobson's makespan rule finds a sequence, which equalizes the inter-visit times between consecutive appearances and is based on the power-of-two method which assumes that the frequencies $m_i, i = 1, 2, ..., N$ can be rounded off to integers which are powers of two. Note that the approximate mathematical program was derived under the assumption that variance in inter-visit time are negligible. In view of this assumption, Dobson's rule is a possible choice for construction of item sequence. However, representation of frequencies in powers of two can be a serious limitation in many cases. To surmount this, a heuristic procedure is suggested which attempts to find a sequence that equalizes the inter-visit times. To this end, start with an initial sequence generated by Golden ratio rule as described below.

Since absolute frequencies can be determined only when the size of the table T is fixed, determine the table size based on the relative frequencies $f_i, i = 1, 2, ..., N$ by finding the smallest integer M such that the maximum error incurred by rounding off the absolute frequencies $m_i = Mf_i$ is within a tolerance limit. Fix up such an M as the table size.

With a given value of M , generate an initial sequence based on the Golden ratio rule. For this, create m_i copies of item $i, i = 1, 2, ..., N$ and assign indices to these jobs from 1 to M . Associate an index $I(k)$ to a job $k, k = 1, 2, ..., M$ as follows:

$$I(k) = k\varphi^{-1} \text{ (modulo 1)} \tag{5.36}$$

where the Fibonacci number, $\varphi^{-1} = \frac{\sqrt{5}-1}{2}$ and position the jobs in the table according to the increasing order of the indices, $I(k)$.

Rearrange the terms in the above sequence such that for all items, the mean inter visit time between any two consecutive visits is the same. To achieve this, observe that if inter-visit times, $V_i^j, j = 1, 2, ..., m_i$ for the item i have identical mean values, then

$$E[V_i] = \frac{(1-\rho_i)E[C]}{m_i} + s_i \tag{5.37}$$

The following recursive procedure for rearrangement of terms in the initial sequence is suggested so that the sequence generated conforms to the approximation.

- Select the first item, say k , in the initial sequence and remove all m_k copies of item k appearing in the sequence retaining the order of the remaining elements of the sequence.

- Now concatenate the remaining sequence into $m_k - 1$ subsequences such that maximum of deviations from the target value (5.2) is minimum.

- Repeat the procedure over all $i = 1, 2, .., N$ until no improvement is observed over N consecutive repetitions.

- Replace the existing entries for item k by the newly obtained sequence if it incurs a lower cost.

The above heuristic can be improved further by incorporating efficient heuristics by concentrating on the sum of absolute deviations of individual inter-visit times of any item from its mean value. In this case, the problem can be formulated as a shortest path problem. However, in the proposed methodology no attempt is made to invoke any such heuristics existing in the literature.

5.6 Experimental study

In order to check the performance, and also the robustness, of the periodic policy derived from the above approximate mathematical program against cyclic policies, extensive experimental study has been conducted by varying all relevant parameters of the model described in the foregoing. In the design of the experimental scenarios the conditions cited in Case 1 and Case 2 in the selection of system parameters have been ignored. In all the scenarios, four queues ($i = 1,\ldots,4$) have been considered, assuming Poisson arrivals and exponential service times. Further, it has been assumed that switching times between any pair of queues are sequence independent and are equal with value 5 time units. Similarly, in all the scenarios switching costs are assumed to be, again, sequence independent with value 800. The overall system utilization, *viz.*, $\rho = \sum_{i=1}^{4} \rho_i = \sum_{i=1}^{4} \frac{\lambda_i}{\mu_i}$ is varied from 0.3 to 0.90, where $\lambda_i, i = 1,\ldots,4$ denotes the arrival rate at i and $rac1\mu_i, i = 1,\ldots,4$ denotes the mean service time at queue i. The values of initial set of input parameters in different scenarios are listed in Table 5-1 below. For the given set of parameters, the tabular policy corresponding to each scenario is found as detailed in the previous section. For Scenario 1, Scenario 2 the table size M , turned out to be 32 whereas for other scenarios the table size was 48. The tabular sequence in each of the scenarios has been determined using the algorithm in Section 5.4. In this performance study, exhaustive cyclic policies have been used for comparisons against tabular policies.

Table 5-1: Input parameters for tabular policy

Scenario	queue	λ_i	μ_i	Holding cost	Backorder cost	Scenario	queue	λ_i	μ_i	Holding cost	Backorder cost
ρ = 0.3	1	1.0	10	150	10	ρ = 0.7	1	1.0	5	150	10
	2	1.0	10	150	100		2	1.0	5	150	100
	3	1.0	20	10	150		3	1.0	5	10	150
	4	1.0	20	150	10		4	1.0	10	150	10
ρ = 0.4	1	1.0	5	150	10	ρ = 0.8	1	1.0	5	150	10
	2	1.0	10	150	100		2	1.0	5	150	100
	3	1.0	20	10	150		3	1.0	5	10	150
	4	1.0	20	150	10		4	1.0	5	150	10
ρ = 0.5	1	1.0	5	150	10	ρ = 0.9	1	1.0	3	150	10
	2	1.0	5	150	100		2	1.0	5	150	100
	3	1.0	20	10	150		3	1.0	5	10	150
	4	1.0	20	150	10		4	1.0	5	150	10
ρ = 0.6	1	1.0	5	150	10						
	2	1.0	5	150	100						
	3	1.0	10	10	150						
	4	1.0	10	150	10						

An exhaustive cyclic policy follows a pre-determined polling order for serving the queue. Each queue once selected is served exhaustively. The tabular policy of each scenario is evaluated against all possible exhaustive cyclic policies of that scenario. In other words, the total cost is evaluated against each possible enumeration of cyclic policies and the best cyclic policy is identified. Further, each scenario is repeated for 5 simulation runs and the total cost for policies are averaged. Later, experiments are repeated by varying the ratio between backorder and holding cost for the queue with the highest utilization.

Table 5-2 below gives details of total cost comparisons averaged over all simulation runs against each scenario. It is interesting to note that in the scenarios corresponding to $\rho = 0.3, 0.4$, the total cost resulting from the best cyclic policy is almost close to that of the tabular policy of the scenario, sometimes outperforming the tabular policy. This can be mainly attributed to the approximation involved in our derivation of tabular policy.

Table 5-2: Performance comparison of tabular and cyclic policies

Scenario	$\frac{C_b}{C_h}$	Cost of Tabular Policy T_p	Cost of Best Cyclic Policy T_c	Scenario	$\frac{C_b}{C_h}$	Cost of Tabular Policy T_p	Cost of Best Cyclic Policy T_c
ρ = 0.3	1	6263	6279	ρ = 0.7	1	57823	62111
	5	3387	3190		5	44525	58124
	20	1690	1511		20	38331	49110
ρ = 0.4	1	8879	9424	ρ = 0.8	1	93167	112,345
	5	4800	4321		5	88183	103,117
	20	2781	2933		20	73456	99,324
ρ = 0.5	1	13721	16324	ρ = 0.9	1	162,348	198,006
	5	9875	12386		5	142,879	173,238
	20	8311	8765		20	139,312	157,437
ρ = 0.6	1	23118	32175				
	5	17424	23516				
	20	16525	18113				

Note that at higher system utilization, the gap between the best cyclic policy and the tabular policy is pronounced. At higher utilization rates, to balance the impact of bias due to holding costs, the ratio of backorder cost to holding cost of the queue(s) was varied with higher values of utilization. Again, the same trend in performance can be seen from the results. These results clearly demonstrate relative effectiveness of tabular policies with respect to cyclic policies.

5.7 Software implementation

Sugar cane is procured by the sugar factories from various farmers in different fields in the region of the sugar factory and it is supposed to arrive in lots at the sugar factory according to pre-determined schedules based on quantity, quality and time. However, the arrival of sugar cane lots often deviates from the pre-determined arrival schedule, causing multiple queues to be formed at the factory gate. Waiting time has an impact on yield, the quality and crusher usage. To address such problems, the crusher has been modeled as a single-server multiple-queues model with server vacation, along with a tabular policy for handling the multiple queues.

This software has been implemented as a stand-alone simulation programme in the "C" language which accepts input parameters described in Table 5-1 and generates the optimal cost for the static tabular policy as shown in Table 5-2.

5.8 Conclusions

In production-inventory systems, static policies are of great value compared against their dynamic counter parts. In this chapter the focus was on periodic tabular policies which may be viewed as generalized version of cyclic policies, and to derive a tabular policy by formulating an approximate mathematical program for total cost minimization over tabular policies. Later, a comparative performance study of the tabular policy with respect to cyclic policies was provided which demonstrated that though cyclic policies offer comparable performance with respect to tabular policies at low utilization rates, the performance gap widens significantly as system utilization tends to increase. The experiments have only been done on the class of exhaustive policies, which are not necessarily optimal from the perspective system wide costs. In such scenarios, it would be valuable to experiment on the class of threshold policies.

In this chapter, the production of multiple standardized items on a single machine with limited capacity and random set-up times was considered under random demand and random production times: a problem that falls under the genre of stochastic economic lot-sizing problems (SELSP). The primary focus of the chapter has been on optimization of total cost, that is, the sum of set-up, holding, and back-logging costs, specifically under local lot-sizing policies—that is, base-stock policy derived based on the inventory level of the product that is currently set up. As a result of such localized policies, one single product, for which high demand arrives for a certain duration, may dominate the machine for a while leading to stock-outs, high costs, and high variability in cycle lengths of other products. Since the problem addressed herein is generally intended to model bottleneck machines in any production environment, it is important to have these lot-sizing decisions depend on global information, that is, on the stock levels of all individual products and on the state of the machine- a complex but practically relevant problem worth addressing.

Another important question of practical relevance is to study impact of process variations on machine performance; a comprehensive sensitivity analysis with respect to input distributions can be carried out to that effect. In fact, in many situations, responsiveness to variations is of more practical relevance than the total operational costs. An important feature of this practical problem that could not be modeled in the proposed model is the perishability nature of the finished product and of the raw material. This feature warrants development of production plans incorporating bounds on cycle lengths and safety-stocks- a theoretically challenging constrained optimization problem. This is an area of future work.

Since sugarcane yield is dependent on the time spent between harvesting of sugarcane to its crushing for subsequent conversion to sugar, the waiting times at the crusher needs to be minimized and the crusher has to be optimally utilized. This chapter proposes a periodic tabular policy for the crusher schedule compared to a cyclic policy.

While the simulation programme for the tabular policy is implemented as a stand-alone programme, it can be integrated into the decision support system to provide the supply chain manager an additional tool for managing the crusher schedule in real-time. It should be possible to implement this simulation model on an Android wireless tablet as mathematical tools become available on such mobile devices. This provides scope for future work in this area.

With this chapter, the mathematical modelling framework for sugar supply chain developed in this thesis has been completed and the Public Distribution System, the next critical component in the sugar supply chain, will be described in the next chapter along with a mobile solution for an improved service delivery mechanism.

5.9 References

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6. SmartPDS, an improved Public Distribution System

6.1 Introduction

In this chapter the focus will be on the Public Distribution System (PDS) which forms the last important link in the sugar supply-chain because it provides the primary interface to the rural consumer. The PDS plays a significant role in the government's poverty alleviation programmes and enables the government to discharge its social responsibilities by providing food grains and essential items to the rural and urban poor at subsidized rates in order to protect them from the vagaries of market forces. Since sugar, a relatively low-cost source of calories, is an important component in the basket of products under the PDS, this study of the sugar supply-chain would not be complete without studying the Public Distribution System itself. The Public Distribution System is a programme where systemic improvements through appropriate technology have the potential to result in significant social impact.

In this chapter, the major problems in the PDS have been highlighted. While the previous chapters have developed mathematical models for optimization of the sugar supply-chain, decision support tools required by the cooperative sector, and optimization of the crusher schedule, the focus of this chapter is on the improvement of citizen-centric PDS services, the last major link in the sugar supply chain, through the use of mobile technologies. The rationale for deploying mobile computing and communications technologies in the PDS is based on the rapid growth in the cellular infrastructure, with increasing coverage in rural areas and decreasing cost of communication (see Section 6.3.1). Thus, mobile technologies can enable a disruptive transformation in existing PDS services by improving systemic efficiency, reducing response times, reducing transaction costs, increasing the foot-print of coverage, and introducing transparency, with the potential to create maximum positive impact.

6.2 The Public Distribution System - a survey of the literature

The Public Distribution System is the oldest and one of the most comprehensive anti-poverty programmes in India in terms of budgetary expenditures provided by the central and state governments (Food Corporation of India, 2003; 2005). The basic principles for the public distribution system in India were laid in 1942 with stabilization of food prices as the primary objective. Since India gained independence in 1947, the Public Distribution System has evolved into a price support-cum-quantity-rationing-cum-subsidy programme. The original objectives of the PDS, which was envisaged as a deliberate tool of social policy by the Government of India, were:

- To provide food-grains and other essential items to vulnerable sections of society at reasonable prices which are normally subsidized
- To provide a moderating influence on the open-market prices of cereals, the distribution of which constitutes a fairly big share of the total marketable surplus
- To ensure equitable distribution of essential commodities so that vulnerable sections of society are not left to fend for themselves in the market

The Food Corporation of India was established in 1965 to oversee grain procurement and distribution. The Targeted Public Distribution System (TPDS) was introduced in 1997 to address certain systemic problems in the existing PDS which had been present in India since inception in 1942. While the earlier PDS provided food items to a large population, including those who were not listed as being below the poverty line, the primary focus of the TPDS shifted to delivering essential food items to the poor who fell below the poverty line in all areas of the country and to keep food subsidies within control, following the failure of the earlier PDS (TPDS, 2005). In the TPDS system, consumers above the poverty line were to be provided essential food items at an economic cost whereas only those identified consumers who fell below the poverty line were supposed to benefit from budgetary food subsidies. Initially, sixty-five million families were identified as falling below the poverty line and were covered by the TPDS. The state governments were tasked with the responsibility of implementing the policies and processes involved in the public distribution system. Their responsibility was to formulate and implement foolproof arrangements for identification of poor, delivery of food-grains to Fair Price Shops (FPSs) and the distribution of food-grains to the end beneficiaries in a transparent and accountable manner from the fair price shops under their supervision (Asthana, 2000).

