Orchestrating the Print Supply Chain in Emerging Markets *

N. Viswanadham, Fellow IEEE, **Sowmya Vedula**, **Rakesh Kulkarni**

Abstract — **Print supply chain includes document design, material procurement, document creation, production, warehousing and delivery. Several small and medium scale industry players are involved in this supply chain process. Thus the print supply chain network is a loosely coupled system of spatially dispersed independent companies, working together for delivering value to the customer. This network consists of specialists in printing and complementary players such as packaging companies, logistics providers, IT companies, etc. Our focus in this paper is to design an orchestrator for the governance of end to end print service chain network in consumer oriented sectors such as banking, retail and insurance. The orchestrator typically does three functions: partner selection, supply chain planning and supply chain execution. In this paper, we concentrate on the second step - the supply chain planning and scheduling and develop a mixed integer programming model, illustrating it with an example.**

I. INTRODUCTION

Despite rapid advances in digital communications, printed output continues to drive business processes in many organizations today. Industries such as legal, financial services and health care continue to rely heavily on the quality and availability of printed documents. Technology advances have made printing easy, accessible and fast. Many organizations purchase a printer or copier hardware under contractual relationship, which includes maintenance, support and supplies, based on a cost-per-page contract.

The printer supply chain networks and print shop designs are well studied subjects particularly by manufacturing companies such as Xerox, Canon, and HP. Retail networks with print shops such as Kinko's where customers submit their work order and collect printed documents are very common both in developed as well as in emerging markets. These service networks which cater to selling solutions rather than products are very common in the printer sales.

However, studying the entire supply chain from procurement of paper, ink, printing machinery and other materials, flow of these materials through well designed print shops, and finally delivering the printed material to the clients is not a well studied subject. The logistics both inbound and outbound and also in the print shop is an important cost center.

------

*N.Viswanadham, Computer Science and Automation, Indian Institute of Science, Bangalore, India (corresponding author – email: n.viswanadham@gmail.com)

Sowmya Vedula, Data Analyst with IFMR Rural Finance Services Pvt. Ltd. Chennai, India

Rakesh Kulkarni, Research Scientist, Xerox Research Center, Webster, USA.

Such print supply chains are in demand for books, magazines, stationary; application forms for loans, insurance; advertising materials and host of others. The market is fragmented and inefficient and has opportunity for cost savings.

The Printing Industry in emerging markets such as India has thousands of printing presses which are both new as well as refurbished. With the growth of liberalization and also outsourcing, the Indian print supply chain has grown in an ad-hoc manner. The print shops may be well designed in some cases and the couriers may follow the tracking and consolidation principles but the supply chain is not designed in an integrated manner.

Printing supply chain business network consists of material suppliers, inbound transportation to printing plants, outbound logistics direct to selected customers and/or their distribution centers, and transit through a network of consolidation facilities such as bulk mail centers, sectional center facilities, and destination delivery units. The printing facilities themselves could be regionally distributed and are sequentially connected i.e. output of one feeds to the other. When the business network is crowded with small enterprises and the capabilities are distributed among them, the supply chain needs to be orchestrated by one of the players or an outsider. The print locations and distribution networks need to be strategically chosen. The operations of the supply chain stakeholders should be visible to each other and well-coordinated. The design should mitigate risks such as regulations changes, weak infrastructure and labor problems.

A. Organization of the paper

This paper considers print supply chains where on a client request and design, a specified number of documents have to be printed and the printed output has to be handed over to the courier (again chosen by the client) for delivery to client locations. In our example, we consider a bank with a number of branches throughout the country as the client; company P is the print provider; the documents in question are the commercial print requirements at bank namely the envelopes, stationary, application forms, customer account statements etc.

This paper is organized as follows: In section 2, we survey the print supply chain and bring out the issues in emerging market print networks. We also map the forward and backward print supply chain in case of a bank. In section 3,

we propose orchestration consisting of three steps - partner selection, planning and scheduling and execution. In section 4, we develop a mixed integer programming for supply chain planning and scheduling and illustrate with an example. Finally, in section 5, we discuss the future markets that can be created through efficient print supply chain management.

