Lean print manufacturing: operations simulation and analysis of digital printer

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Abstract

Print manufacturing is a make-to-order process; it converts customers' print demands into shipped print products such as books, calendars, and stationeries. Its service level objectives are usually dominated by the on-time delivery constraint. Given the existing resource makeup, the business objective of the print service providers is to drive up the throughput to dilute the fixed cost and maximize the profit while guarantees the quality of service.

The print manufacturing process outlined above, in particular on-demand digital print, cannot be simply treated as a standard manufacturing activity. The highly variable and dynamic nature of the job mix combined with personalized customer requirements results in numerous combinations of factory configuration and business philosophy. This has been identified as a key reason that hinders the print productivity growth. In this paper we report our recent development of a simulation platform of digital print manufacturing operations adopting an open-source electronic design automation tool, and shed light into paths towards implementing a lean print manufacturing paradigm.

Keywords

Digital print production system, lean manufacturing, numerical simulation, operations modeling

Introduction

Commercial print has annual retail sales over US$700B. It is a major business focus for HP. General commercial print is observing a secular trend: the job run-length gets shorter; the significant setup cost of the plate creation is making analog press less economical for a growing number of jobs. This is further validated by the predictions made by industry experts during this year's International Congress on Imaging Sciences [1], that, the paradigm shift in commercial print will be "not a massive decrease in the use of print but clearly indicate a massive change in the use of print", more precisely, the ever growing demand for "mass customization and personalization of print". These all point towards the promise that the digital print will be the driver for the future growth of print.

Digital print, foremost, refers to marking technologies that do not involve a makeready procedure (without a physical printing plate with a fixed image), which is usually a costly procedure in both time and material. Example digital print marking technologies include electrophotography and ink jet. The term "digital print" also refers to the "*just in time*" print manufacturing practices that are uniquely enabled by digital print marking technologies and make fulfilling short run-length jobs economical even to the extreme of "*batch of one*".[2] As a pioneer and leader of digital

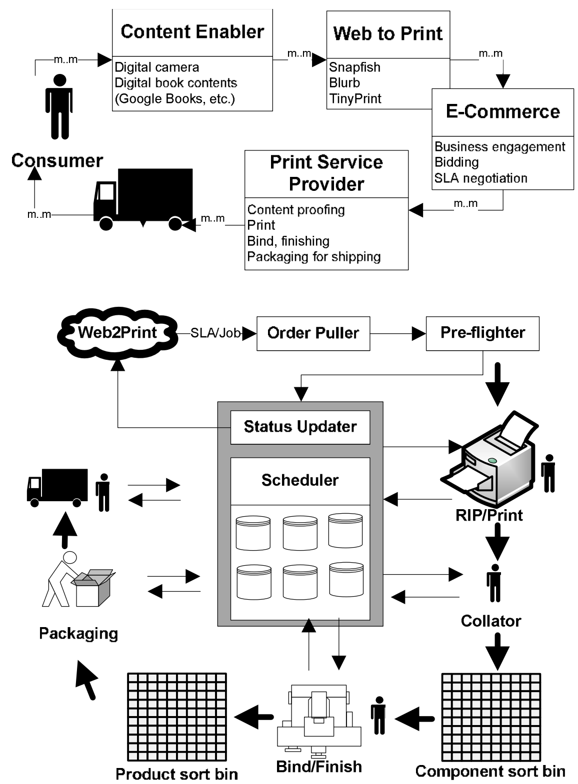
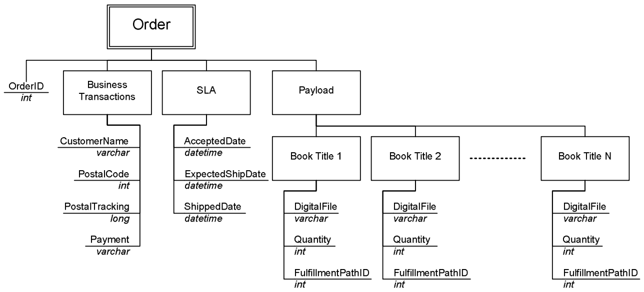


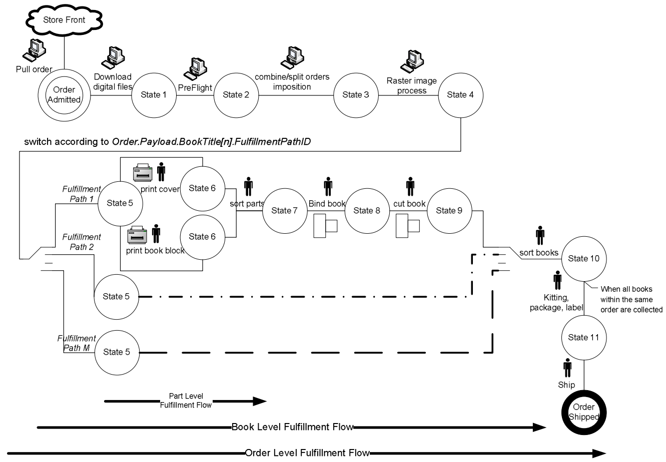
Figure 1: Commercial print. Top: the print consumption eco-system. Bottom: a typical end-to-end print workflow within a print service provider.