In 2008, the Public Distribution System comprised a nation-wide network of around 489,000 fair-price shops (FPS), perhaps the largest retail network of its kind in the world that involves complex agricultural supply chains (Planning Commission, 2008a). Thus the PDS, and now the TPDS, plays a significant role in the Indian government's poverty alleviation programmes and enables the government to discharge its social development obligations by providing food grains and other essential food items to the rural and urban poor at subsidized rates. Timely and efficient procurement of food grains and their distribution to the poor requires the cooperation of state governments. For example, the identification of the poor to be targeted and management of the fair-price shops is done by the state governments. The TPDS involves monitoring of food-grain production and prices, procurement of various food-grains, maintenance and storage of food stocks, movement and delivery through different distribution channels, and providing incentives to farmers through minimum support price mechanisms. Certain locally specified food items are also meant to be available to citizens who fall below a defined poverty line so they do not have to fend for themselves by being entirely dependent on market forces. The importance of the Public Distribution System in ensuring equitable distribution of food grains in a timely manner in the remote corners of a large landmass imposes high demands on the in-bound and out-bound distribution supply chain infrastructure and governance issues relating to the maintenance of such infrastructure.

Various studies, including studies conducted by the Food Corporation of India which manages the Targeted Public Distribution System, have pointed out that inefficiencies, leakages and lack of governance in the TPDS prevent it from meeting its primary objective of providing food grains at subsidized prices to the targeted rural and urban poor (Ramaswami and Balakrishnan, 2002). Certain states like Kerala have earlier demonstrated a well run and effective public distribution system but after the introduction of TPDS, evaluations of the programme in that state have shown a steady decline in effectiveness which is attributable to large-scale errors in targeting, corruption and systemic failures that have resulted in large sections of the poor and marginalized people from being excluded from the system (Nair, 2011).

While India has made tremendous economic progress in the last fifteen years since economic liberalization was kicked off in the early 1990's, social development indicators portray a picture that social sector development has not kept pace with economic development. Social development indicators such as primary education, literacy, development of human resources, consumption of fuel and power, availability of public transport, lack of access to timely and cost-effective government services, infant mortality, poor woman's and child health etc., point to inequitable growth due to poor governance in many areas that directly affect the common citizen (Tarozzi, 2005; Planning Commission, 2008, 2008a, 2008b). There is an evident disconnect between the needs of the various stakeholders, ranging from citizens (primarily poor people) to suppliers (primarily poor farmers) to the government, all amidst a complex web of external dependencies on the monsoon, the annual budget and political constituencies. Lack of timely and relevant information from the field has led to the formulation of inefficient and ineffective food security policies and non-remunerative pricing for producers and consumers. As a result, the poor consumer as well as the poor farmer suffers and large parts of the population suffer from food insecurity despite tremendous progress in agricultural production.

Different aspects of the public distribution have been studied and urban bias was one such aspect. An early study claimed that there was no serious evidence of an urban bias in the public distribution system (Ahluwalia, 1993) but this was subsequently disputed in another study which analyzed the same data using different measures and concluded there was strong evidence of an urban bias (Howes and Jha, 1994). Another study has cast doubts on whether the public distribution system has adequately addressed food security since even in states like Andhra Pradesh where the PDS has been considered to be well run, there has not been any significant impact on improving child nutrition (Tarozzi, 2005). Studies in other countries like Bangladesh with large public distribution systems indicate that governments have tried to counter price increases due to middle-men cornering subsidized commodities, through alternate strategies such as market-based price support to encourage farmers to store grain and for gradual release through the system (Khan and Jamal, 1997). To achieve food security for the large population of rural and urban poor, it is considered important to have a targeted public distribution system that functions properly despite its large scale (Asthana, 2000).

The Food Corporation of India (FCI), a Government of India public-sector entity which was tasked to manage the Public Distribution System, has itself acknowledged the systemic weaknesses leading to losses in transit and storage, and the need for vigilance "in sensitive areas which are prone to corruption" in one of its annual reports (Food Corporation of India, 2005). Internal assessments of the Public Distribution System conducted by FCI (Food Corporation of India, 2003; Food Corporation of India, 2005) indicate that the PDS has not been particularly efficient in meeting the stated objectives for the following reasons:

- Inefficient procurement, storage, and delivery mechanisms
    - Often result in the government warehouses overflowing with food-grains (wheat and rice), of which a significant proportion of stocks is believed to be rotten and generally unfit for human consumption

- The cost of holding a huge inventory of food- grain is massive

- Procurement and handling costs in the PDS are generally twice as high compared to private traders whereas the quality of food-grains procured and supplied is generally of lower quality and substandard
- Food-grains are often lost in transit between warehouses in the supply-chain through systemic leakage, thefts and corruption
- The salaries and perks of the PDS workers consume a significant portion of the PDS budget
- The productivity and performance level of PDS workers is amongst the lowest in the country

A three-phase programme called “Integrated Information System for Food-grains Management (IISFM) Project” was launched in 2003-04 under the 10th Five-year Plan. However, this programme appears to be entirely bureaucracy-oriented and not citizen-centric as it should be, even though there are recommended norms for e-government readiness indices accepted by all countries (United Nations, 2004; 2005; 2008). There does not seem to be any service offered for the common citizen on this web-site. Even though tentative steps have been taken by the Food Corporation of India to bring IT into the distribution chain through the IIFSM Project which could provide a quick and dynamic feedback system to potentially even out the imbalances in the system to improve efficiency, the public distribution system remains largely divorced from any technological interventions (Food Corporation of India, 2003; 2005).

There is recognition in official circles that these systemic problems need to be corrected through a more transparent and efficient PDS and that technology intervention can provide adequate checks and balances to reduce leakage due to corruption (Planning Commission, 2005). As additional evidence of this recognition of systemic problems, the Planning Commission's evaluation report (Planning Commission, 2005) on the targeted public distribution system highlighted the following major problems:

- The Government of India spends Rs. 3.65 to transfer a benefit of Rs. 1 to the poor, due to inefficiencies in the TPDS
- 36% of wheat and 31% of rice are diverted from the system to the open market
- Implementation of the TPDS is plagued by large-scale errors of inclusion and exclusion amongst the targeted poor
- The economic costs of grain are higher than the market price, resulting in an inefficient system for the transfer of benefits to the poor
- Only about 23% of the fair price shops are economically viable
- The delivery system needs to be made more efficient and transaction costs need to be lowered through rationalized cost structures, to improve the benefits

One of the conclusions that can be drawn from this list of problems is that transaction cost, or the cost incurred in providing the TPDS service of transferring a benefit to the targeted beneficiary is a candidate for technology intervention. Another conclusion that may be drawn is that the large-scale errors of inclusion and exclusion, probably attributable to a lack of verifiable identity management in the system, could also be addressed through the appropriate technology interventions.

Several frameworks have been proposed in the literature on e-Governance initiatives, using different technologies for different aspects of the e-Governance delivery system. One of the key requirements of an effective public distribution system is the management of identities within the system since the research already shows large scale errors in inclusion and exclusion of people within the targeted population. How does the PDS system ensure that members of the targeted population can be appropriately identified so that their entitlements reach them and are not diverted to others who are not entitled to those benefits?

The management of digital identities is of critical importance to the success of the SmartPDS system proposed in this thesis since the objective is to move from a paper-based ration-card approach followed in the existing PDS/TPDS, to an electronic voucher based system for the transfer of benefits and entitlements to the targeted citizens.

Relatively low-cost technologies like smart-cards for maintaining consumer identity in a digital form have been used in a variety of applications since smart-card technology allows the implementation of secured and authenticated access to private identity and consumer data. Smart-card based digital identity management has been used in Italy for public administration as well as in private sector applications (Corradini, Paganelli et al., 2006; Corradini, Paganelli et al., 2007). The management of digital identities is also important in the context of many other e-government services, especially for web-based services (Grandi, Mandreoli et al., 2004; Hoffmann & Stotz, 2005; Leenes, Schallabock et al., 2007). Various identity management techniques have already been applied successfully in the context of health-care services (Coyle, 1999; Leenes, Schallabock et al., 2007; McClanahan, 2008). Social networking, an increasingly popular mechanism for delivery of services in the private sector, also requires reliable mechanisms for the management of digital identities (Gover, 2005; Damiani, di Vimercati et al., 2003; Damiani, di Vimercati et al., 2003; Lahlou, 2008).

The governance of existing public distribution structures remains a topic of study. Much of the literature on the Public Distribution System indicates there are many problems due to poor governance, corruption and leakages resulting in unmet policy objectives. A conceptual framework for e-governance consisting of knowledge aggregation, process constructs, content constructs and delivery methods with different forms of connectivity and modes of access was proposed for an improved public distribution system (Sundar & Garg, 2002; Garg & Sundar, 2011). In this abstraction, process constructs represented different government departments and content constructs represented the portals that advertise these services. The knowledge aggregation abstraction represented the department-specific data warehouse and personalization of services occurred through smart-cards though other forms of identity personalization could be used (Garg & Sundar, 2011).

From a review of the above literature on e-Governance systems and the public distribution system, there appears a clear gap in which frameworks for improvements in service delivery and governance within the PDS may be considered. The role that mobile computing and communication technologies can potentially play in improving service delivery has not been sufficiently studied. This thesis presents a scheme that can help address issues of governance through the closely monitored delivery of benefits.

However, technology intervention is not enough to streamline a large and complex system like the PDS. There is sufficient evidence in the literature that the application of information technology to improving productivity cannot be assumed and that increased productivity is not always assured. This “Solow paradox” or the "information technology paradox" has been studied by several researchers in the context of governance initiatives to improve services through the application of technology (Crafts, 2002; Triplett, 1999; Brynjolfsson, 1993; Sandulli, Fernandez-Menendez et al., 2008). This paradox postulates that the application of information technology does not necessarily result in productivity gains unless other attributes such as change in mindsets are also addressed simultaneously. The information technology paradox in the context of improving governance has been discussed in Chapter 2. For any significant improvements to occur in large-scale systems like the PDS, any technology intervention must also incorporate the issues of governance within its implementation framework. In this thesis, this aspect is addressed through the monitoring of the transfer of benefits from the retail service provider to the consumer under the supervision of the SmartPDS server through a cashless transfer mechanism of electronic vouchers.

Another area of concern is the urban-rural divide. As evidence of this, the information technology revolution in India also seems to be an urban-centric phenomenon which increases the friction already prevalent in the rural-urban divide and the socio-economic divide through the addition of a deeper “digital divide". This imbalance occurs primarily when one section of society has relatively easy access to information compared to other sections of society, resulting in loss of competitiveness and access for the affected sections of society. As the Indian economy transforms into a knowledge economy, the digital or information divide will widen even further unless the technology and software tools are universally accessible in the daily lives of the people. So interventions to improve a system must be based on technologies and applications that are appropriate and easily adopted, without requiring a barrier to be scaled. The typical IT-enabled services model does not go far enough in being able to reduce transaction cost and increasing operational efficiency. Various reasons can be attributed to this failure of the traditional IT-enabled services model:

- Lack of applications in local languages creates a “digital divide” since villagers with relatively lower levels of English language literacy may not be able to use these services easily
- Lack of appropriate and meaningful applications that service community needs
    - For example, information on cropping patterns, irrigation techniques, soil conditions, weather reports, markets, etc for the benefit of farmers
- Lack of distributed access to services
    - Farmers spend most of the time in remote fields during the working day where services should be available, whereas that is generally not the case

- High transaction costs for the delivery of government services

In this chapter SmartPDS, a framework of an improved public distribution system, is presented. SmartPDS has been developed to leverage the increasingly sophisticated cellular communications infrastructure, the availability of mobile devices at progressively reducing cost and increasing functionality, to provide essential food security services at the doorstep of the citizen. The SmartPDS system is designed to be citizen-centric rather than bureaucracy-centric and tries to address some of the concerns raised by the information technology paradox, by placing governance at the core of the framework and enabling service delivery at the doorstep of the citizen. Since the SmartPDS leverages the cellular infrastructure, the next section on the architecture of SmartPDS also provides a rationale for the use of cellular telephony in the SmartPDS system. The growth of cellular communications and its rapid adoption in rural areas will provide the enabling infrastructure that is required for leveraging cellular telephony for other data-centric applications that have the potential to create large social impact.

6.3 Architecture of SmartPDS system

In this section of the thesis a solution called "**SmartPDS**" that uses mobile phones for improving service delivery in the PDS is presented. SmartPDS uses a workflow management system to orchestrate the interactions between the various stakeholders in the system to enable the PDS system in reaching out to remote rural communities by deploying the most appropriate mobile technologies and leveraging an expanding cellular communication infrastructure. Existing retail outlets or fair-price shops (FPS) would use mobile technologies to interface with consumers and the PDS. All interactions would be through electronic forms-based applications, and the objective is to deliver information about essential food items to remote rural communities in near real-time conditions. Governance would also be improved through tracking of information in near real-time across the entire PDS supply chain, ensuring that entitlements and other services are properly delivered to the targeted individuals. This has the potential to create significant social impact since low-cost mobile technology is proposed without adding any significant cost to an already existing cellular communications infrastructure.