II. CURRENT STATE OF PRINT SUPPLY CHAIN NETWORKS

Electronic and auto supply chains are well integrated and well-coordinated. In other industries, particularly for the indirect procurement products, the supply chains are not mapped or designed to minimize the lead time and inventories. This is true especially for most of the services related chains such as food, publishing, health care, education, and others.

For example, the print supply chain map for document supply to banks is depicted in Figure 1. Here, banks have various kinds of document requirements at their branches such as envelopes, stationary, application forms for account opening, car or housing loans, motor, health and home insurance, etc and also for depositing or withdrawing cash or check. These print requirements that arise in geographically distributed branches are consolidated, ordered for printing and then are to be supplied back to bank branches. Couriers are the logistics providers that transfer document bundles among the stake holders and the logistics cost could sometimes be as much as or more than the print cost.

A profound challenge in this scenario is that stake holders do not communicate internally among themselves regarding the demands, inventories, changes in the document content to follow the changes in the regulations. They work in silos and hence there is information gap that widens over time. The result is high cost, obsolete inventory, unavailability of the required documents at the branches resulting in customer dissatisfaction. Printing and couriering can to some extent be realized by customer care call centers, e-documents and email. The structure of these chains is shown as backward supply chain in Figure 1.

A. Orchestration

The notion of orchestration within the supply chain has been thematic in the recent literature (Fung et al. 2009, Zach G. Zacharia et al. 2011). The concept is that supply chains, or supply networks, is governed by a ''hub'' firm—whose role is to provide the required services and assume control of a part of the supply network (Bitran et al. 2006). Fung et al. (2009) state that orchestration is imperative for supply chains to remain competitive in today's global environment. Bitran et al. (2006) hypothesize that supply chains can only sustain themselves if governed by an orchestrator.
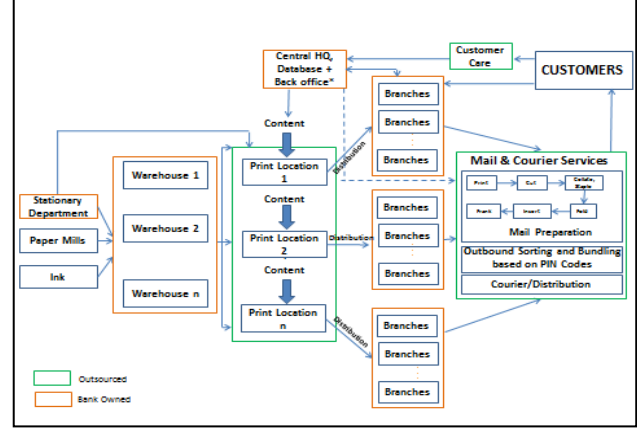

Figure1: Document Print Supply Chain – Banks

Orchestration includes - Mapping the supply chain, finding strategic partners for supplies, printing, courier, technology changes and their effect on production distribution and business models; globalization and outsourcing strategies. Orchestrating a print supply chain is nontrivial and requires domain knowledge of the industry both in terms of geography and goods. Connections with stakeholders and interconnecting with them through personal and business relationships are the soft skills needed. Soft skills in terms of negotiations and organization structure are critical for the orchestrator to sustain long standing relationships with banks, branches, print suppliers and courier service providers. This is often not given the attention it deserves and is often dispensed as trivia and the price paid is high cost and customer dissatisfaction.

III. FRAMEWORK FOR ORCHESTRATION OF PRINT SUPPLY CHAIN

Governance should ensure that critical management information which is complete, accurate, and timely should be available with the executive team to make informed decision making. This provides control mechanisms to ensure that strategies, directions, and instructions from management are carried out systematically and effectively.

The Governance model we propose has three steps: Partner selection, Coordination and Execution.

Partner selection (Structural & Relational) involves selection of partners for a particular order. In the dispersed networks, each order may visit different supply chain members depending on location of the customer, political and economic situation, resource costs, transport costs and capacity availability. Because of the short time span for the order execution the suppliers can be selected with minimal partner or political risk.