print, HP's strategic position in driving up its print growth is through accelerating the analog to digital print conversion and by improving the unit profitability in commercial print. While great progresses have been made in the printing technologies, there are still technological barriers in print manufacturing operations management tools and methods.

The sketch at top of Fig. 1 outlines the print consumption eco-system. The explosive volume and diversity of printable digital contents drives the print manufacturing transitioning towards a form of mass customization fulfillment [3] rather than the conventional streamline manufacturing targeted at high volume but limited diversity products. As the demand fulfillment arm, the print service provider needs to adjust its capacity planning and operations policies to accommodate the variability in demand characteristics. The bottom sketch zooms in print manufacturing process. It illustrates an example end-to-end workflow within one print service provider. The customers' requests for prints are submitted through the store front. This includes customers'



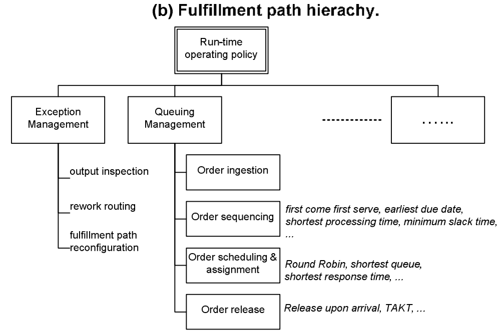
(a) Content of an order.



(b) Fulfillment path hierachy.

Machine Type	Tasks Fulfilled	Quantity	Performance (mean)	Performance (std)	Interruption
SRS Servers	State 3 → State 4	10	1 sheet/second	…	no
Indigo 5000	State 5 → State 6, book block	6	1 sheet/second	…	operator break; service break; paper jam.
Indigo WS6000	State 5 → State 6, book cover	1	0.5 meter/second	…	operator break; service break; paper jam.
Duplo DC-645	State 5 → State 6, book cover	2	0.4 sheet/second	…	operator break; service break; malfunction.
Duplo DPB-500	State 7 → State 8	4	0.1 cycle/second	…	operator break; service break; malfunction.
……	……	……	……	…	……
Worker: shift A	all	16	……	…	[6AM, 2:30PM], 15-minute breaks at 8AM, 10:30AM, 12:30PM
Worker: shift B	all	10	……	…	[2:30PM, 11PM], 15-minute breaks at 5PM, 7PM, 9PM

(c) Makeup of resources.



(d) Operating policies.

Figure 2: Model characterization of a print manufacturing operation.

physical visits, and, increasingly, jobs submitted electronically through the internet (web-to-print, for instance, *www.blurb.com*, *www.snapfish.com*). Once accepted, a unique job ticket is assigned. A job ticket usually contains a job number, number of copies, due dates, prices and payments, client information, inks and presses, finishing, and shipping methods. The submitted electronic files (*e.g.*, pdfs and tiffs) are examined for the correctness (preflight), edited for color quality and accuracy, imposed, and flattened and half-toned (raster imaging process) to create the bitmaps. Printer-ready electronic files are then sent to the printers to produce physical copies. Printed sheets or web are first singulated into printed pages which are then folded, collated, and bound into book blocks. The book blocks are joined to book covers. The finished books are then sorted, labeled, and shipped.

Print manufacturing process outlined above demands both product diversity and mass manufacturing, and is both capital-intensive and labor-intensive. The print orders are usually high frequency, low volume, and short time to allow for fulfillment. The highly variable and dynamic job mix and highly personalized customer requirements calls for a modern, data-driven decision-making paradigm for the print manufacturing operations.

In this paper, we describe a holistic, model-based approach that provides quantitative prediction and analyses of the print manufacturing operations. [4] The print service provider is modeled as a heterogeneous, concurrent, integrated system, accounting for the performance, efficiency, stability, and sustainability as organic system attributes. We illustrate example applications of this model-based approach to provide operational level assistance in the ever-changing dynamics of the production floor, and contribute to providing automated digital commercial print solution.