The SmartPDS system has been developed as a mobile solution in which various stake-holders such as consumers, service providers at the retail outlets, administrative officials and others can access the public distribution system on a range of mobile devices such as low-cost Java-enabled cell-phones, smart-phones, tablets or even through the web. SmartPDS uses electronic forms for the primary interface between the consumer and the PDS and the only requirement is that a forms interpreter should be available on the different, pre-existing mobile devices that might be used in the system so that users are not forced to upgrade their existing mobile-phones. The core components of SmartPDS are three major applications that interchange data through XForms:

- the SmartPDS Consumer who uses mForms, a mobile client application that interprets XForms metadata to enable electronic forms to be deployed on mobile devices such as low-cost cell-phones or smart-phones
- the SmartPDS Retail Outlet or service provider who uses a client application (SmartRetail), running on a smart-phone or wireless tablet, to implement the business logic for the retail services provided at fair-price shops within the PDS network
- the SmartPDS Server, which is a back-end server incorporating a set of platform services for the forms infrastructure including a database-engine for persistent storage of data and forms, and a workflow engine that implements the business logic for servicing consumer requests, authentication of identity, and management of all transactions as per the entitlement norms.

Figure 6-1 presents a diagrammatic representation of the top-level interactions that occur between the various entities within SmartPDS.

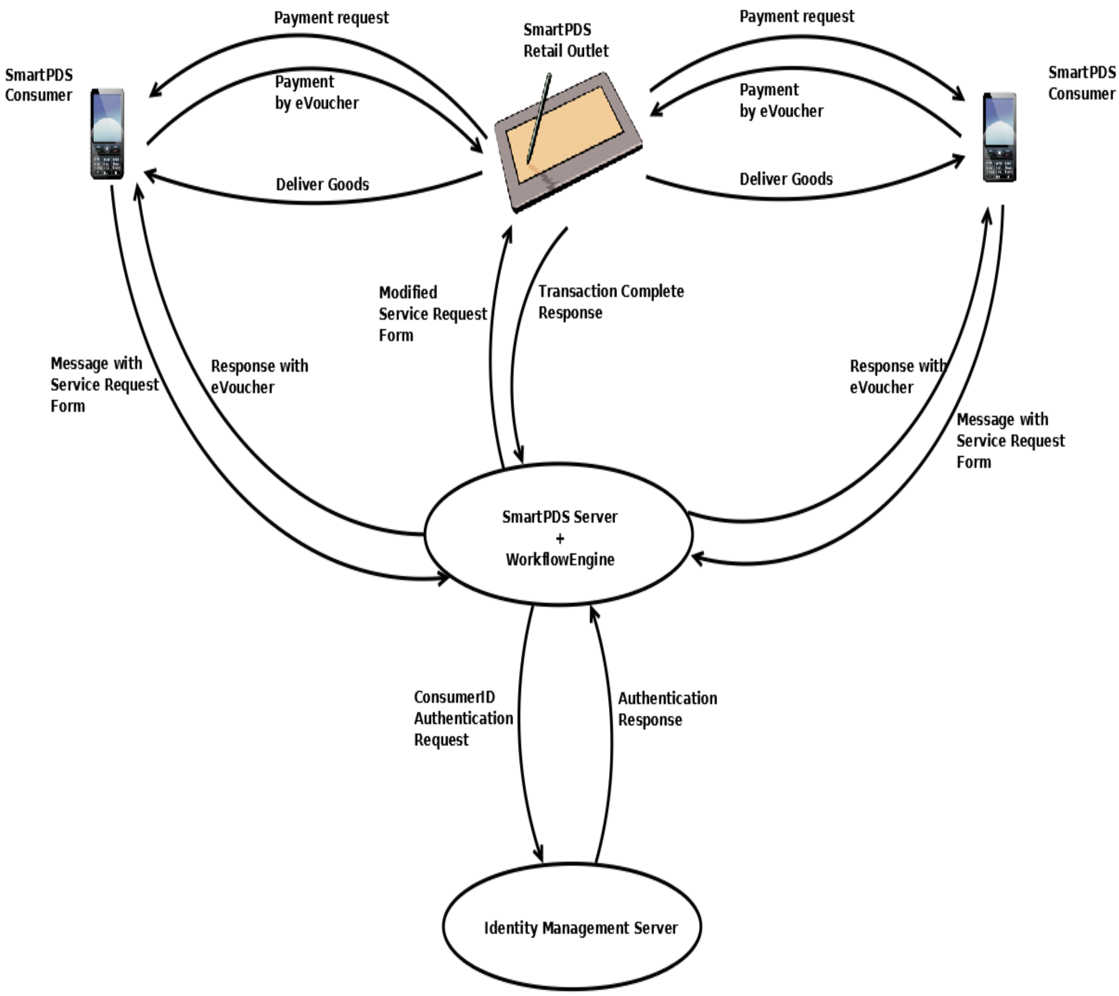


Figure 6-1: High-level interactions between entities in the SmartPDS System

To highlight the fact that different mobile devices can be used within the system, consumers are shown with low-cost cell-phones whereas the retail service provider has been shown as a user of a wireless tablet, which could also be a smart-phone or even a low-cost cell-phone. The mForms client application is used by consumers to access services within the public distribution system. The SmartRetail client application is used by service providers at the fair-price shops to service requests from rural and urban consumers who are registered with the targeted PDS and the SmartPDS server mediates and manages all interactions between the consumers and retailers to ensure delivery of essential food items to the consumers, based on their entitlements. The above figure shows the flow of xml/XForms data between the various entities in the SmartPDS framework. Each of the user entities (the targeted consumers, the service providers at the retail outlets and the back-end server) interact with the SmartPDS system through a set of pre-defined forms and a set of pre-defined workflows to manage these interactions. The SmartPDS system uses several key technologies such as cellular connectivity, eVouchers and electronic forms which are described here.

6.3.1 Rationale for a mobile-phone based solution

The cellular communications infrastructure is at the core of the SmartPDS framework presented in this chapter and potentially for other m-governance applications, because it can enable the real-time exchange of data between mobile devices in the field and the application servers located at district headquarters. For example, identity verification requires access to national identity databases and for the citizen to expect responsive service the communications infrastructure must be able to allow such authentication transactions to complete within a reasonable time. The annual reports of the Telecom Regulatory Authority of India (TRAI) provide insight into the growth of the cellular infrastructure in the last decade and establish a clear case for delivery of services through the cellular infrastructure. These annual reports present the evolution of cellular telephony through a period of rapid transition from a high-cost telecom regime to one of progressively lowering costs and increasing coverage and functionality (TRAI, 2006; 2007; 2008; 2009; 2010a; 2011).

Table 6-1 shows the data for the growth of telephony infrastructure, in particular cellular telephony, in India during the four-year period from 2007-08 to 2010-11 (TRAI, 2007; 2008; 2009; 2010a; 2011).

Table 6-1: Growth of Telephony in India

	(Financial Yr from April 1 to March 31)			
	2007-08	**2008-09**	**2009-10**	**2010-11**
Wire-line Subscribers (in millions)	39.42	37.96	36.96	34.73
Wireless Subscribers (in millions)	261.07	391.76	584.32	811.59
Broadband Subscribers (in millions)		6.22	8.77	11.89
Subscribers added per month (in millions)	8	10	15	18.9
Rural Tele-density	9.2%	15.2%	24.29%	33.79%
Overall Tele-density	26.22%	36.98%	52.74%	70.89%

Source: (TRAI, 2007; 2008; 2009; 2010a; 2011)

While the wire-line subscriber base has declined steadily every year during this period, the growth of wireless subscribers has been explosive. The overall tele-density has increased from 26.22% to 70.89% with rural tele-density having increased from 9.2% to 33.79% and it has now overtaken the rate of growth of urban tele-density. The growth rate in rural areas was 40.64% compared to 34.11% in urban areas. This trend is likely to continue for some time till rural tele-density attains a steady level. This rate of growth of cellular telephony, coupled with the increased coverage in rural areas is of significant value in terms of the last mile connectivity issues. Further, since cellular communication uses digital techniques the same infrastructure can be used for simultaneous voice and data applications. These reasons provide sufficient justification for developing a mobile solution in which the cell-phone is the primary access device for a variety of applications, specifically in the social sectors like the public distribution system where any productivity gains have the potential to create a positive social impact.

Even if rural tele-density lags urban tele-density and pricing inhibits personal ownership of cell phones, the increasing wireless foot-print that now covers large swathes of rural India makes it possible to reach out to rural citizens with e-government services through wireless-enabled mobile devices. Where cell-phone ownership may be an area of concern, sharing of mobile devices or access to services through kiosks may still be feasible if meaningful government services are available to the consumers. Since the cellular communications infrastructure can also be used for data transfer between wireless-enabled mobile devices in remote field-sites and distributed servers located at regional headquarters, business and e-governance processes can be executed in real-time. It is also time to shift the paradigm from e-Governance to m-Governance, through the delivery of essential services at the doorstep of the citizen. Since the cell-phone is becoming a ubiquitous tool, delivery of services through the cell-phone can offer the benefits of increased coverage of the target population and real-time service delivery at reduced transaction costs.

Cellular telephony has already touched the lives of over 810 million people in India, making it the second largest market after China ever since India crossed the 300 million subscriber level in 2006-07. The e-governance infrastructure must now leverage this cellular infrastructure which provides "last mile" connectivity by offering data-oriented services that the citizens need. The Public Distribution System is one such essential government service that awaits this transformation through a “disruptive” evolution into a transparent, efficient and cost-effective service to those living at the margins.

6.4 Key technologies used in the SmartPDS System

The SmartPDS system presented in this chapter uses several key technologies to enable the mobile phone to function as an access device. These key technologies used in SmartPDS are:

- XForms technology for electronic forms
- OpenXdata platform
- Consumer Identity Management, for better targeting of the consumers
- An electronic voucher (eVoucher)

These technologies are described below.

6.4.1 Role of XForms technology in SmartPDS

Most government services are initiated when a form is filled up to make a specific request. In a manual system consumers convey their requests through paper forms. The data on the paper form is then transcribed into a computer application, a manual process which is inherently prone to errors. Hence, even with manual systems, forms may be considered to be the most basic method of input for the initiation of any service. Electronic forms have the same role when considering online applications. However, electronic forms have traditionally been used to enable a user to interact with an application on the web because the growth of the Internet has preceded the growth of cellular telephony. However, that could now change as it is evident that cellular penetration has already outstripped broadband penetration. Even access to the Internet will change when cellular communication moves to 3G and 4G levels. Till now, mobile applications that required form input have been designed with customised input mechanisms. On the other hand, open standards now exist for the design and implementation of electronic forms that could be rendered on the web or on a mobile device in a reasonably platform- and device-independent manner. Thus, it is now feasible to develop mobile applications that can use electronic forms on the mobile device for the collection of input data.

Electronic forms, which are used for all interaction between different user entities in SmartPDS, are based on XForms technology which has already been described in Chapter 4 (see Section 4.3.2) since it is used in DECOSS, the decision support system for optimal supplier selection.

The SmartPDS consumer uses the mForms client which runs on a Java-enabled cell-phone and is simple to use, whereas the retail service provider may use a wireless tablet or an Android smart-phone with a browser-based client.

The SmartPDS system has used the capabilities provided by XForms technology extensively in the development of the user interfaces for the various entities in the system.

6.4.2 The OpenXdata platform

Based on the explosive growth rate of wireless telephony and increasing rural tele-density, it is reasonable to assume that the last-mile access to e-Governance services will increasingly be provided on the wireless telephony infrastructure. The low-cost cell-phone is now the ubiquitous mobile computing and communication device. This requires a paradigm shift in migrating from a mind-set of e-Governance to that of m-Governance. Civic services can now be provided at the citizen's door-step if the electronic government delivery architecture is enhanced to incorporate mobile communications. The OpenXdata architecture, an open-source project with which the author has been associated since its inception, can play that enabling role (OpenXdata, 2011).

The OpenXdata platform is a community developed end-to-end set of forms design and data capture tools that enable a service provider to design electronic forms, make them available on the website of the service provider for access to users through various client interfaces. It incorporates a web-based Forms Designer, a web-based dashboard for system administration, report generators, mathematical analysis tools, a persistent database engine and a variety of mobile client front-ends for rendering forms on different mobile devices. Forms are designed using XForms technology described earlier. Thus, the forms designer facilitates the design of virtually any type of forms to be rendered on mobile devices and as well on the web. The forms designer also designs the database tables automatically, for holding the data collected through forms. This provides an application developer the flexibility to design forms for any application that requires data collection, include validation logic to minimize error in input, complex skip-logic that enables the designer to change the flow of control in the data collection process depending on the value of data received in certain fields, and perform a range of simple calculations on the client device itself.

Interaction with civic officials often requires filling up various paper forms. If forms were filled out electronically, it would make the process smoother, more accurate and transparent. Further, using mobile phones to fill forms would enable the vast population of cell-phone users to contact civic officials remotely and reduce the need to specifically visit government offices for grievance redressal since requests would be aggregated at the community portal and then distributed to relevant civic officials based on content within the electronic forms. Email and SMS alerts would enable users to track the status of their requests. This electronic forms submission architecture would also help civic officials remain engaged with citizens under their jurisdiction.

A community portal and mobile client application based on the OpenXdata platform architecture, and extended for the needs of SmartPDS, is proposed here as a key government-citizen interface tool to enable citizens to register requests and complaints for various civic services via the cell-phone. The task of the portal is to aggregate service requests arriving from thousands of cell-phone users and to pass them on to appropriate civic service providers for further action. A web-enabled dashboard can enable citizens to track the status of their complaints or requests either through email or SMS alerts.

The combination of the mobile client application and community portal has the potential to empower citizens to connect with the civic authorities and demand service. At the community portal, incorporating the OpenXdata Server and tools will enable the service providers to design and publish electronic forms for data collection and for the maintenance of data uploaded from mobile devices. The mobile client application will render these electronic forms on the cell-phone and collect data on complaints and requests for service. A downloadable mobile-client OpenXdata application provides access to context-specific service requests through electronic forms. Electronic forms may be filled out on cell-phones by the users themselves and the client application will then send the data through the data channel to a government services portal for further action by the civic authorities. This concept of providing civic services at the door-step of the citizens through cellular telephony is a paradigm shift from e-government to m-government.

