Measuring Manufacturing Productivity

David R Spencer, Catherine Fiasconaro, Vishal Sahay; SpencerLab Division, Spencer & Associates Publishing; Melville, NY/USA

Abstract

Whether manufacturing 2D or 3D printed products, the press itself is one of your largest investments; improving your Return-on-Investment is one of your key goals. For many presses, the ROI is predicated on producing hundreds of thousands or even millions of dollars worth of output. An increase of just a few percent would have a very significant impact on ROI. The industry has heretofore been satisfied with merely tracking job flow. Historically, identifying the obstacles to improving press productivity, utilization, and ROI has relied on anecdotal information; real information – quantitative press productivity data – has not been available.

Recognizing the problem, we focused upon the lack of data identifying the bottlenecks. One fundamental breakthrough was realizing that only press operators on the shop floor know much of the needed information. The information must be acquired in a minimally invasive manner, categorized, aggregated, analyzed, and presented as metrics that support and facilitate identification of the real obstacles and bottlenecks.

We will describe and demonstrate a new, patent-pending methodology and system that actually measures productivity of any press or other output-producing machine over time. This is not another printing MIS system; rather, it highlights bottlenecks and opportunities for productivity improvement. Implemented with today's state-of-the-art technologies, the system incorporates touchscreen, tablet-based data collection GUI, cloud-based data storage and analysis, and browser-based anytime, anywhere graphical dashboard and reporting.

Background

Far from the sub-$99 desktop printer, manufacturers are shipping tens of thousands of production digital printers capable of producing billions of full color pages annually. As an example, a Hewlett-Packard T400-series digital web press requires a multi-million dollar investment, but its ability to print over 3000 full-color, double-sided A/A4 pages per minute provides a major return on that investment. Industrial 3D printers are also producing high-value output; their productivity is of increasing interest.

Production presses are a major investment; in order to maximize the return on that investment the press needs to produce as much usable output as possible during its operational time. Our studies have indicated that many users focus on job production, and assume that downtime is inevitable – but they don't know whether all that downtime is required; in fact, they don't really know how much downtime they actually have, why and on what that downtime is being spent, nor most importantly what unnecessary obstacles and bottlenecks are adding to that downtime. If 'time is money', 'wasted time is wasted money'. Efficient tools have not been available to collect, organize, and present the downtime as actionable intelligence – until now.

Management Information System (MIS) software tracks jobs as they flow through a printing press, and such software often extends to support job acquisition, job estimating, job accounting, etc. While it is an important and helpful tool for the press owner managing his business, this software overlooks key information… When the press was not available to process the jobs, why was it not available? Was there a consumable replacement, preventative maintenance or unscheduled service, a quality adjustment, defective prints, an incorrect job specification or setup, poor color matching, etc.? Downtime and its causes are not tracked by typical MIS systems. It is only in answers to these questions that downtime can be analyzed, and improvements can be implemented.

MIS systems cannot know whether the output is usable as sellable output, for example, whether it meets the color requirement of the job, whether the correct media was used, what additional training could reduce downtime, or what in-line equipment is stealing time from the press, etc. Accordingly, current technology does not incorporate either the "human element" or the sell-ability factor. Good management needs data measurement and analysis – business intelligence we call Productivity Intelligence – in order to improve productivity and thereby increase ROI with all its associated financial benefits.

Overview

We have developed a novel method for measuring how much time is spent not producing usable output and in what ways that time is being consumed in order to facilitate identification of wasted time, its causes, and corrective actions; this data-based information has fundamental value in enabling the identification and elimination of bottlenecks to productivity in the printing process. The methodology includes data collection from the shop floor, storage in a database, real-time analysis, and intuitive graphics-based reporting.

It is important to remember that the fundamental parameter of productivity measurement is Time. There are only 24 hours in a day, and whether you run two 12-hour shifts or three 8-hour shifts, the important thing is how that time is utilized. It is instructive to consider the full 24-hour period as Total Production Time, and to parse that time into meaningful categories for analysis. In order to maximize ROI, we want to maximize the percentage of those 24 hours that is spent producing usable output. Obviously, this can be accomplished by minimizing the percentages of time spent non-productively. Press owners have invested in a high-value asset, and in order to maximize its ROI the task is to measure how the 24 hours is spent, and to identify activities that are wasting precious moments – and turn them into productive ones.