Coordination: There are several activities that need to be repeatedly performed in a timely and sequential manner by the network participants. More importantly, decisions need to be made on the following:

1. For every order, selection of suppliers; assigning the functions to them such as what to supply, how is it to be produced (e.g., product tolerances and process standards), the production and delivery schedules (how much to produce and when) and to whom and when to deliver, etc
2. Up-gradation of suppliers in terms of equipment, capacity and delivery methods to meet the regulations, standards and delivery schedules

Operations Execution: This step involves real time control of supply chain execution which involves monitoring the goods flow from origin to destination and making decisions to counter events that cause disruptions. Also, this step includes exception management using tools such as expert systems, decision support systems, case based reasoning etc. Currently this step is ignored and is done through expediting in case of failures.

Centralized orchestration, streamlined printing, distribution for multiple locations and remote monitoring of the work progress will tremendously improve the situation. We propose an orchestration model equipped with call center based monitoring for Operations execution as shown in Figure 2.
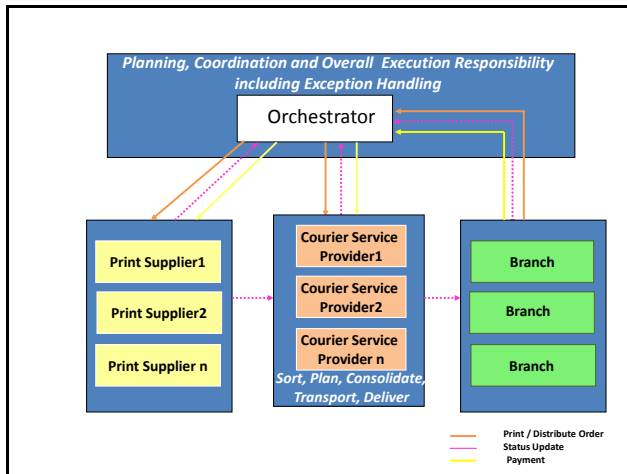

Figure 2: Orchestration Model

The orchestrator consolidates requirement patterns, streamlines the document flow, coordinates the printing and delivery of the documents to the bank branches, and also audits the printers and courier service providers. The coordinator has access to the resources and services of a number of printers as well as courier service providers for smooth information flow and to avoid any discrepancies in the service chain. The courier service providers have their own delivery routes and modes, capacity constraints and shipping schedules. It is possible to route some materials through transshipment hubs, where materials bound to the same destination can be bundled or packaged together for shipment, usually at a much lower overall cost. Information is also available on the ordering costs for procuring services from the printers and their capacities. Also, all these

operations can be monitored by a call center which can be a small team of operators with the list of print suppliers, courier service providers, network for every order for monitoring through a rule based system to handle any exceptions. Thus, it can be a call center based execution with the orchestrator managing the information flow between all stakeholders.

IV. ANALYTICAL MODEL FOR ORCHESTRATION OF PRINT LOGISTICS

The design of governance framework involves a variety of models.

1. The partner selection problem can be formulated as Fuzzy AHP or MIP problem. One can also use the transaction cost economics approach for supplier selection. All these methods are data intensive and require both regular and fuzzy data. One can rank order the suppliers for each of the components.
2. For the coordination problem, i.e. selection of partners for a particular order - one can use optimization techniques, Fuzzy AHP or transaction cost economics.
3. Theoretical tools useful for exception management include expert systems, decision support systems, and case based reasoning. Currently execution is through reactive expediting in case of disruptions rather than proactive control and execution.

There are different varieties of commercial documents types that are required by a Bank. They could be application forms for bank account opening, credit card applications, housing and car loans, student education loans, etc and also advertising material for attracting investments. The document requirements may be different at different branches. The rural branches may require account opening and agricultural loan forms more where as the city branches may require more auto loan, credit card, housing loan application form. These document forms are printed by commercial printers located in major metropolitan cities and are sent by courier service providers to the bank branches which are distributed throughout the country and exist both in rural as well as urban areas.

A. Problem Formulation for supply Chain Planning

In the following model, we assume that required number of suppliers and logistics providers are already identified and consider supply chain planning and scheduling as the first step.

The print document requirements of the bank branches can be fulfilled by different sets of printers and courier service providers at different costs and in different lead times. Importantly, they all share information on their production schedules, capacity, cost, quality, etc. with the Orchestrator. With access to such detailed operational information from all the participants in a supply chain, the challenge for the orchestrator is to best meet the supply requirements of the

bank using a combination of printers and courier service providers, at minimal operational cost.