The innovative use of cell-phones for filling out complex electronic forms, rather than using the more common pre-formatted SMS schemes followed by most providers, enables a whole range of complex services to be accessed by citizens. Civic officials can use the OpenXdata tools to design different service offerings and develop highly responsive complaint registration systems to provide better accountability, without having to factor in the constraints posed by cell-phones since the mobile client is capable of rendering electronic forms designed through OpenXdata interface.

The architecture of OpenXdata can be used as a platform for seamless integration of e-governance applications with mobile technology due to the flexibility and device independence offered by XForms. So far e-governance applications have been constrained due to the requirement for internet access for web-based applications, but mobile technology can remove that constraint.

In the SmartPDS system, the OpenXdata platform has been extended through workflows and the core set of forms based services essential to the requirements of SmartPDS.

6.4.3 Consumer identity management of retail consumers

Consumer identity is an important component in the process of food distribution in the targeted Public Distribution System since there is need to reduce the errors in inclusion and exclusion of consumers from the system. The system must properly identify the target beneficiaries to provide them the services and entitlements in a transparent manner and prevent the use of fake identities to deter non-beneficiaries from manipulating the system. Duplication of identities and masquerading often occur at this stage, leaving the real poor uninformed of their rights and robbed of essential goods and services. This problem was also highlighted in the internal assessments of the Food Corporation of India (Food Corporation of India, 2003).

State governments in India have traditionally used various forms of paper-based ration cards to help in this identification process. Ration cards are assigned on a per-household basis and define whether the card holder is “above poverty line" (APL) or “below poverty line" (BPL) since each categorization has its own set of entitlements. BPL card holders deserve special handling as they are the poorest of the poor in our society and the TPDS was designed to address those consumers. Unfortunately, paper based ration cards have not proven to be very effective as various socio-economic studies have pointed out that the benefits of the TPDS and PDS fail to reach the intended beneficiaries due to duplication of cards, inadequate authentication of identity and other systemic problems (TPDS, 2005). Hence it is absolutely critical that the process of consumer identity management be as efficient, robust, non-replicable, transparent and auditable as possible.

Relatively low-cost technology like smart-cards for maintaining consumer identity in a digital form have been proposed in the literature, as smart-card technology allows the implementation of secured and authenticated access to private identity and consumer data which can be used in a variety of applications. Smart-card based digital identity management has been described in various e-Governance applications in the public and private sectors (Corradini, Paganelli et al., 2006; Corradini, Paganelli et al., 2007). The management of digital identities in the context of web-based e-government services has been extensively studied (Grandi, Mandreoli et al., 2004; Hoffmann & Stotz, 2005; Leenes, Schallabock et al., 2007). Several health-care systems have been implemented with support for digital identities (Coyle, 1999; Leenes, Schallabock et al., 2007; McClanahan, 2008). Social networking also requires a reliable mechanism for management of digital identities (Gover, 2005; Damiani, di Vimercati et al., 2003; Damiani, di Vimercati et al., 2003; Lahlou, 2008).

In the context of a Public Distribution System where targeting of consumers is a considerable problem, it is essential to provide an efficient and low-cost identity management at the citizen interface level in rural communities. While a smart-card based digital identity system and smart-card enabled mobile devices may well be key components of the SmartPDS framework, the cost implications of using such solutions need to be recognized. Hence, identity management in the SmartPDS framework is not primarily based on smart-cards but on low-cost 2D-barcoded and laminated cards that carry basic identity information of the consumer and authentication of credentials is done over the communications channel which is already available. Whether 2D-barcoded cards or smart-cards or USB tokens are to be used will largely be a matter of preference and costs to be decided by user agencies. As the cost of cellular services and products comes down, the cell-phone may even replace smart-cards for authentication and identity management purposes since it could hold a bar-coded image and other credential information within the mobile device.

When discussing identity management in the PDS, it is relevant to discuss the role of India's Unique Identification project (UID). The Unique Identification Authority of India (UIDAI) was created in 2009 by the Government of India under the direct supervision of the Planning Commission with a charter to develop and implement the necessary institutional, technical and legal infrastructure to issue permanent, unique identity numbers to Indian residents in a cost-effective manner. According to an initial working paper (UIDAI, 2009), the goal of the UID scheme was to enroll all citizens in the country within 6 years and the initial objective was to make the registration of citizens voluntary. According to current figures released by UIDAI, over 130 million people have already been enrolled in the scheme till February 2012 (UIDAI, 2012).

The unique identity number, called Aadhaar, comprises a 12-digit unique number which is to be issued to all residents who will be registered through a rigorous process of enrolment in which duplication and fake identities will be cleaned out. The Aadhaar number is a random number which contains no particular intelligent coding, designed with the intention of preventing any external entity from making an inference and determining the physical identity of the individual who has been assigned that number. This random numbering makes it quite different from other major identity numbering schemes that have been used in other countries for social security requirements.

As part of the registration process for Aadhaar, the basic demographic details and biometric information of each citizen, such as photograph, fingerprints and iris scan are captured and stored in a centralized database. The details of the data fields and verification procedures are available to user agencies to enable these agencies to integrate the Aadhaar scheme into their applications. Aadhaar is expected to provide cost-effective online service for easy verification of identity. Over a period of time it is expected that all service providers will seamlessly integrate their applications and services with the Aadhaar scheme for identity verification and management. Aadhaar will provide online authentication services to user agencies whereby these agencies can request a comparison of a resident's biometric parameters with records in the online database.

Individual privacy and confidentiality of information are important for the success of any government identity management scheme. The government identity management system that collects individual data has to maintain and protect the confidentiality of each individual's personal identifying information. The design of the Aadhaar addresses this issue by using a random number which ensures that there is no in-built pattern or intelligence in the number itself to characterize a person or to extract any inferential or profiling information about the person holding that random number. This is quite a unique approach since most other countries that have a citizen identity number have invariably used numbers which have identifying patterns inherent in the coding schemes. The Aadhaar scheme, in its ability to prevent profiling or tracking, is already proving popular though various citizen groups are concerned about its ability to maintain individual privacy and the government's ability to prevent willful or accidental misuse of such data for tracking and profiling or for linkage of sensitive data to any specific individuals. Hence, the random number generated by Aadhaar scheme will go a long way in addressing such privacy concerns since there is no specific inferential intelligence built into the random number itself. In the case of the SmartPDS system, authentication is left as an external web service which can be integrated into SmartPDS when the Aadhaar scheme stabilizes.

6.4.4 An electronic voucher (eVoucher)

One of the major gaps identified in this thesis is the difficulty in implementing a transparent system of cash based entitlements that can be delivered effectively to the targeted poor in the existing PDS. Anecdotal evidence and the literature suggest that either cash entitlements do not reach the end beneficiary or they are often abused by the men in the family, resulting in unmet social objectives. For example, some of the problems that have been identified in traditional paper-based food stamps or food coupons in many countries are high administrative costs, abuse of food stamps and diversion of benefits through an underground economy in which food stamps are transacted for other goods and services (Harris, 1997). A pilot project for electronic benefits transfers through banking channels was implemented in Maryland (USA) and an empirical study designed to obtain feedback on this project indicated that the various stake-holders were largely satisfied with electronic benefits transfers compared to the paper-based system of food stamps (Harris, 1997).

Since the SmartPDS system is targeted towards the poor with relatively negligible access to modern banking services like mobile banking, an electronic voucher has been developed to replicate the functionality of food coupons or other forms of entitlements. The eVoucher system of electronic benefits transfer in the SmartPDS is an abstraction that implements cash-less transactions in the targeted public distribution system. It uses electronic forms and mobile devices for a seamless payment mechanism that is essential to the success of SmartPDS itself.

An eVoucher is an electronic record incorporating a unique identification number, a consumer ID, and a field that defines the value of the eVoucher in monetary terms. Since the eVoucher contains a consumer ID, it can only be assigned to a specific consumer or family, unlike food-stamps which are freely transferrable and are often ineffective in controlling the exclusion of people from the targeted group. The value embedded in the eVoucher represents the notional cash value of this entitlement. In an electronic form the voucher can be transferred between various systems and then destroyed when its value drops to zero. Hence an eVoucher has a finite life that starts when a cash entitlement or allocation is issued to a consumer and ends when the stored value is exhausted after multiple purchases have been made by the consumer in the PDS chain. A new number is then generated in the next cycle of disbursement of entitlements.

The basic premise behind the eVoucher is that certain cash entitlements are supposed to be provided to the targeted poor in rural and urban areas at some periodic intervals based on social and food security policies laid down by the government from time to time. Physical cash is known to be expropriated before it reaches the ultimate beneficiary and the normal banking channels are not easily available to this section of the population due to inadequate financial inclusion efforts. Within the confines of the Public Distribution System which provides essential items of food security to the targeted poor, it is feasible to define a new approach that replaces the periodical disbursal of cash entitlements from physical cash transactions to their electronic equivalents which can only be used at the retail outlets within the PDS network.

Of course, this may appear to place limits on the social acceptance of eVouchers due to their limited applicability within the public distribution system but that is not the case. Any retail service provider willing to offer other goods and services on the basis of eVouchers could potentially join the PDS system and use the SmartPDS Server to mediate the interchange process. However, the application of eVouchers in other applications should be used judiciously since it exposes the eVoucher concept to potential abuse through diversion into other services and is beyond the scope of this thesis.

The eVoucher is conceptually analogous to the food-coupon system that is prevalent in the IT industry where a certain component of monthly perquisites to employees is distributed through food coupons which can then be used to purchase food items at any retail outlet that accepts those coupons. The Sodexho food coupon system is one such system that prevails in urban India. The contention is that the targeted poor should also have similar benefits of food coupons through a secure, identifiable and traceable electronic voucher system that uses mobile communications and computing technologies, whose rationale has been described earlier.

6.5 Software components of SmartPDS system

The software of the SmartPDS system developed in this chapter comprises the following modules, which are described through flowcharts in the subsequent sub-sections:

- The SmartPDS Server, a back-end server incorporating services for forms design, a database-engine for persistent storage of data and forms, and a workflow engine that implements the business logic for servicing consumer requests and manages all transactions as per the entitlement norms.
- The SmartPDS Consumer uses mForms, a mobile client application on a low-cost Java-enabled cell-phone, to access the services provided by SmartPDS for the end consumers.
- The SmartPDS Retail Outlet or service provider who uses a client application (SmartRetail) on a smart-phone or wireless tablet, to implement the business logic for the retail services provided at fair-price shops within the PDS network.

6.5.1 Process flows in the SmartPDS system

A simplified notation from the Business Processing Modeling Notation (BPMN) specification has been used to describe the functional tasks and interactions as parallel processes within the SmartPDS system comprising a server, a retail outlet and the consumer (OMG, 2009). A BPMN diagram provides a high level abstraction of the processes interacting on behalf of stake-holders. It provides a level of abstraction that can define complex processes in a Services Oriented Architecture (SOA) in terms of hierarchically decomposed sub-processes of increasing levels of complexity. The SmartPDS system extends the "smart pump" retail outlet process concept for a dynamic gasoline pricing system developed by Garg & Sundar (2008).

There are conceptually four different entities involved in the transaction: the retail consumer, the SmartPDS retail outlet, a centralized identity management service and the SmartPDS backend service. When a retail consumer visits an outlet and makes a request, her digital identity is sent by the SmartPDS outlet to the centralized identity management service which authenticates the consumer in real time. On successful authentication of the consumer's identity, a request is sent to the SmartPDS backend server for checking on the food entitlements that are to be available to the targeted consumer. On receiving the list of food entitlements, the SmartPDS retail outlet dispenses the food items and collects a payment. Since the back-end server maintains a record of all transactions, it provides a check on the service provider and helps improve transparency and accountability in the distribution system. Since all of the transactions happen within the cellular infrastructure whose cost is progressively decreasing even as coverage is increasing, relatively low transaction costs are incurred by the service providers and other stake-holders.

A business process diagram for a SmartPDS system shown in Figure 6-2 provides an overview of the various business processes involved when a PDS consumer visits a retail PDS outlet for purchasing food on her virtual smart ration card residing on her low-cost cell-phone.