Methodology

Our methodology is based upon the classic circle of continuous improvement: Measure, Analyze, Improve, and Measure all over again to assure current improvements – and seek further improvement possibilities (see Table 1).

Measure	Identify processes to be evaluated
	Categorize activities within the process
	Collect data on each activity
Analyze	Analyze data over time to identify trends
	Compare quantified performance to benchmarks
	Identify improvement opportunities and causes for deficiencies
Improve	Develop improvement strategy with priorities
	Implement strategy and improve productivity
Repeat	Repeat the process to assure results and identify further opportunities

Table 1. *Continuous Improvement: Measure, Analyze, Improve, Repeat*

Definitions

There are many words used in discussions about productivity. In order to minimize semantic confusion, we have defined three common ones in a self-consistent manner. These words are ***Utilization***, ***Uptime***, and ***Productivity***. Some definitions rely on the IDLE TIME category – time when the press appears to be available, but is not being utilized. We have defined these words in terms of these Times (also shown in Figure 1):

- **Actual Production Time** – time PRINTING USABLE OUTPUT
- **Potential Production Time** – time in all press-related categories together, excluding IDLE TIME; that portion of the workday when the press might be in use
- **Total Production Time** – total time, time spent in all press-related categories together, including IDLE TIME; the total shop workday

During the Potential Production Time, the more time a press spends actually producing sellable print pieces without stoppages, the more benefit will be realized to the organization. Therefore, we define ***Productivity*** as the ratio or percentage of **Actual Production Time** to **Potential Production Time**:

$$\boldsymbol{Productivity} = \frac{\textbf{Actual Production Time}}{\textbf{Potential Production Time}} \tag{1}$$

We define *Utilization* as the ratio of Actual Production Time to Total Production Time:

$$\boldsymbol{Utilization} = \frac{\textbf{Actual Production Time}}{\textbf{Total Production Time}} \tag{2}$$

We define *Uptime* as the ratio of Actual Production Time plus Idle Time to Total Production Time:

$$\boldsymbol{Uptime} = \frac{\textbf{Actual Production Time + Idle Time}}{\textbf{Total Production Time}} \tag{3}$$

Users focus on optimizing ***Productivity*** and ***Utilization***, while ***Uptime*** is of most interest to manufacturers.

Categorization

One of the criteria for developing a universal methodology for measuring manufacturing productivity is to be independent of the specific machine technology. The corollary is to create a fixed set of categories that are universally applicable to the class of machines of interest:

- PRESS STARTUP ACTIVITIES
- JOB SETUP/MAKE READY
- PRINTING USABLE OUTPUT
- PRINTING UNUSABLE PRESS WASTE
- QUALITY CONTROL ACTIVITIES
- CONSUMABLE REPLENISHMENT
- JAM/BREAK/CLOG
- PROCESSING TIME
- PREVENTATIVE MAINTENANCE
- IN-HOUSE REPAIR
- SERVICE CALL
- IDLE TIME

For printing presses, whether color or monochrome, whether digital or offset, cut sheet or web, inkjet or laser, 2D or 3D, we created these categories (also shown graphically in Figure 1).

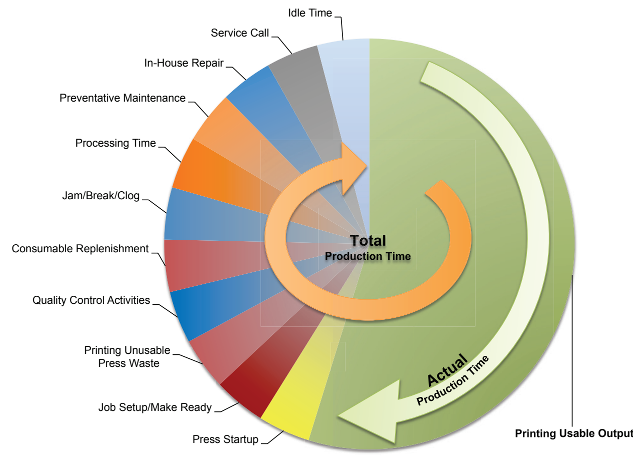

Figure 1. *Categories for Universal Productivity Analysis*

Each of these top-level categories is designed to allow comparison of like activities among a range of different printing devices. For example, JAM/BREAK/CLOG would include paper jams on cut-sheet presses, web breaks on web-fed presses, and breaks or clogs of 3D printer filament feeds. Within each category, there may be subcategories appropriate for a specific press, enabling analysis that is more detailed. This categorization evolved through test and analysis of a variety of presses to date[1, 2].