Apart from incorporating the capacity constraints in the supply chain model, production activities need to be synchronized with the schedules of the logistics service providers, so that items can be ready for pickup in a just-in-time manner, instead of having to wait in inventory. There can be significant cost-savings through this exercise, especially in terms of synchronization of activities leading to reduced inventory levels.

B. The MIP Model

We now develop a mixed integer-programming model for print supply chain orchestrator. We assume that the orchestrator has access to operational information of entire in-bound supply chain and employs this model to select printers and logistics partners, and to synchronize the material flow throughout this network.

Objective Function

The objective of the model is to minimize the cost of printing, inventory and in-bound logistics subject to various capacity, production and logistics schedules and flow balancing constraints.

The total cost is calculated, as given in Eqn. 1, as the sum of costs incurred in the procurement of sub-assemblies. The first term in the equation represents the costs for printing followed by the costs for transportation and inventory holding. The notations for all variables are given in detail in Appendix I.

Suppose printer j was chosen to print ith document during time interval t then [PFC_{ij} F_{ijt}] is the cost of negotiation for this transaction. [PC ij Qijt] is the (Per unit production cost for document type i produced by Printer *j)* X (Quantity produced of document *i* by printer *j* in time period *t*) gives total cost of production of document i by printer j during time period t. By summing this term over all document types, all printers and all time periods, we get the total cost of print production.

The cost of transportation is TC$_{abcdt}$: Per unit transportation cost for shipment of document type *a* from printer *b* to Bank branch *c* through mode *d* in time period *t multiplied by* S$_{abcdt}$: Quantity shipped of document type *a* from printer *b* to the bank branch *c* through transportation mode *d* in time period *t*. We get the total shipping cost by summing this over all document types, all printers, to all bank branches via all modes over the time period T. Add to this the cost of setting up the operation.

WC$_{ab}$: Per unit inventory cost for document print type *a* in the possession of printer *b*.

I$_{abt}$: Inventory of document *a* with printer *b* in time period *t*.

Minimize

$$\left[\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{t=1}^{T} (PFC_{ij}F_{ijt} + PC_{ij}Q_{ijt}) \right] +$$

(Print Cost)

$$\left[\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{d=1}^{D} \sum_{t=1}^{T} (TFC_{ijkd}F_{ijkdt} + TC_{ijkd}S_{ijkdt}) \right] +$$

(Transportation Cost)

$$\left[\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{t=1}^{T} WC_{ij}I_{ijt} \right]$$

(Inventory Cost)

(1)

There are various capacity constraints on the printers, bank branches and the logistics service providers that make the solution non-trivial.

Printer Constraints

The quantity produced by printers is utmost equal to the maximum capacity when fixed cost of production is incurred and production is undertaken or else will be zero. Conversely, if the quantity produced is zero, fixed cost of production will not apply. Hence, the maximum production of the print documents is constrained by the production capacity of the printers.

Q$_{ijt}$: Quantity produced of document *i* by printer *j* in time period *t*.

PCap$_{ijt}$: Maximum production capacity for document of type *i* offered by printer *j* in time period *t*.

$$Q_{ijt} \le Pcap_{ijt}F_{ijt}, \ Q_{ijt} \ge F_{ijt}$$
$$for \ all \ i \in I, j \in J, k \in K, d \in D, t \in T$$

(2)

The documents produced are held with the printer until they are shipped off to the branches. The inventory of documents at the printer's end increases at the end of each period by the quantity produced and decreases by the amount of documents shipped out to the branch, in that time period.

$$I_{ij(t-1)} + Q_{ijt} = \sum_{k=1}^{K} \sum_{d=1}^{D} S_{ijkdt} + I_{ijt}$$
$$for \ all \ i \in I, j \in J, t \in T$$

(3)

However, the quantity that can be transported in a single period is constrained by the maximum capacity of the transportation infrastructure. Considering our scenario with fixed shipping schedules, in time-periods when the service is available the transportation capacity is non-zero. However, for time-periods where particular flights or shipments are not scheduled the transportation capacity is zero. Hence the transportation of the sub-assembly types from the sub-assembly suppliers to the manufacturers are bound by the constraint given below. Once more, the fixed cost of shipping is modeled through a binary variable representing whether shipment is undertaken or not.

$$S_{ijkdt} \le Tcap_{ijkdt}F_{ijkdt} \ and \ S_{ijkdt} \ge F_{ijkdt}$$

for all $i \in I, j \in J, k \in K, d \in D$

$$(4)$$

Special cases

Several special cases can be considered.