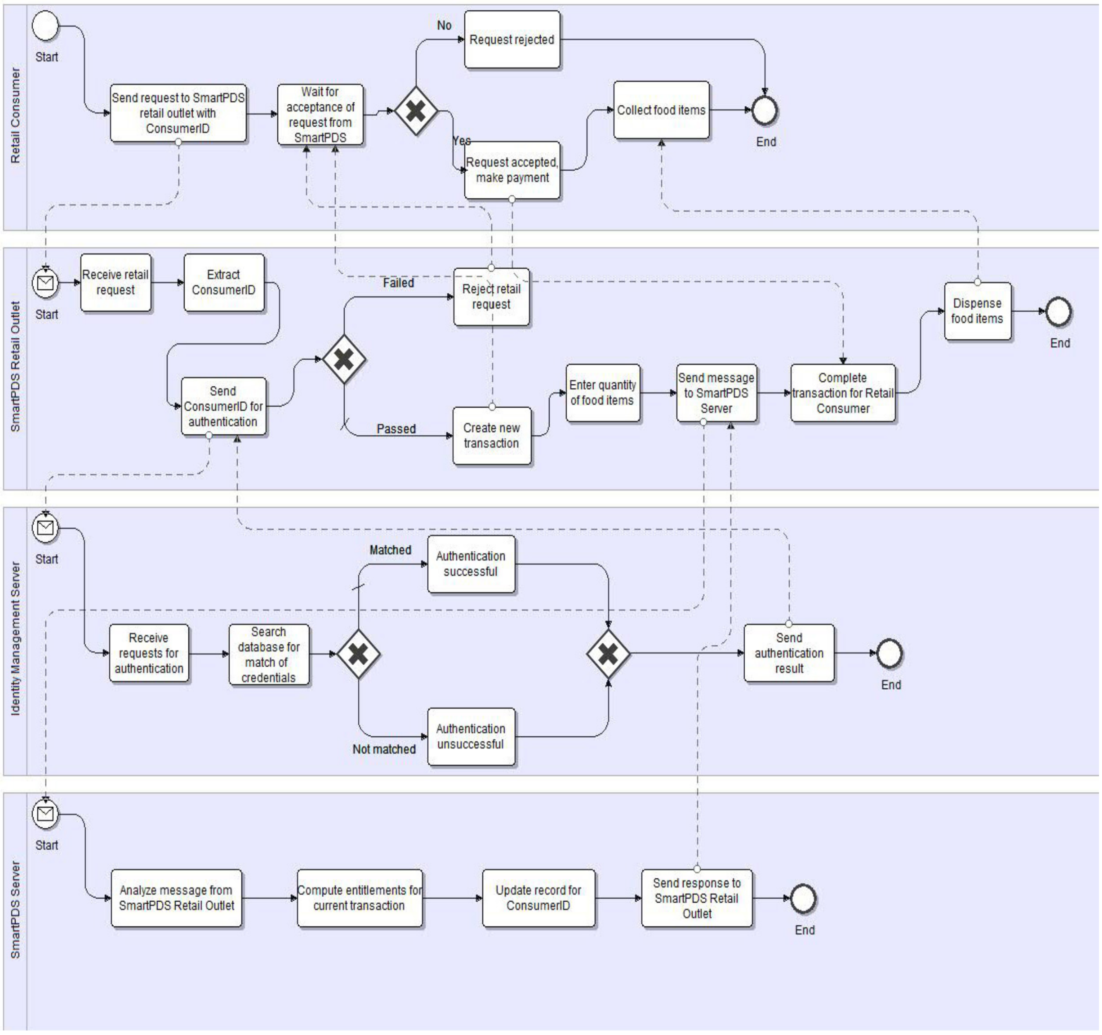


Figure 6-2: The SmartPDS retail outlet

6.5.2 The interface between SmartPDS retail outlet and logistics

The SmartPDS retail outlet provides the primary interface between PDS services and the citizen beneficiary of those services. However, it is only the last element in the PDS supply chain. An important aspect of the solution is also improving the logistics in the sugar supply chain. Figure 6-3 below depicts the interaction between the retail outlet, the warehouse and the logistics provider. Various processes have to work in conjunction with the logistics provider to fulfill the consumer request when goods may not be immediately available and have to be acquired from a larger upstream warehouse.

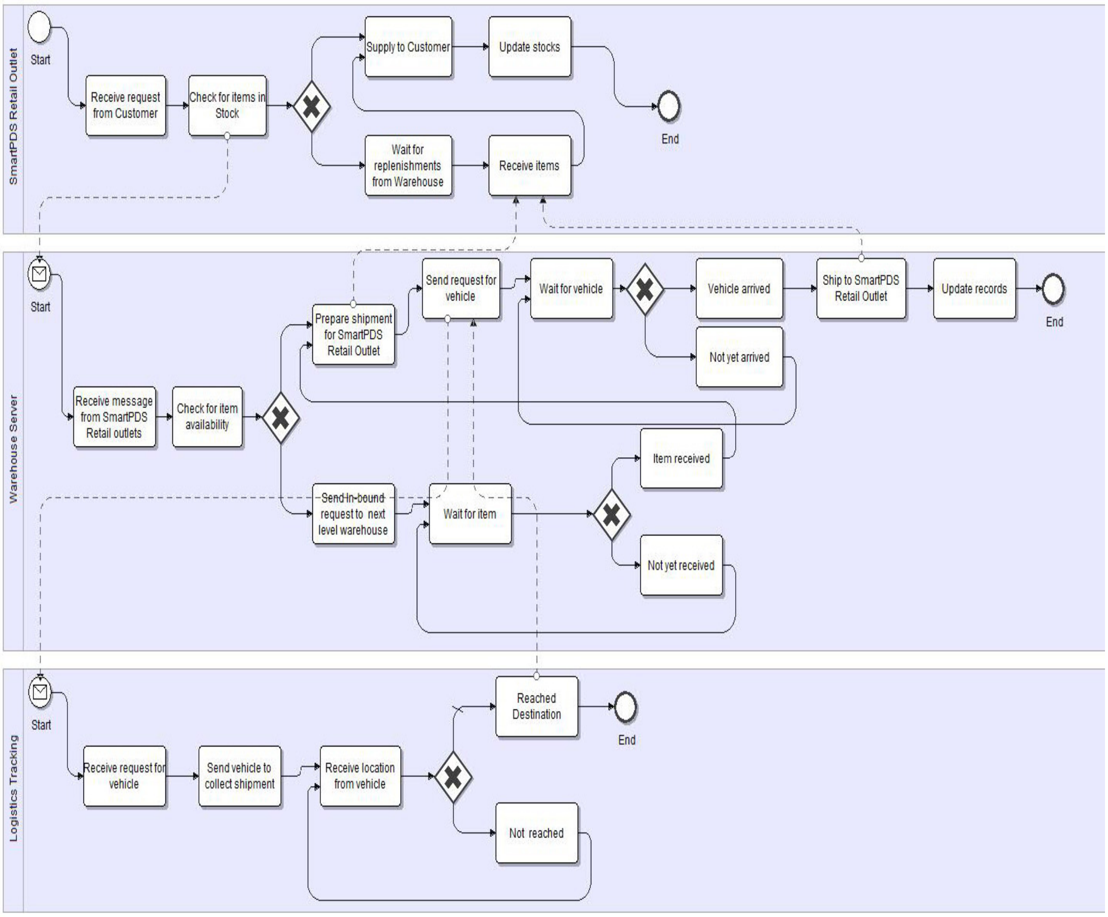


Figure 6-3: Workflows in the logistics of the retail outlet

When a consumer requests a food item, it may not be in the stock of the retail outlet. A request is automatically generated by the SmartPDS retail outlet to the warehouse which then has to arrange for its shipment to the retail outlet. In the current scenario at a fair-price shop, the service provider does not inform the user about the likely time-frame in which the goods will be available. This lack of information results in lack of transparency in the system which is potentially exploitable by the retailer to harass the consumer. Hence, the ability to provide information on the estimated time it will take goods to arrive is an improvement on existing quality of service. This information is now automatically provided as part of the purchase request form sent by the retailer to the consumer.

6.5.3 The SmartPDS server

The SmartPDS Server provides all the back-end services and workflow processes required to implement the services and interactions between a consumer and the retail service provider. It comprises the forms based services encapsulated in a layered architecture of software modules that incorporate a forms designer, a workflow engine and workflow Servelets, SmartPDS business processes, a set of platform services for the administration of the SmartPDS Server, and a persistent storage repository for forms and data. The SmartPDS Server comprises a software stack that resides within the Tomcat Java Servelet Container and uses a database like MySQL accessed through a *hibernate* interface layer which isolates the database services from the specifics of the database engine. Thus, any database engine that supports hibernate could be used. The architecture diagram for the SmartPDS Server is given in Figure 6-4 below:

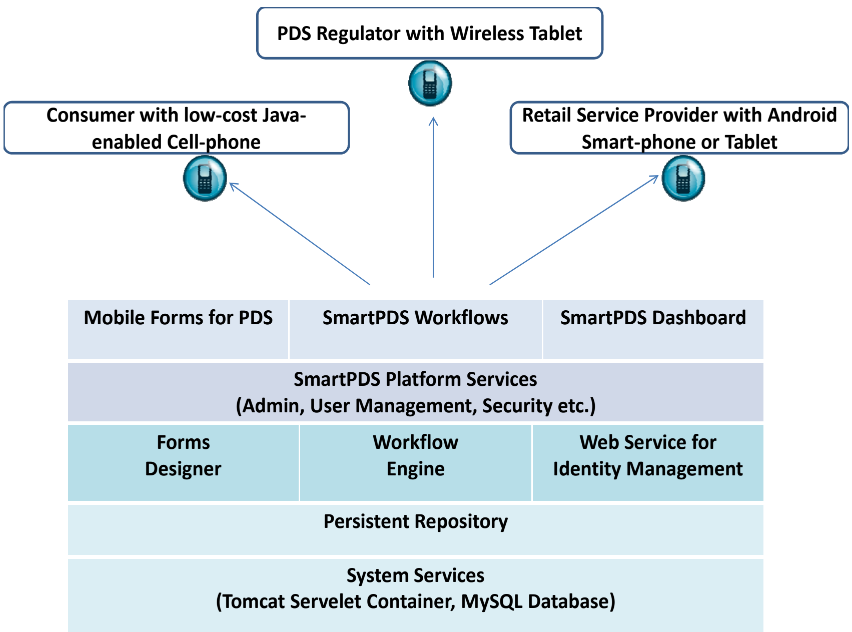


Figure 6-4: Software architecture of SmartPDS server

The SmartPDS server can interface with other applications such as an external identity management service through a web-services architecture. Figure 6-5 presents a flowchart of the various interactions that take place within the SmartPDS Server when a user initiates a service request for the purchase of food items from the public distribution system. All interactions are managed by a workflow engine that uses electronic forms to exchange data between different processes. The SmartPDS server waits for messages from the consumer, in the form of consumer service requests, or status messages from the retail service provider. XML documents are used to exchange data between processes in the SmartPDS workflows.

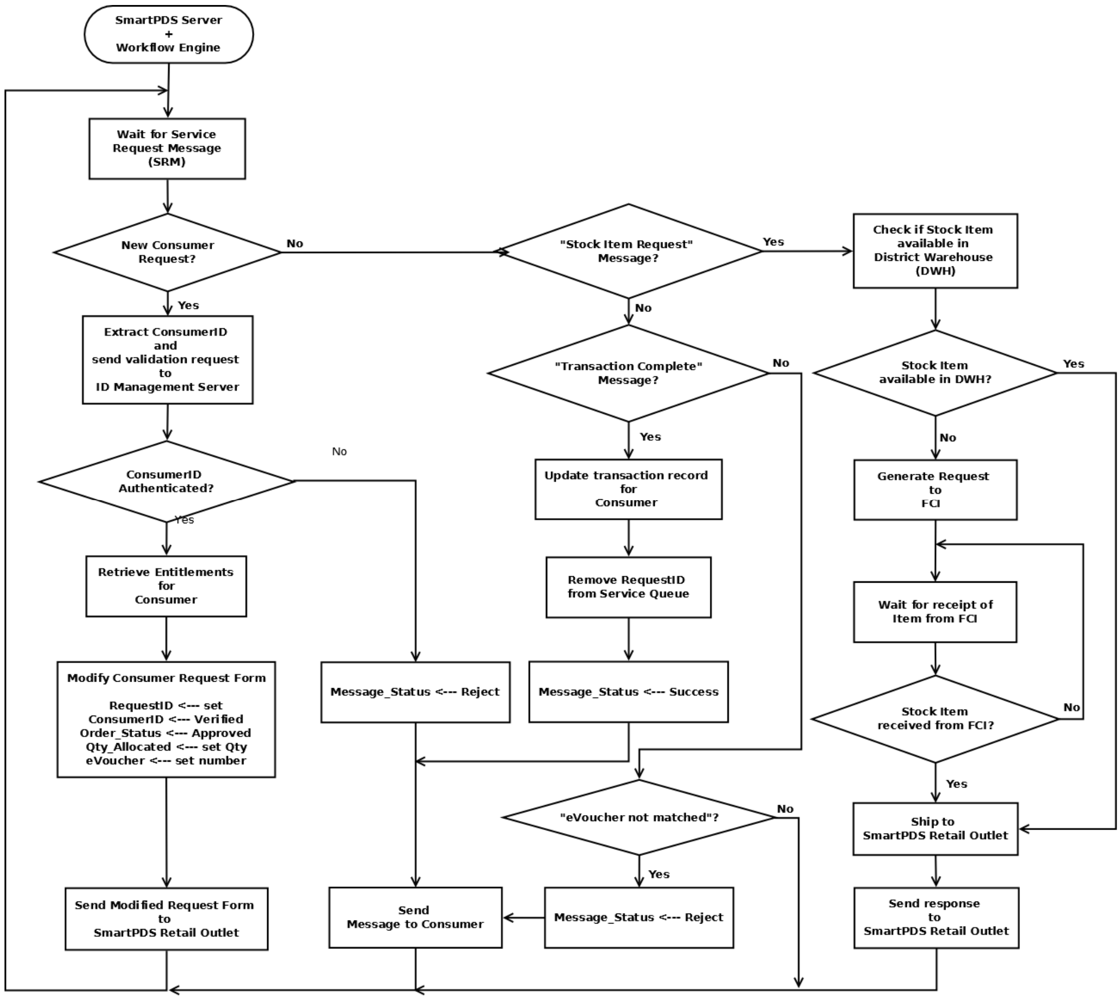


Figure 6-5: Flowchart for SmartPDS server

Since the SmartPDS server is always waiting for messages from the consumer or the retail service provider, it analyzes these messages and takes appropriate action. On receipt of a new service request message it is queued up. When the consumer fills up a Service Request Form and uploads it to the SmartPDS Server, the workflow engine initiates a work-item for the SmartPDS Server. The SmartPDS Server extracts *ConsumerID* information from the service request form and sends a request to an identity management service for establishing the identity of the consumer.