Operations Modeling

The scope of this modeling effort is the fulfillment of the print consumption eco-system, that is, the print manufacturing operations within a print service provider. Per the argument given above, our attention is primarily given to digital printers that practice print on-demand. The starting point of this modeling exercise is to extract only the first-order effects and reduce the problem dimensions to minimal so that we can formalize this problem mathematically. Fig. 2 illustrates the minimal set of the characteristics required to fully define and re-construct a print operation:

a) Admitted orders. An order can be a JDF [5a] file directly created in Acrobat during the content creation stage. It may also be in other forms of XML [5b] or PPML [5c] file format of which has been negotiated upon beforehand between the print service providers and their upstream digital content providers. An order describes complete fulfillment specifications in addition to other information. These specifications are then used in a print manufacturing environment to produce and ship the final printed product. The customer information including shipping and payment provides a financial measurement of late penalty, for instance, the costing to upgrade shipping method to make up the manufacturing delay. The service level is primarily determined by the possible late shipment (the *ShippedDate* is later than the *ExpectedshipDate*). A floor manager (a person or automated factory floor management software) may raise the priority of an order so that it jumps ahead of the queue when seeing its *ExpectedshipDate* is approaching and there is a danger to be late. The *AcceptedDate* may not necessarily be the time that the order has to be released to the factory floor. Order release mechanisms attempt to dampen the volatility of order arrivals. The payload provides the complete specification of the manufacturing process. For each book within this order, a *FulfillmentPathID* (also see Fig. 2b) specifies a particular workflow.

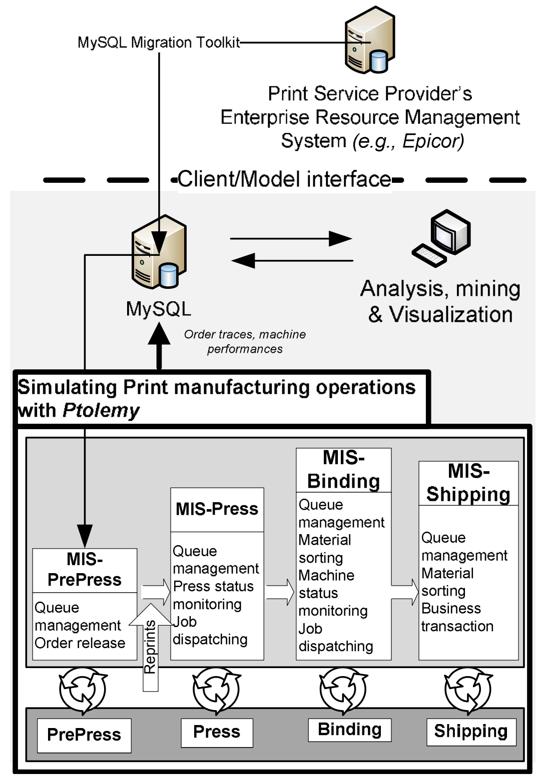
b) Set of all possible fulfillment paths. Product customization and personalization is one of the principal challenges to the digital print productivity. To enable productivity optimization yet simultaneously accommodating product diversity, one approach is to narrow the fulfillment to a handful product types that contribute to most of the revenue according to past order history and marketing forecast. [6] This list of product types is then used to guide the optimization of the factory floor and order admission. Each product type has its pre-defined fulfillment path; resources are shared among different fulfillment paths whenever optimal.

Fig. 2b indicates a tree structure of depth three: the root node is an order; each order contains multiple book types, which are its children nodes; each book may be composed of multiple parts (*e.g.*, a cover and a book block), which are the leaf nodes. Fig. 2b illustrates one particular digital print factory. An order breaks into book tokens at the switch after *state 4*; a book token breaks into part tokens after *state 5*; corresponding parts assemble into a took token after *state 7*; and multiple book tokens assemble into an order token after *state 10*.

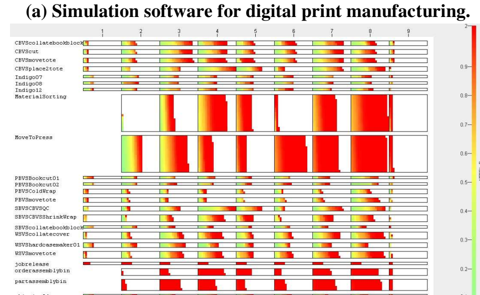
c) Available resources. The fulfillment paths illustrated in Fig. 2b must be further augmented with the list of resources that map the tasks demanded by the fulfillment paths with the "workers" — including software, automated machines, operator-assisted machines, and operators — that carry out the respective tasks.

d) Runtime policies that guide real-time operations. Usually there are multiple orders released to the factory floor simultaneously and they compete for resources, priorities for services need to be given to *urgent* orders — order sequencing is a rule or algorithm that calculates the order urgency according to the operations objective and orders' attributes (see Fig. 2a). Similarly there may be multiple machines that can fulfill the same task (see Fig. 2c), priorities for the task assignment need to be given to the most *effective* machines orders — order assignment or resource binding is a rule or algorithm that calculates the machine effectiveness according to the operations objective and machines' attributes and states. Exception handling specifies the faulty rate of each resource and rules or algorithms that guide rework such that the production setbacks caused by the faulty works are minimized. Machines may be interrupted due to services or breakdown; fulfillment path reconfiguration deals with dynamically re-routing orders such that the production setbacks caused by the machine interruption are minimized.