System Implementation

System Architecture

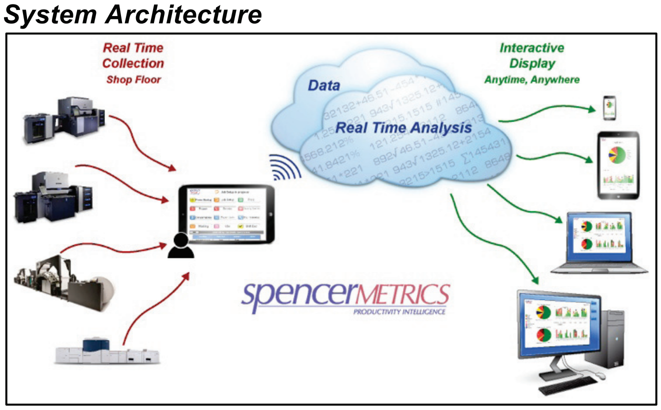

Figure 2. *SpencerMetrics System Architecture*

The system, which we call *SpencerMetrics*, embodies touch data entry, cloud-based storage, real-time analysis on demand, and reports that can be displayed in any browser (see Figure 2).

Its stand-alone nature means that installation does not require IT support (other than reliable Wi-Fi Internet connectivity), that setup is immediate, and users can be on-line in less than 24 hours.

The on-demand anytime, anywhere analysis allows for the flexibility of exploration, of customized displays of data, and facilitates for trend analysis, forecasting, and problem identification. With almost instantaneous feedback one can think of a related question, change a parameter, and see the analysis before the thought is lost – invaluable in this multitasking age (see Figure 3).

Figure 3. *SpencerMetrics Continuous Productivity Improvement System*

Data Acquisition

We are interested in 24/7 data – knowing how the machine is being utilized at any moment of time on a continuous basis. To accomplish this, each press operator begins his/her log at the start of their shift and records the events in real-time. Every log entry is automatically tagged with $\text{Time}_{\text{START}\boldsymbol{n}}$, the Event Start Time. Event durations are calculated during analysis.

With categories established, time spent by the machine in any category is logged within the category, and frequently within a sub-category. Most common events are incorporated in submenus within the predetermined categories.

The value of the data increases as the operator provides additional detail for each entry, such as comments (*i.e.*, why was an In-House Repair necessary), Press Waste descriptions, etc. The quality of the data determines both the accuracy of the results and its value (GIGO rules). The press itself cannot provide shop floor data that only the human operator knows; operator input is essential.

The challenge in data collection is to not interfere with the workflow of the operator nor take away from press operational tasks. Methodologies to minimize the operator's data entry time and entry strokes while maintaining accuracy must be established and utilized. Significant attention has been paid to minimizing operator keystrokes. Two years of operator feedback have been incorporated in the refinements of the data acquisition mechanism.

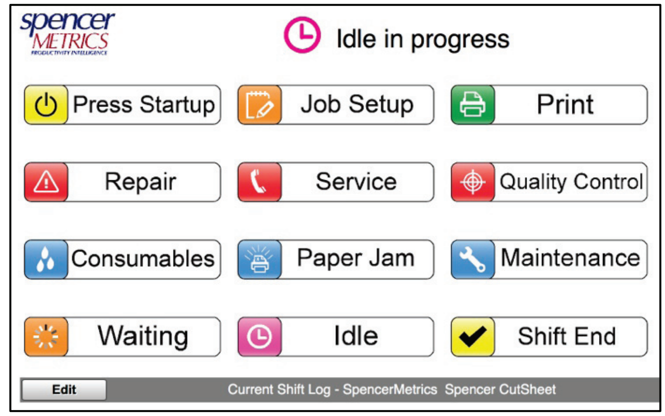

Figure 4. *Data Entry Terminal Screen*

The operator interfaces with the system through our Data Entry Terminal, comprising a touch screen with our proprietary software (see Figure 4). We utilize a high-quality tablet (an iPad mini) to assure ease of use, durability, support, overall system quality, and a balance with physical size. The submenus allow auxiliary information to be collected quickly from the press operator. The entire process and graphical user interface has been streamlined to maintain data integrity while having the least impact on the operator. Without additional comments, average event entry takes less than seven (7) seconds.