While the current version of SmartPDS does not incorporate capturing biometric attributes of the consumer, a future version of the software will allow biometric credentials to be captured on the mobile device at the Retail outlet. Once the consumer's identity is established, the SmartPDS Server pulls up the consumer's record from the repository and extracts information about the entitlements for this consumer including the quantities of the food items that can be allocated to this consumer, assigns an electronic voucher with a value, and queues it up as a work-item for the SmartRetailer. It is also sent as a response to the consumer who will use the eVoucher to complete the transaction with the retail service provider. If the Server receives a "Transaction Complete" message, the consumer's transaction record is updated and the service request is removed from the queue.

The Server may also receive a "Stock Item Request" message from the retail service provider in case of a shortfall in stocks of food items with the retailer. This initiates the process of shipping food items from a district level warehouse to the requesting retail outlet. If the district warehouse does not have adequate stock the request is accelerated up the supply chain and the goods are acquired from the Food Corporation of India (FCI) which has warehouses geographically distributed around the country.

The workflow engine forms the backbone for the interactions between the various entities. For example, after the consumer is authenticated the server generates a modified service request form with allocation of quantities for different food items based on the entitlement policy, assigns an electronic voucher (eVoucher) and queues it up as a work-item for a specific SmartRetailer. The SmartRetailer receives this request as a work-item, fills out another form (Payment Request Form) with the list of items that are deliverable and the cost of each item. This Payment Request Form becomes available to the consumer as another work-item.

The consumer sends back a Purchase Order Form with the eVoucher number that was assigned to this transaction, along with the value of the purchase in terms of eVoucher units. The SmartRetailer verifies the eVoucher number with the information available from the SmartPDS Server, credits his account with the number of eVoucher units available for this transaction and delivers the food items to the consumer. The SmartRetailer generates a message to the server indicating completion of the transaction. The eVoucher credits in the SmartRetailer's account are aggregated and can be periodically converted into cash by the PDS system.

6.5.4 The SmartPDS consumer

All citizens registered with the targeted public distribution system have a consumer identification number, analogous to the ration-card number in the current manual PDS scheme. The SmartPDS Consumer is a PDS consumer who can access the services of the SmartPDS system using a front-end mobile client application that can run on any standard low-cost cell-phone which is Java-enabled and has GPRS data connectivity. The consumer has to enter user credentials, typically user name and password, to get access to the SmartPDS system. On a successful login, the consumer is presented a service request form which he fills up to order food items from the PDS.

On filling out the consumer service request form the form is uploaded to the server. The server authenticates the consumer and sends back a response in a modified request form, a pre-filled form that lists the quantities of food items allocated to the consumer based on the entitlement policy, along with an eVoucher with a unique number and with a specific stored value. Since the server also sends the modified request form to the retail service provider, the service provider issues a payment request to the consumer based on goods that are deliverable.

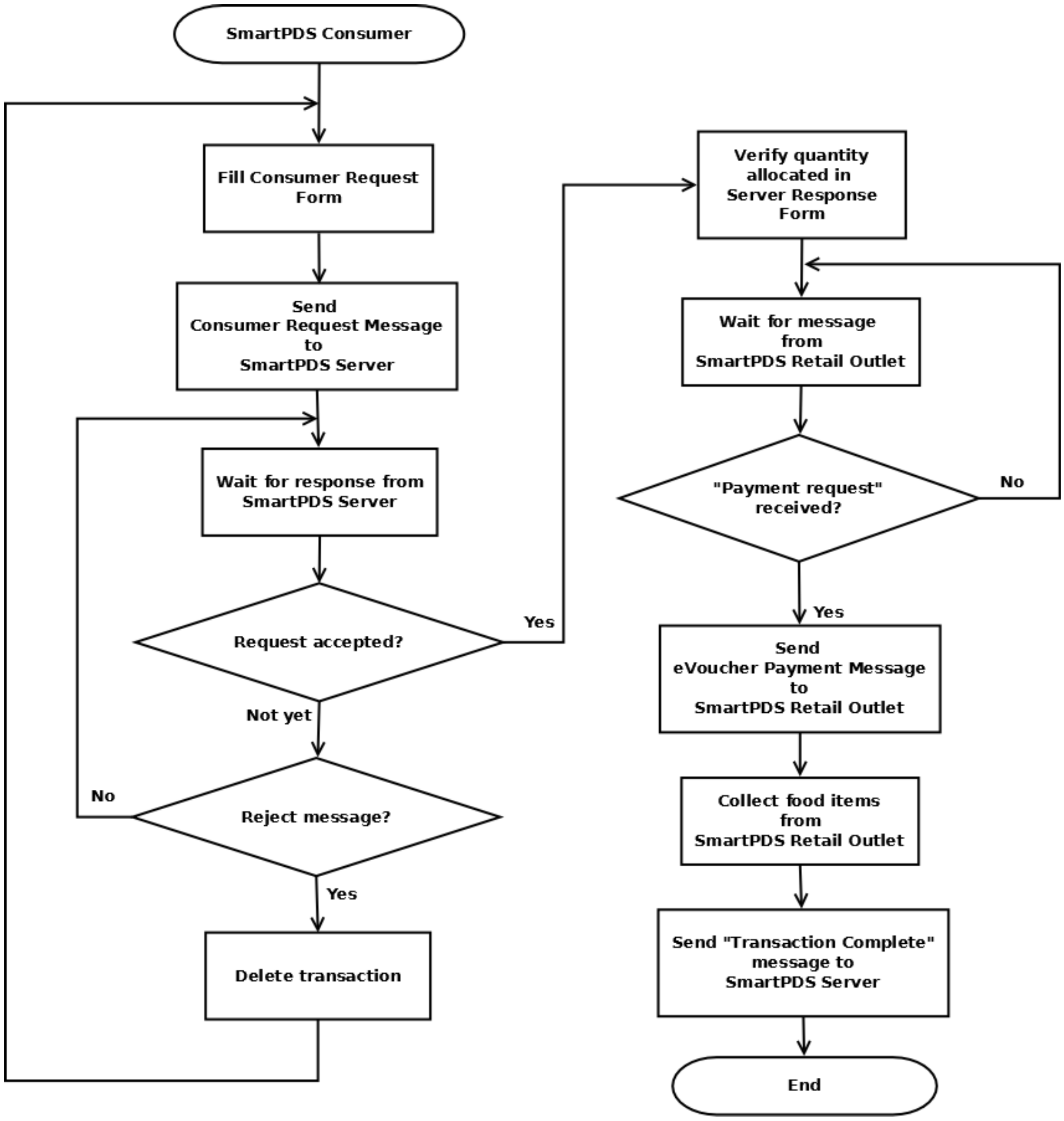


Figure 6-6: Flowchart for SmartPDS consumer

The consumer waits for a payment request from the retail service provider, and approves the purchase by selecting those items he wishes to purchase at the indicated price. This approval process is implemented through a purchase order form into which the consumer places his eVoucher number. Based on the value of the purchase, the appropriate number of eVoucher units are debited from the consumer's account and credited to the retail service provider's account. Thus a complete transaction can take place without any cash transfers in the process, entirely mediated by the SmartPDS Server at each stage of the process.

This sequence of interactions is orchestrated by the server-based workflow engine between the consumer and the SmartPDS system which are described in the flowchart for the SmartPDS Consumer in Figure 6-6 above.

6.5.5 The SmartPDS retail outlet

The next major entity within the SmartPDS system is the retail outlet or service provider which represents the fair-price shop in the existing public distribution system. The retail outlet serves as the last-mile link in the PDS supply chain. Since the targeted consumers interface with the food security system through the retail outlets, it is important to monitor the working of the retail outlets to improve accountability and transparency in the system. The literature has already highlighted several of these problems in this consumer interface link of the PDS supply chain (Asthana, 2000; Food Corporation of India, 2005).

In the SmartPDS system that is presented here, the back-end server maintains control over each transaction from the time a consumer raises a service request to the time that food items are delivered on payment of eVouchers at the retail outlet, eliminating cash transactions. The retail outlet receives its work orders from the server and not directly from the consumer. This mechanism helps to ensure that the complete transaction is executed under supervision of the server. The server sends a modified service request form to the retail outlet with details of the quantities of food items allocated, based on an entitlement record of the consumer, and an eVoucher with a certain value.

The retail service provider workflow checks if the requested food items are available in the quantities required. If the goods are available it generates a payment request for the consumer who then makes the payment through eVoucher value assigned to him by the server. If the retailer has a shortfall of food items, a stock request is generated to the SmartPDS server which informs the warehouse to issue the ordered items.

Figure 6-7 shown below, describes the working of the SmartPDS retail outlet.

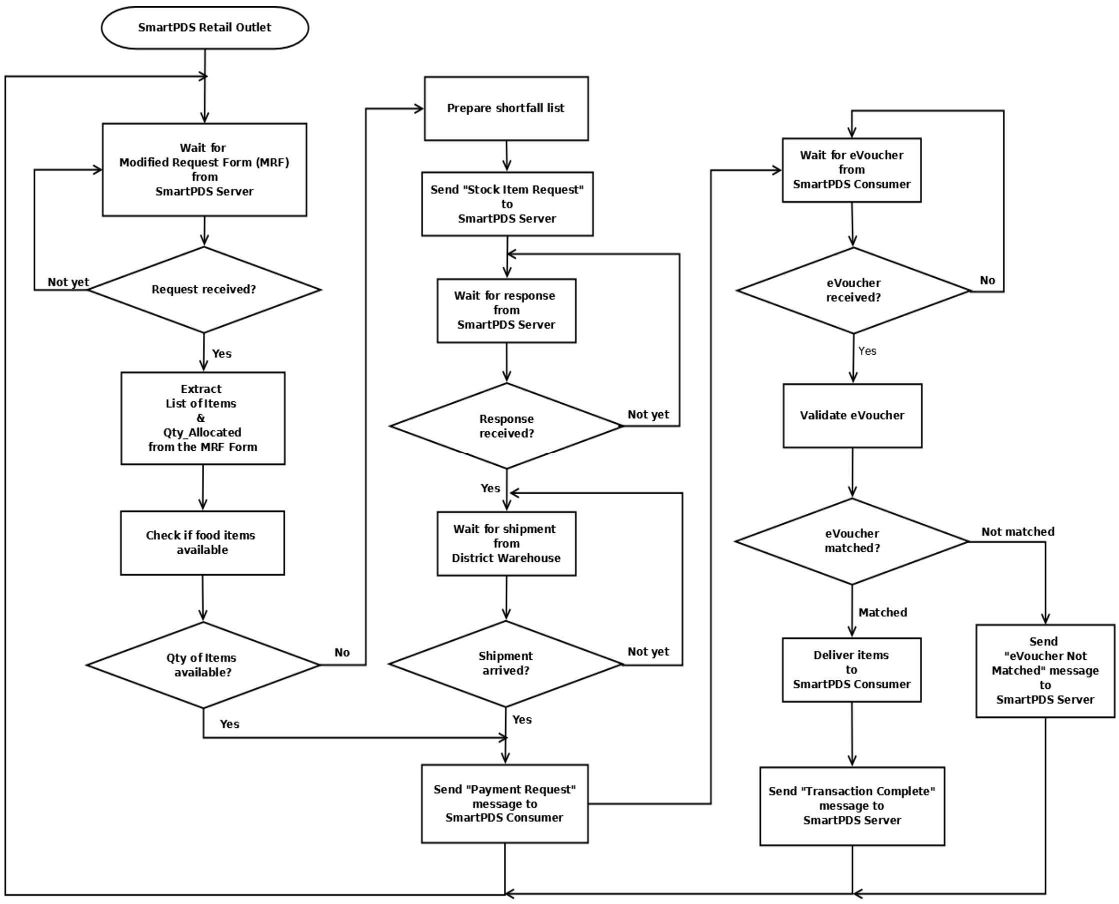


Figure 6-7: Flowchart for SmartPDS retail outlet

6.6 The human interfaces in SmartPDS

The SmartPDS system has been presented as a workflow based system in which several communicating processes exchange information through electronic forms. These electronic forms are not merely for information interchange between processes but are also the primary form of human interface in the system. This section describes the major forms that are used in the SmartPDS system. The consumer-centric forms are shown on a low-cost cell-phone as well as on a smart-phone or tablet because it cannot be assumed that a consumer will use his own cell-phone to access the SmartPDS system. The services can also be accessed from a kiosk located at the retail outlet for the convenience of consumers which will provide web-based access to forms or through a smart-phone.

6.6.1 Service request form on a consumer's device

The service request form, the form used by the SmartPDS consumer is shown in Figure 6-8 and Figure 6-9 below. Since a basic cell-phone has a small display screen and limited graphics capabilities, the form is designed to appear in a linear format on the cell-phone whereas on a mobile device with rich graphics capabilities, a more elaborate form layout is possible. Figure 6-8 shows the form as it appears in a linear format on a low-cost, Java-enabled cell-phone in which horizontal scrolling is not permitted. As the number of items to be entered increases, the user has to merely scroll downwards.

Figure 6-9 shows the same form as it appears on an Android smart-phone. A form rendered on the smart-phone is capable of displaying a lot more information. Once data is filled up and saved, it is uploaded to the server and deleted from local storage.