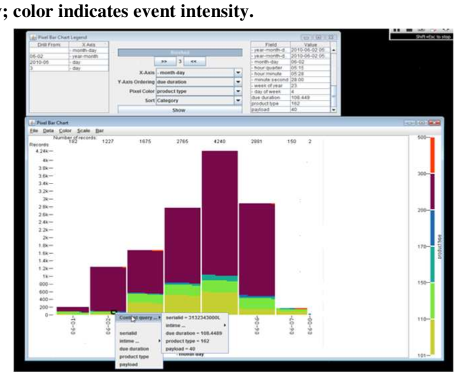
Fig. 3a illustrates the architecture of the operations simulation software developed for commercial print services and print manufacturing. The order stream is acquired from printers' enterprise resource management system; the fulfillment paths, resources and the operating policies are programmed using an open source code Ptolemy, electronic design automation software developed by University of California, Berkeley. [7] Fig. 3b and 3c show example results that apply visual analytics tools (*VisTS* and *PixelBarChart*, both developed by Hewlett Packard Laboratories



(a) Simulation software for digital print manufacturing.



(b) Time series of machine activities. The horizontal axis is the date; vertical axis is list of machines under surveillance; bar volume indicates event frequency; color indicates event intensity.



(c) Multi-level order statistics of a subset of product types of interest (e. g., products with high margin). High activity area is automatically marked.

Figure 3: Simulation of digital print manufacturing. The example simulation shown in (b) and (c) uses direct inputs and measurements from a digital printer partner.

[8]) to query the massive site data generated by the simulation. We are looking into integrating the simulation and the visual analytics tools into a single view of a dashboard that can display both the factory level performance and cell-machine level dynamics, and provide automated query and correlation discovery among different attributes.

Lean Print Manufacturing: *"what's in a name?"*

Originated from the manufacturing practices perfected by Toyota, lean manufacturing [9] became a highly celebrated term in 1990s owing to its success in seemingly different sectors from aerospace industry to hospital service management. In recent years, the application of lean philosophy to print production has been investigated by both print technology vendors (*e.g.*, [10]) and digital print service providers.

Many lean preaching come in the form of lists of detailed operations rules (e.g., "seven zeros" [11]). However it is critically important to understand that the lean rules are negotiable and only means to an end. [12] From systems dynamics perspective, the lean rules are a set of implementation solutions of a systems optimization problem. In print, the operations frontier can be described by its unit cost, faulty rates, product diversity and service level, which can be further deduced into measurable optimization objective: maximizing *right* throughput in terms of prioritized product types, and minimizing inventory and operational expense. The optimization space is defined by all the flexibilities within the print manufacturing system, as illustrated in Fig. 2. Digital print holds a unique, additional dimension in its optimization space: it is economical to dynamically reconfigure the fulfillment paths in the event of machine failure, surge of certain product type, or driven by other motivations in pursuing the system optimization objective.

The operations simulation can pave ways to accelerate lean adoption in digital print: it can serve as a verification tool before various lean rules be implemented at factory floor, a performance measurement component within a system optimization infrastructure, a platform to implement collaborative planning, forecasting and replenishment (CPFR), and supplemental to management intuition. The following illustrates an application example of operations simulations. "Zero surging" [11] is one of the principal lean rules demanding smooth manufacturing flow. This is particularly challenging for digital print as there exists intrinsic uncertainty and variability in customers' demand. Therefore, a smart management of an order buffer is required to de-couple the highly volatile demand flow and downstream smooth manufacturing flow accounting for the service level requirement. Simulations have been successfully applied to choose an optimal order pool management solution.

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[5] [a] Job Definition Format, see: http://www.cip4.org/ ; [b] Extensible Markup Language, see: http://www.w3.org/XML/; [c] Personalized Print Markup Language, see: http://ppml.podi.org/ .

[6] Pareto principle states roughly 80% of the effects come from 20% of the causes. That is, 80% revenue may come from top 20% of the product types.

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Gary Dispoto is the director of the Print Production Automation Lab, which seeks to streamline the processes required to produce industrial and commercial digital print, enabling new types of printed products and broader access to commercial print production. He holds several U.S. patents related to color imaging. Gary received B.S. and M.S. degrees in electrical engineering from Stanford University and an MBA degree from the University of Santa Clara.

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