As each event is entered into the Data Entry Terminal, it is transferred to our cloud-based database. An acknowledgement is returned to the Data Entry Terminal and displayed below the data entry panel.

Data Analysis & Reporting

Complex analysis can be performed on-demand and aggregation of data based upon specific variables such as event, month, shift, or operator can be presented. The personalization of data analysis allows the user to choose content detail based upon their individual request and requirements. Through any web browser, from the time of a user's request, analysis summaries are provided almost instantaneously via an intuitive user dashboard. Effective data aggregation is the key to enhanced analysis and simple to comprehend at-a-glance results. This is turn allows for quick and easy identification of areas for improvement.

The first step in data analysis is the computation of event durations. Since we are interested in 24/7 data – knowing how the machine is being utilized on a continuous basis – the end of any activity ***n*** is determined by the start of the next activity ***n+1***.

$$\text{Time}_{\text{END}\boldsymbol{n}} = \text{Time}_{\text{START}\boldsymbol{n}+1} \tag{4}$$

Of course, the duration of any activity ***n*** is the time between the start of activity ***n*** and the end of activity ***n***.

$$\text{Duration}_{\text{n}} = \text{Time}_{\text{END}\boldsymbol{n}} - \text{Time}_{\text{START}\boldsymbol{n}} \tag{5}$$

This means that all activity durations may be determined solely by the start times.

$$\text{CategoryDuration}_{i,n} = \text{Time}_{\text{START}\,n+1} - \text{Time}_{\text{START}\,n} \tag{6}$$

Data acquisition therefore only has to consist of acquiring the start time of each activity (including IDLE TIME). This detailed information can be displayed both graphically (see Figure 5) and in tabular form in TimeLine.

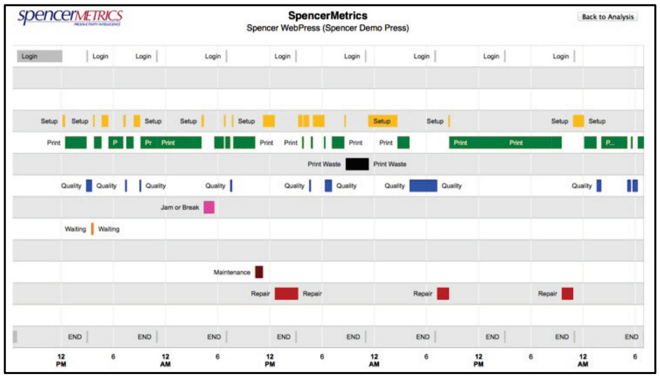

***Figure 5**. Analytical Report – TimeLine*

The next step in analysis is to aggregate the time spent in each category and each sub-category over a selected period. Available periods include Shifts, Days, Calendar Weeks, and Calendar Months.

For category (or sub-category) i, the aggregated time within a given period is the sum of all category durations within the period:

$$\text{CategoryDuration}_{i} = \sum\nolimits_{n,period} \text{CategoryDuration}_{i,n} \tag{7}$$

The category durations are shown in a stacked column bar graph for each period and tabulated. The ending date of any period may be selected by the user. In order to better understand trends and to be alerted to potential obstacles and bottlenecks, multiple periods are shown in the stacked column bar graph. As with the date, the number of periods is selectable by the user (see Figure 6).