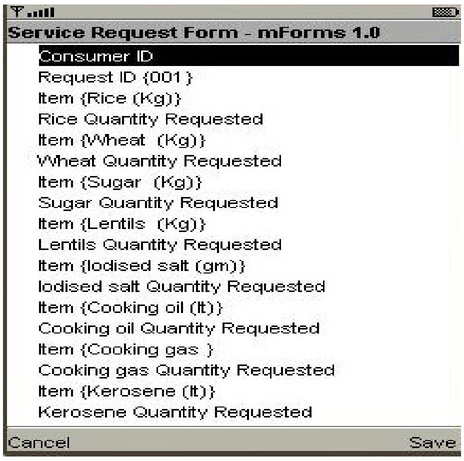


Figure 6-8: Service request form on low-cost cell-phone

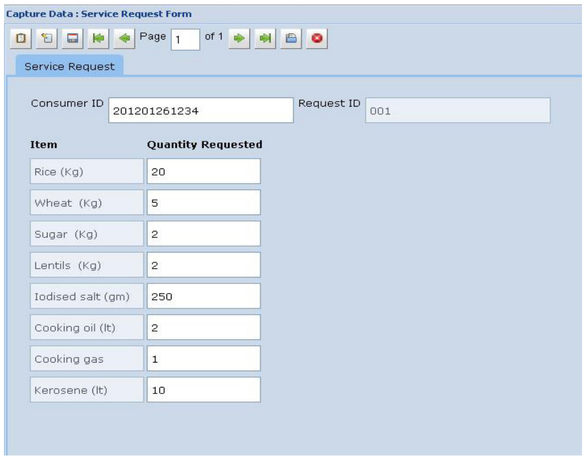


Figure 6-9: Service request form on a smart-phone

6.6.2 Modified service request form on a smart-phone or tablet

Figure 6-10 shows a modified service request form which is generated by the SmartPDS server after it receives a request from the Consumer and has authenticated the consumer. It adds a "Quantity Allocated" column in addition to the existing "Quantity Requested" column which is grayed out and is no longer available for editing. Quantity allocated is based on the specific consumer's entitlements which may change from time to time. This information is maintained in the database by the SmartPDS Server. An eVoucher number is assigned along with the value of the eVoucher units. The server also indicates that the request has been approved. This form is sent to the consumer as well as to the retail outlet for follow-up. The SmartPDS Server always retains monitoring and control over all transactions to ensure that the retail service provider has actually provided the appropriate quantity of goods that the consumer is entitled to and has accepted.

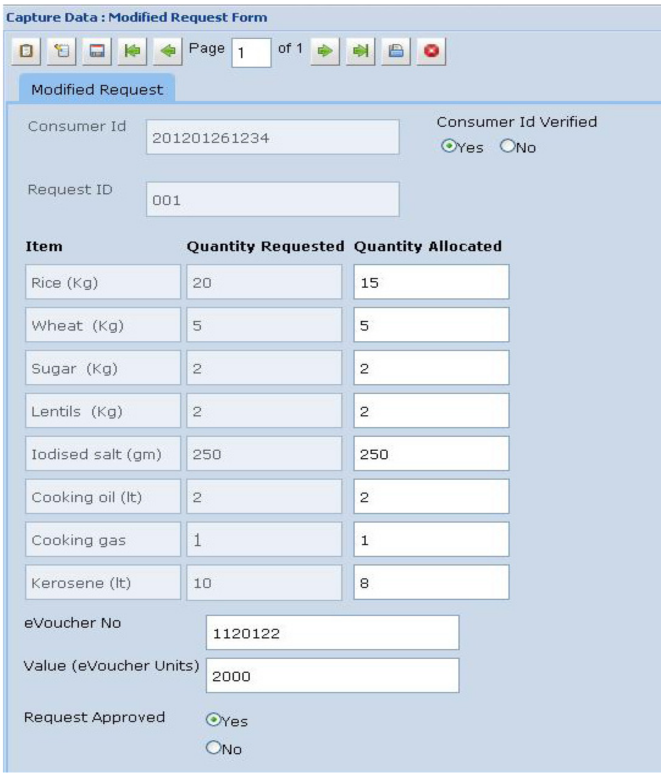
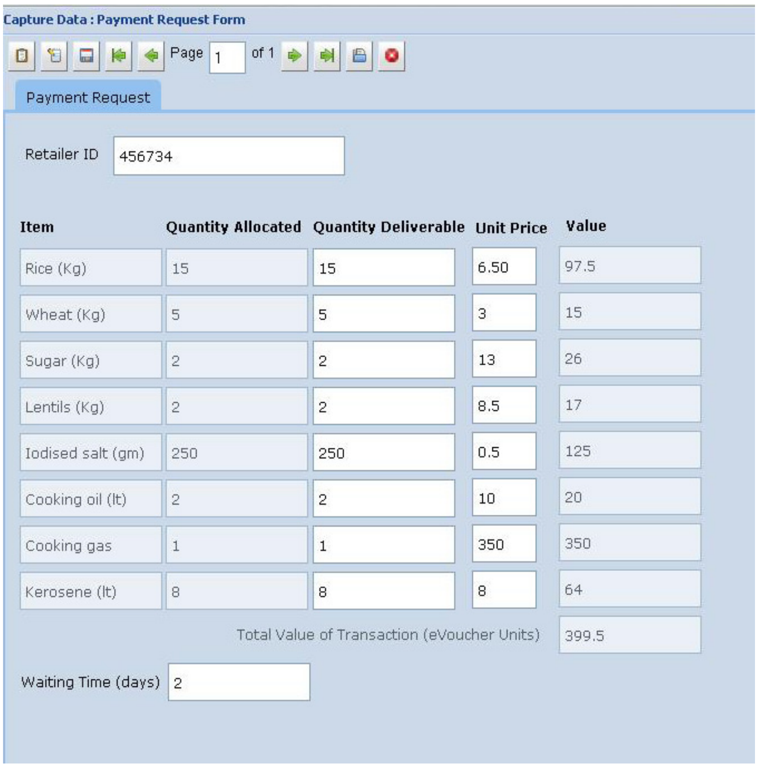


Figure 6-10: Modified service request form generated by the server

6.6.3 Payment request form on a smart-phone or tablet

Figure 6-11 shows the payment request form which is generated by the retail outlet and sent to the consumer in response to an approved request from the server. It retains the "Quantity Allocated" column and adds the "Quantity Deliverable" column, a "Unit Price" column and a "Value" column. It also specifies a waiting time because the goods may not be immediately available. The value field is computed automatically within the form itself as the retail service provider fills up the "Quantity Deliverable" and "Unit Price" fields for each item. The total eVoucher units are also computed automatically, thereby minimizing the potential for human errors. Cells that are grayed out are no longer available for editing by the retail service provider. This form is sent to the consumer for issuance of the payment and confirmation of the purchase order.



Capture Data : Payment Request Form

Page 1 of 1

Payment Request

Retailer ID 456734

Item	Quantity Allocated	Quantity Deliverable	Unit Price	Value
Rice (Kg)	15	15	6.50	97.5
Wheat (Kg)	5	5	3	15
Sugar (Kg)	2	2	13	26
Lentils (Kg)	2	2	8.5	17
Iodised salt (gm)	250	250	0.5	125
Cooking oil (lt)	2	2	10	20
Cooking gas	1	1	350	350
Kerosene (lt)	8	8	8	64
			Total Value of Transaction (eVoucher Units)	399.5

Waiting Time (days) 2

Figure 6-11: Payment request form generated at retail outlet

6.6.4 Purchase order form on a consumer's mobile device

Figure 6-12 shows the purchase order form generated by the consumer on a low-cost cell-phone, in response to the payment request form, and sent back to the retail service provider to accept the quantity of items specified in the payment request form.

Figure 6-13 shows the same purchase order form on a smart-phone. Against each item, the consumer can specify whether that item is required or not. Hence the total value of the transaction is recomputed. In addition to indicating approval, the consumer also enters his eVoucher number. This is verified with the eVoucher number that sent to the retail outlet by the server in the modified request form and the value in the eVoucher is accepted if the eVoucher numbers match. The retailer send a "transaction complete" message, the eVoucher is credited to the retailer's account and debited from the consumer's account by the server and food items are handed over to the consumer.

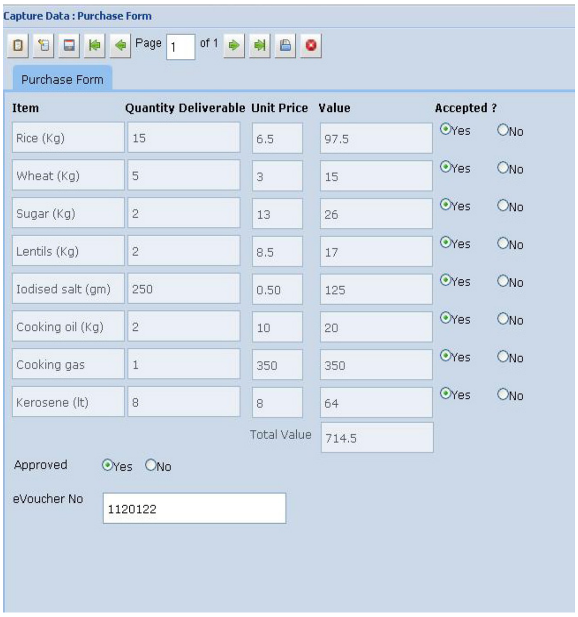


Figure 6-12: Purchase form on a low-cost cell-phone

Figure 6-13: Purchase form on a smart-phone

6.6.5 Stock request form sent by a retail outlet to the server

There may be a situation in which the retail outlet does not have the appropriate quantity of goods to service a consumer request. This initiates a request from the retail service provider to the SmartPDS Server to supply the specified quantity of items specified in a stocks request form filled up by the retail service provider.

Figure 6-14 shows the stock request form. The server arranges for the shipment of goods from a warehouse in the district or from another warehouse and informs the retail service provider.

Figure 6-14: Stock request form generated by a retail outlet

6.7 A mobile SmartPDS outlet

To facilitate improvements in the service delivery of PDS and TPDS services, this thesis has developed a framework for a smart PDS system comprising a server, a retail outlet and consumers. The SmartPDS system leverages the technology infrastructure of mobile devices, electronic forms, digital identity management, and logistics tracking. The SmartPDS system is able to manage the delivery of targeted services to clients in the TPDS in real-time through a set of well defined business processes cooperating across the communication network and ensuring that only duly authenticated consumers are served. However, a critical goal of mobile governance is to deliver government services at the door-step of the rural citizen. Many rural communities comprise nomadic tribes who stay in remote regions and are always on the move. Such communities have significantly higher poverty levels as they are forced to live on the fringes of the already impoverished rural communities. It is important that government services and facilities be provided to these communities too. Ideally, a system of delivering PDS services through a mobile delivery system would be useful for targeting such communities. So, here a mobile smartPDS retail outlet is proposed which can operate out of a van but has access to the entire information architecture of the SmartPDS system that has been developed. This mobile retail outlet should have the capability to deliver goods and services to the door-step of remote rural communities.

A mobile tracking platform can record location information in real-time and therefore allow the SmartPDS system to track the mobility of all mobile PDS vans and automatically dispatch them to different points of delivery on a flexible time schedule. Since the location of the mobile retail outlet can be tracked in real-time, it also creates a certain amount of accountability for the last-mile service provider. A low-cost mobile device with a small LCD display, a built-in smart card reader, an RFID reader, GSM cellular connectivity, and some non-volatile storage for handling and storage of data would be essential. Non-volatile storage would primarily be for situations when connectivity to back-end servers may not be available. The average Android-based smart-phone already incorporates most of the basic functionality required for the mobile SmartPDS retail outlet. Hence, specialized mobile devices are no longer required for this purpose. Of course, the mobile PDS retail outlet would be fully capable of operation in a disconnected mode for limited periods in which cellular connectivity might not be available.

6.8 Conclusions

This chapter provides the framework for an improved Public Distribution System since sugar is an important component of the food basket and the thrust of this thesis is on the development of an integrated framework for the sugar cooperative sector. This SmartPDS framework addresses some of the known problems of leakage, poor service delivery and transparency through the use of workflow-based mobile devices to empower rural and other poor consumers to access these food entitlement services at their doorstep. A mobile phone based system is scalable and replicable since the cost of technology intervention is relatively low since specialized devices are not required and the existing cellular infrastructure is used. Such a framework can address the weakest link in the sugar supply-chain, which is currently the retail outlet in the Public Distribution System. Improvements in service delivery are possible because unlike several other e-Governance initiatives which primarily address the problems of the bureaucracy, this system focuses on empowerment of the individual rural consumers using the cellular infrastructure that already exists. The client access device for the end-consumer will be his personal low-cost cell-phone which can now be used with electronic forms. In this framework even the SmartPDS retail outlet does not need any specialized hardware since the required functionality is now available on many low-cost Android smart-phones and tablets from multiple suppliers. Further, the smartPDS outlet does not have to use smart-cards to replace paper-based ration-cards or for authentication because of higher cost outlays. At the most, the consumer may be expected to carry a laminated card with 2D-barcoded identification information which is possible to produce and distribute at a much lower cost than a smart-card. The system uses mobile connectivity to properly authenticate users in a central database for transactions between the retail outlet and the end consumer.

While smart phones are likely to become ubiquitous and could be used for various applications as costs come down progressively, it is reasonable to assume that rural users may not acquire such smart phones in significant numbers in the foreseeable future because of the digital barrier and lack of applications that are of direct relevance to them. These phones may currently be too complex for the average user but as mobile technologies and software mature, this may no longer be a problem. When compelling e-governance applications like the SmartPDS become available, this will make the smart-phones useful for the rural population too and electronic forms can reduce the barrier even further. Hence, the proliferation of smart-phones will be guided less by voice communications needs but more by meaningful data connectivity-oriented applications that have direct relevance to the rural consumers. Several other e-Governance applications that may potentially trigger wider acceptance, but are not within the scope of this thesis, are:

- Property Records and Taxes
- Village Mapping with mobile device
- Water-shed management
- Public Health & Disease Surveillance applications

A mobile computing and communications technology framework in which the ubiquitous cell-phone is no longer a voice communication device but is also appropriate for an advanced level of e-governance services at the door-step of the citizen has been presented here. Government services can be delivered to rural users at a lower transaction cost and in near real-time.

With this chapter the study of the sugar supply chain is concluded in this thesis and a summary of conclusions, specific contributions of this thesis and a discussion on the future scope of work will be presented in the final chapter.