1. Suppose the delivery costs are the same from any printer to any branch, then we need to do choose the printer with minimum cost

2. Suppose for each document type i there are mi specialist printers' j_1, j_2, j_{mi}. Each document type can be printed at these printer locations and can be shipped directly to the branches. Thus we have I number of smaller optimization problems. The solution provides the printer location to minimize the total cost of printing and shipment.

3. Suppose clusters of bank branch are assigned printers depending on the geography, taxes, etc. They can we have as many decoupled optimization problems as the number of clusters.

C. Example

In this example, there are two printers P1 and P2 supplying three document types D1, D2, D3 to three bank branches B1, B2, and B3. There are two courier service providers CSP1 and CSP2. It may be noted from the tables that the printing costs, the connectivity, and the logistics costs vary. For example from the courier data, we see that only CSP1 provides transport services from P1 and P2 to bank branch B1 and the cost of transport is the same from either printer.

Branch	Demand for document type		
	Document 1 (D1)	Document 2 (D2)	Document 3 (D3)
1	25000	13000	5000
2	40000	20000	-
3	35000	15000	20000
Total	100000	48000	25000

TABLE 1: Orders from Branches

Printer	Specialty	Print Cost (INR[1])	Fixed cost (INR)
P1 - Mumbai	D1	2	5000
	D2	1	3000
P2 - Delhi	D1	1.5	2000
	D2	3	4000
	D3	2	2000

TABLE 2: Printers Data

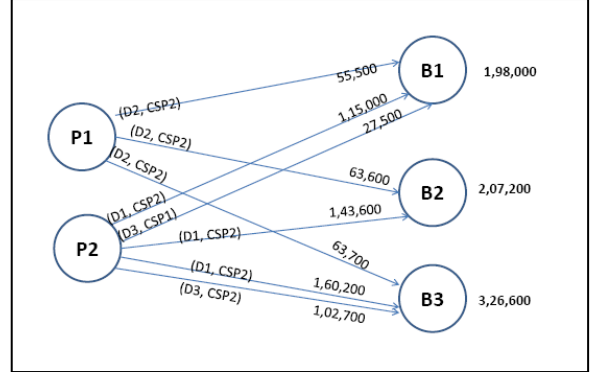| Courier SP	Printer Service	Network	Transport Cost (INR)	Fixed Cost (INR)
CSP 1	P1, P2	B1	3	500
		B2	4	400
CSP2	P1, P2	B2	2	600
		B3	3	700

TABLE 3: Courier Data

Figure 3: Optimal Solution

----

[1] INR: Notation for Indian Rupee - currency in India

The optimal solution is given in Figure 4. We find that document D2 is printed at P1 and transported by CSP2 for all the three bank branches. All other printing is done at P2 and transported by CSP2 except D3 from P2 to B1 which is transported by CSP1.

V. RECOMMENDATIONS FOR FUTURE WORK

In this paper, we introduced the generic document service chain framework, presented an optimization model for choosing the least cost route printer, courier for a particular request from bank branch. We also introduced the concept of an orchestrator supervising and controlling the entire printing network. There are several directions in which we can extend this work, the primary one being introducing real world processes and data.

End-end Supply Chain Visibility: Software platform controllers to automate operations in print shops and courier networks, by tracking and tracing capabilities using GPS and Internet. Interconnecting all the supply chain stake holders through orchestration will lead to efficient monitoring and control of the entire chain.

Strategic print sharing: Newspapers and other print chains are undergoing sea change. While the demand for print papers is coming down in developed markets, regional news papers are gaining momentum in countries like India. There is a need for low cost print shops located probably in districts supplying local content as well as global news as relevant, is a way forward. Companies can create print franchises at selective, strategic locations where a bulk load could be created by consolidating requirements of multiple clients.