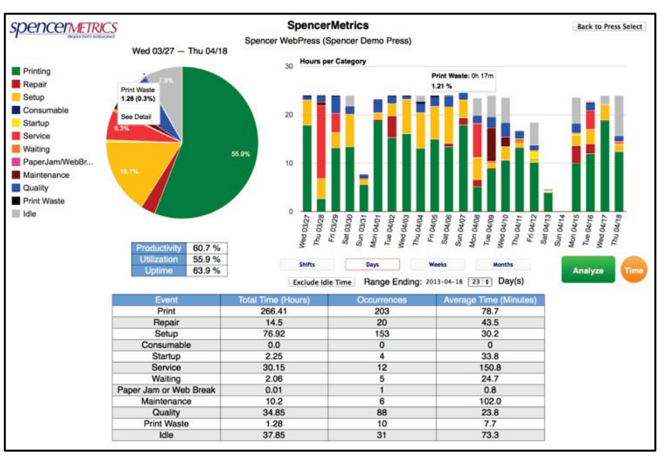

***Figure 6**. Analytical Report – Days*

In the third step, all of the time within selected periods is further aggregated into a total time for each category, displayed in a pie chart and tabulated. This easily communicates the message of how time is actually being spent.

As noted above, analysis of a press can be requested for the time between any two dates by specifying the number of periods and end date; this result is shown both in the table and in the pie chart. The granularity can be set to Shifts, Days, Weeks, or Months; each such period is shown in a stacked column.

Mouse-over either the pie chart or the stacked column and the category time and percentage are shown in a pop-up. This emphasizes the difference between anecdotes or feelings about how things are going and an understanding based upon real data, between qualitative and quantitative information that may be quite different.

Potentially problematic trends often appear quite clearly, and where needed, corrective action can be taken and the consequences can be tracked.

Comparisons

It is natural to want to compare results in order to facilitate the communication and understanding of differences and their importance. In addition to a comparison between two presses, perhaps similar models, it is desirable to be able to compare productivity of different shifts, and even to compare different times – such as before and after a potential improvement is implemented – in order to gauge its value (see Figure 7).

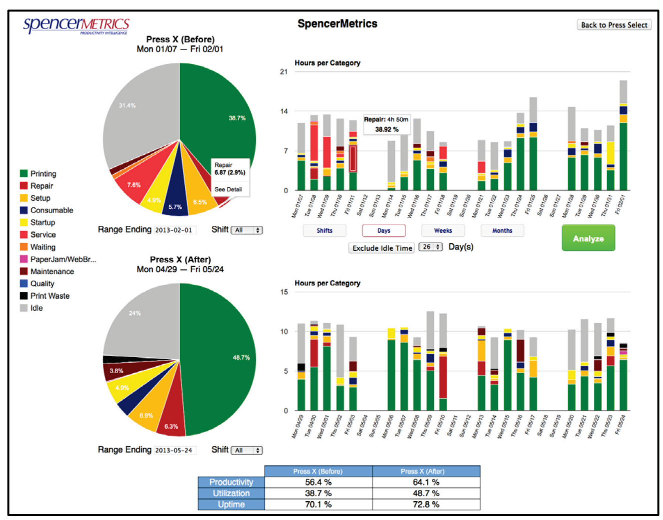

***Figure 7**. Analytical Report – Compare (Times – Before and After)*

With this data, one can compare with group norms or industry standards. Identification of areas for improvement can be readily ascertained and prioritized according to greatest ROI.

Improvement

With the increased segment growth of high-speed production printers, even small improvements in productivity can result in the potential increase of revenue worth hundreds of thousands of dollars.

As an example, a 1% productivity improvement on a press such as the toner-based Xerox iGen150 (Figure 8) would yield a large financial benefit.

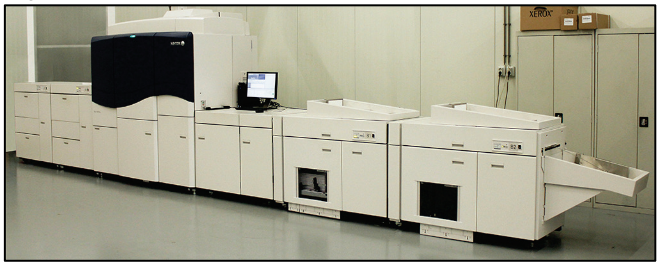

***Figure 8**. Xerox iGen150 Press*

This press prints 150 A/A4 pages per minute in full-color duplex (4/4; that is, 4-color images on both sides of the sheet). If it were used for 16 hours of operation a day, 5.5 days of operation per week for 50 weeks, at 100% utilization it could produce nearly 40 million pages annually:

$$150\,\frac{pages}{min} \times 60{\times}16\,\frac{min}{day} \times 5.5\,\frac{day}{wk} \times 50\,\frac{wk}{year} = 39.6{\times}10^6\,\frac{pages}{year} \quad (8)$$