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7. Summary, Conclusions and Scope of Future Work

7.1 Summary and conclusions

Increased exposure to global competition due to the opening up of the Indian sugar sector in the last decade has highlighted the inefficiencies in the existing system and its inability to compete effectively. Since the sugar sector, in particular the cooperative sugar sector forms an important component of India's agriculture industry and sugar distribution is a critical component in the nation's food security initiatives, technology interventions are required to improve productivity and competitiveness in this sector. This has provided a rationale for this research work.

A detailed survey of the literature has indicated that while optimization techniques are often used in many aspects of agriculture such as crop planning, land-use management, harvesting, post-harvest production and transportation logistics, problems are complex due to external conditions such as weather variability and perishable raw materials. Thus it is not practical to model the entire agro-products industry through a single unified model. Instead, researchers have focused on smaller, more manageable sections of the supply chain. Consequently, in this thesis the focus has been on optimal supplier selection in the sugar supply chain, crusher scheduling which is modeled as single-server multiple-queues model with server vacation, and the public distribution system.

The sugar supply-chain has been modeled as a network of multiple activities, with its precedence relationships, for which each activity attracts multiple bids from multiple suppliers. A model for market intelligence curves (MIC) has been developed to provide a base-line time-cost solution to the supply chain manager. Since the MIC model does not give a list of suppliers because it is based on a best-fit curve approach which cannot yield a list of suppliers, a linear programming model which provides an optimal solution for supplier selection has developed. However, the linear programming model, which considers the lower envelop of all the bids of an activity in the network model, has its own limitation that some of the selected suppliers may not necessarily have made valid bids for activities for which they have been selected. Thus, a binary integer programming model with stochastic time constraints is developed to provide an optimal solution for supplier selection. This solution generates a supplier list with valid bids. Stochastic time constraints have been used to model the activity time estimates which are often non-deterministic. A penalty structure design has been developed that helps the supply chain managers to handle the network schedules with minimum deviations by imposing a variable penalty which can be announced *a priori,* instead of a standard flat penalty structure that is the usual norm. The *a priori* penalty structure is derived on the data from the previous season's bids of the selected suppliers. The theoretical models have been implemented in two scenarios of a small-sized sugar factory and a medium-sized sugar factory.

A decision support system has been designed and implemented that enables the supply chain manager to manage the process of bidding and negotiation in real-time through a mobile-phone based application. The decision support system incorporates the stochastic IP model for optimal supplier selection and the penalty structure formulated in this thesis. The Regulator in the sugar cooperative sector also has access to bidding data, a list of selected suppliers and the penalty structure in real-time. Since the Regulator can monitor the bidding processes from several factories under his control in real-time and take suitable action, it provides a level of governance that has been missing from the sugar cooperative sector.

The important task of sugar cane crusher scheduling has been modeled on a single-server multiple-queues model with server vacation. In typical production-inventory systems, static cyclic policies are of great value compared against their dynamic counter parts. Periodic tabular policies may be viewed as generalized version of cyclic policies and, to derive a tabular policy, an approximate mathematical program was formulated for total cost minimization. A comparative performance study of the tabular policy with respect to cyclic policies was provided which demonstrated that though cyclic policies offer comparable performance with respect to tabular policies at low utilization rates, the performance gap widens significantly as system utilization tends to increase.

Since the Public Distribution System (PDS) is another important component of the sugar supply chain, a mobile-phone based solution has been developed for improved service delivery in the PDS. The mobile-phone based solution uses the cellular communications infrastructure to enable remote consumers to access the PDS, which increases coverage and helps lower transaction costs in the system. The smart PDS system uses electronic vouchers for the transfer of entitlements from the PDS to the intended beneficiaries and it tracks the entire transaction from a consumer request for specific food items to its payment through eVouchers and the delivery of the food items to the consumer. This helps in improving governance that has been poor in the existing PDS.

7.2 Specific contributions

The major contribution of this thesis has been in proposing an integrated framework for addressing three important aspects of the Indian sugar industry namely, optimal supplier selection, crusher scheduling and sugar distribution through the Public Distribution System. The specific contributions are detailed below.

The development of market intelligence curves enables the supply chain manager to take informed decisions during negotiation using the baseline time-cost optimization of bids based on a best-fit curve approach. A stochastic binary integer programming model for optimal supplier selection in the supply chain network is able to handle uncertainty in the execution of individual activities. A heuristic model for derivation of penalty structures provides a framework for penalties to be charged to suppliers and service providers in the event of delays in execution of their activities. The development of a mobile-phone based decision support system which incorporates optimal supplier selection and penalty derivation in a unified tool enables supply chain managers and the sugar regulator to monitor and manage negotiations with suppliers in real-time.

In the area of crusher scheduling, in which the scheduling problem is modeled as a single-server, multiple-queues system with server vacation, the comparative performance of a static tabular policy over a cyclic policy, especially as system utilization levels increase, can help the sugar industry to optimize yields by coordinating the arrival of sugarcane at the crusher based on the crusher schedule, to reduce post-harvest waiting times.

A mobile-phone based SmartPDS solution will improve service delivery in the Public Distribution System since the developed solution ensures that every consumer is properly authenticated against an identity database. This ensures better targeting of food entitlements to the intended beneficiaries compared to the prevailing system which has been found to have problems in this area. Further, the use of an electronic voucher system to facilitate cashless transfer of entitlement benefits to the targeted beneficiaries eliminates a potential source of revenue leakage that is present in the current PDS system.

7.3 Scope for future work

This section describes the scope for future work in the focus areas of supplier selection, crusher scheduling and mobile governance in the public distribution system, based on the integrated framework presented in this thesis. The techniques used and the technology developed as part of the integrated framework in this thesis can be applied to other commodities in the agriculture supply-chain.

Using market intelligence curves to develop game theory based negotiation models for better cost control of the supply chain is an area of future work. To study the effect of stochastic time constraints on the optimization of cost other random distributions, besides normal distributions, may also be explored. The concept of the penalty structure proposed in this thesis also has potential applications in other activity networks where multiple suppliers provide multiple bids for each activity but are unable to meet the committed time-cost bid due to aggressive bidding behaviour or the tendency to win at any cost. This often results in delays in the execution of activities and cost over-runs.

In the area of crusher scheduling, the perishable nature of the raw material (sugarcane) and the finished product (sugar) warrants development of production plans incorporating bounds on cycle lengths and safety-stocks, which is a theoretically challenging constrained optimization problem that is an area of future work. The static polling table approach for crusher scheduling yields good results at higher utilization rates, but this can further be improved by developing dynamic scheduling policies since most of the input and output of this industry is perishable in nature. But the challenge in implementing dynamic scheduling policies is the complexity involved in modeling multi-stage processes. While the case of production of multiple standardized items, on a single machine with limited capacity and random set-up times under random demand and random production times was considered in this thesis, such problems fall under the genre of stochastic economic lot-sizing problems (SELSP). The primary focus has been optimization of total cost, comprising the sum of set-up, holding, and back-logging costs, specifically under *local lot-sizing policies.* Hence, base-stock policy has been derived based on the inventory level of the product that is currently set up. As a result of such localized policies, one single queue for which high demand arrives for a certain duration may dominate the machine for a while leading to stock-outs, high costs, and high variability in cycle lengths of other queues. Since the problem addressed herein is generally intended to model bottlenecks in any production environment, it is important to make these lot-sizing decisions depend on global information, that is, on the stock levels of all individual queues and on the state of the machine, which is a complex but practically relevant problem worth addressing. Another important question of practical relevance is to study the impact of process variations on machine performance; a comprehensive sensitivity analysis with respect to input distributions can be carried out to that effect.

The electronic voucher (eVoucher) proposed in this thesis as a method for the cashless transfer of benefits from the service provider to the targeted consumer may also be explored further. This can be extended to other e-Government service besides PDS, because the eVoucher is traceable and can be attached to a specific identifiable individual to whom certain entitlements have to be passed on. While the cell-phone has been used as the access device for the transfer of the eVoucher from the service provider to the beneficiary and then to the retail outlet, multi-factor authentication is required to ensure that the eVoucher cannot be misappropriated or misused by another intermediary who poses as the original beneficiary. Development of a simple scheme for multi-factor authentication is an area that requires future work.

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List of Publications

Papers in international journals

1. "A Periodic Tabular Policy for Scheduling of a Single Stage Production-Inventory System”, published in Journal of Computers & Industrial Engineering, Volume 62, Issue 1, February 2012, Pages 21-28, http://dx.doi.org/10.1016/j.cie.2011.08.013

2. "A Mobile Phone enabled Decision Support System for Supplier Selection with *a priori* Penalty Structure for Delays in a Sugar Supply Chain", submitted to Journal of Computers and Electronics in Agriculture (under review)

3. "A Mobile Solution for an Inclusive Public Distribution System" being submitted to The Electronic Journal of e-Government

Papers in international conferences

4. "A mobile decision support system for optimal supplier selection in an agro supply chain", full paper accepted for 4th World Conference: Production & Operations Management (P&OM-2012) to be held at Amsterdam from July 01 to July 04, 2012

5. An abstract "Mobile enabled operations management using multi-objective based logistics planning for perishable products" co-authored by Diatha Krishna Sundar, K. Ravikumar and Shashank Garg has been accepted and full paper invited for the Computers and Industrial Engineering Conference to be held at Cape Town, South Africa from July 16 to July 18, 2012

6. "Electronic Data Capture for a Longitudinal Study in Public Health - A Case study”, full paper accepted for 23rd Annual Production & Operations Management Society Conference (POMS-2012) to be held at Chicago, USA on April 20 to April 23, 2012

7. “Optimal selection of Suppliers in a Supply Chain Network with Multiple Bidders for

Each stage", presented at 22^{nd} Annual Production & Operations Management Society Conference (POMS-2011) held at Reno, USA on April 29 to May 02, 2011

8. "A Periodic Tabular Policy for Scheduling of a Single Stage Production-Inventory System for Agricultural Products", a paper accepted for the 19^{th} Triennial Conference of the International Federation of Operational Research Societies (IFORS2011) held at Melbourne, Australia from July 10-15, 2011

9. "A Mobile Technology Framework for Consumption-based Dynamic Pricing of Gasoline for Developing Countries", presented at 3^{rd} European Conference on Mobile Government, EURO MGOV-2008, at Antalya, Turkey, September 2008

10. "Mobile Governance: A Framework for Indian Urban Local Bodies", presented at 1^{st} European Conference on Mobile Government, EURO MGOV-2005, at University of Sussex, Brighton, UK, July 2005

11. "Mobile Governance: A Mobile Computing Framework for Integrated Disease Surveillance in India" presented at 1^{st} European Conference on Mobile Government, EURO MGOV-2005, at University of Sussex, Brighton, UK, July 2005

12. "Integrated Virtual Logistics Networks for Quick Responses" at 3^{rd} International Conference on Traffic and Transportation Studies (ICTTS'2002), Beijing, China

13. "Creating e-Chains to enable E-Governance through Embedded Technologies" at the 10^{th} International High Technology Small Firms 2002 Conference, Twente, The Netherlands, June 2002

Chapters in books

14. "The Role of Mobile Computing & Communication Technologies in Mobile Governance", a chapter in the book, "Handbook of Research on Enterprise Systems", edited by Sanjay Kumar (School of Business Management, Xavier Labour Relations

Institute, Jamshedpur, India), Elliot Bendoly (Emory University Goizueta School of Business) and Jose Esteves (Instituto de Empressa, Madrid) by SAGE Publishers (New York, New Delhi, Singapore, London), 2011

15. “Rural Empowerment: An Integrated Disease Surveillance System Based on Mobile Technologies”, a chapter in the book “IT and Rural Health-care”, edited by K N Agarwala and M D Tiwari, in the IIIT Series on e-Governance, published by MacMillan India Ltd., 2009

16. “Information Technology in Judicial Delivery”, a chapter in the book, “Electronic Judicial Resource Management”, edited by K N Agarwala and M D Tiwari, in the IIIT Series on e-Governance, published by MacMillan India Ltd., 2005

Bio-data

Brief Bio-data of Candidate

Shashank Garg is the CEO of a start-up, Handheld Solutions & Research Labs, Bangalore which uses mobile communication and computing technologies for developing solutions in Public Health and e-Governance. He was Vice President for Advanced Product Development and Mobile Computing at Encore Software Limited, Bangalore, where he was the chief architect for various mobile computing products including the Simputer and Mobilis. He is currently on long-term sabbatical leave from Encore to complete his PhD thesis.

As a co-inventor of the Simputer, a low-cost mobile computing device developed for bridging the Digital Divide, he received the First Dewang Mehta Award for Innovation in IT from the Government of India in 2002. Shashank was a Fellow in the Reuters Digital Vision Program on Social Entrepreneurship at Stanford University for a year in 2006-07. He had a scholarship from Motorola (USA) for the duration of the fellowship at Stanford.

He obtained a BSc (Physical Sciences) from BITS, Pilani in 1972. He obtained a BE (Electronics & Communications Engineering) in 1975 and an ME (Electrical & Electronics Engineering) with specialization in Computer Science in 1997, both from the Indian Institute of Science, Bangalore.

Brief Bio-data of Supervisor

Dr. D. Krishna Sundar is Associate Professor and Chairperson – ERP Center at Indian Institute of Management (IIM) Bangalore, India. After graduating as a mechanical engineer he took his Masters Degree in Industrial Engineering and Management with majors in IT and OR. He obtained his Doctoral Degree for his work in the area of "Decision Support Systems for Operations Management" from the Indian Institute of Technology (IIT), Kharagpur. He has published in several international journals & presented research papers in international conferences. He is a consultant to many manufacturing and IT companies besides government departments, both in India and abroad, in the areas of E-Governance, E-Business Management, ERP Implementation, Operations Management and Supply-chain Management. Currently, four doctoral research scholars are working under Prof. Krishna Sundar's guidance in the areas of Technology Acceptance Models (TAMs), Banking Supply-chains, and Social Networks.