Third Party And Fourth Party Print Service Providers: Each of the verticals such as banks, retail, mobile services, books, magazines, news papers have their own features but have common print requirements. For example, companies can be an orchestrator for each of the verticals and can be a super orchestrator or choreographer for the overall print services. It will induce similar efficiencies and create new businesses such as print supply chain financing, Global outsourcing, Call center based monitoring and execution and several others.

REFERENCES

[1] Bitran, G.R., Gurumurthi, S., and Sam, S.L., 2007. ''The Need for Third-Party Coordination in Supply Chain Governance.'' MIT Sloan Management Review 48(3):30–7.

[2] Fung, V.K., Fung, W.K., and (Jerry) Wind, Y. 2009. Network Orchestration: Creating and Managing Global Supply Chains without Owning Them, Upper Saddle River, NJ: Wharton School Publishing.

[3] Mc Kinsey Company Report, "India Banking 2010: Towards high performance sector"

[4] Narsimhan and Stoynoff, "Optimizing Aggregate Procurement Allocation Decisions", *Journal of Purchasing and Materials Management*, Spring 1986.

[5] Sudhendu Rai et al; LDP lean document production—O.R.-Enhanced Productivity Improvements for the Printing Industry, Interfaces Vol. 39, No. 1, January–February 2009, pp. 69–90

[6] N. Viswanadham and S. Kameshwaran, A Decision Framework for Location Selection in Global Supply Chains, Proceedings of the 3rd Annual IEEE Conference on Automation Science and Engineering, Scottsdale, AZ, USA, Sept 22-25, 2007, pp 704-709

[7] Viswanadham, N. and Gaonkar, R. (2009) 'A conceptual and analytical framework for management of integrated knowledge based logistics providers', *Int. J. Logistics Systems and Management*, Vol. 5, Nos. 1/2, pp.191–209.

[8] Weber, Charles A. and Current, John R. (1993). "A multi objective approach to vendor selection", European Journal of Operational Research, Vol. 68, pp. 173-184.

APPENDIX I: NOTATION FOR THE MIP MODEL

A. Identifiers

i : document type.
I : Number of document types.
j : Printer identifier.
J : Number of printers.
k : Bank branch Identifier.
K : Number of Bank branches.
l : Shipping Package Identifier.
L : Number of Shipping Packages.
d : Transportation Mode (Bus, Air, Rail.) Identifier
D : Number of Transportation Modes
t : Time Period identifier.
T : Total time horizon of the model.

B. Parameters

$PCap_{ijt}$: Maximum production capacity for document of type i offered by printer j in time period t. It is assumed that the offered capacity is the total available capacity with the producer, taking into consideration other commitments that the printer may have made on his capacity. Also the capacity is specific to the capacity of the printer for printing the bank products.

PC_{ij} :Per unit production cost for document type I produced by printer j.

PFC_{ij} :Fixed cost of production set-up or ordering for document type I produced at printer j.

$TCap_{ijkdt}$: Maximum transportation capacity for shipment of document i from printer j to bank branch k in time period t through mode d. The transportation capacity depends on the schedules of the logistics provider. For days/time-periods when the flights/Trains/Trucks are scheduled the capacity is non-zero, whereas for days/time-periods when the service is not available the capacity is taken to be zero.

TC_{ijkdt} :Per unit transportation cost for shipment of document type i from printer j to Bank branch k through mode d in time period t

TFC_{ijkd} :Fixed cost for procuring capacity for shipment of document print of type I from printer j to bank branch k in time period t through mode d.

WC_{ij}:Per unit inventory cost incurred for document print type i in the possession of printer j.

TL_{jkd} :Transportation lead-time for shipment from printer j to bank branch k through mode d.

C. Variables

Q_{ijt} :Quantity produced of document i by printer j in time period t.

I_{ijt}:Inventory of document i with printer j in time period t.

S_{ijkdt}: Quantity shipped of document type I from printer j b to the bank branch k through transportation mode d in time period t.

S'_{ijkdt} :Quantity received of document type i from printer j at bank branch k in time period t through transportation mode d.

F_{ijt}:Fixed cost of ordering/set-up for production of document of type i by printer j in time period t. Takes on binary values $\{0,1\}$.

F_{ijkdt}:Fixed cost associated with shipping document type I from printer j to the bank brach k through transportation mode d in time period t applies. Takes on binary values $\{0,1\}$.