Assuming an average sale price (ASP) of each full-color duplex A/A4 printed piece to be 25¢, an improvement of only 1% would be worth additional annual revenue of $99,000 for the press shop – with the same resources, the same press, the same staff, and within the same time:

$$39.6{\times}10^6\,\frac{pages}{year} \times 1\% \times 0.25\,\frac{\$}{page} = \$\mathbf{99,000} \quad (9)$$

As another example, the HP T400 Color Inkjet Web Press, prints a 42-inch web in full-color duplex at 600 feet-per-minute (Figure 9).

***Figure 9**. Hewlett-Packard T400 Color Inkjet Web Press*

If it were used for 24 hours of operation a day, 6 days of operation per week for 50 weeks, at 100% utilization it could produce 1.4 billion pages annually:

$$42\,in \times 600\,\frac{ft}{min} \times 12\,\frac{in}{ft} \times \frac{pages}{8½in{\times}11in} = 3234\,\frac{pages}{min} \quad (10)$$

$$3234\,\frac{pages}{min} \times 6{\times}24\,\frac{min}{day} \times 6\,\frac{day}{wk} \times 50\,\frac{wk}{year} = 1.4{\times}10^9\,\frac{pages}{year} \quad (11)$$

Assuming an ASP of each full-color duplex A/A4 printed piece to be only 2½¢, an improvement of 1% would be worth additional annual revenue of $350,000 for the press shop – again with the same resources:

$$1.4{\times}10^9\,\frac{pages}{year} \times 1\% \times 0.025\,\frac{\$}{page} = \$\mathbf{350,000} \quad (12)$$

Conclusion

The productivity of machines that produce sellable output is an important-but-underappreciated attribute with significant financial implications. For an industrial printing press, 2D or 3D, color or monochrome, digital or conventional, a small improvement in productivity can provide a significantly better ROI.

While much attention has been placed upon job flow, negligible attention has been given to improving productivity of the press itself. We have studied and understood the problem, and have developed a methodology and system that can demonstrate how to meaningfully improve the return on asset investment. The innovative *Spencer**METRICS*** tool facilitates understanding of *why* an expensive output-producing asset, a printing press, is not producing more – so that it can.

References

[1] Spencer & Associates Publishing, Ltd., "Digital Press Benchmarks: Availability & Actual Production – Xerox iGen4, HP Indigo 7000, Indigo 5500, Indigo 7500, and Indigo 7600" (Melville, NY, 2013), pp. 1-11, from http://www.spencerlab.com/reports/SpencerLab-Xerox-Availability-White-Paper_Aug2013.pdf.

[2] Spencer & Associates Publishing, Ltd., "Digital Press Benchmarks: Availability & Actual Production – Xerox Color 800, Konica Minolta bizhub C8000, and Ricoh Pro C901" (Melville, NY, 2012), pp. 1-8, from http://www.spencerlab.com/reports/SpencerLab-Xerox_EPC_Availability_WhitePaper_Jan2012.pdf.

Author Biographies

David R Spencer

Having earned SB (1962) and SM (1968) degrees in Electrical Engineering at the Massachusetts Institute of Technology, David Spencer continues to contribute as a technologist and executive. He has been awarded eight issued patents. A successful serial entrepreneur, he is founder and president/CEO of Spencer & Associates Publishing, Ltd. and co-inventor of the SpencerMetrics methodology and system. An expert in color print quality analysis, Mr. Spencer also led development of numerous printing products, including LaserScribe™, the first 1000² dpi printer, the AN/UXC4 tri-service MFP, and the Unifax II Newspicture Receiver. He has also been active in the development of international printing-related standards for NACSEM, ISO/IEC JTC 1 and INCITS, where he received an award for Productivity standards development.

Catherine Fiasconaro

As Director of the SpencerLab Digital Color Laboratory, a division of Spencer & Associates Publishing, Ltd., Cathy Fiasconaro leads all project testing and research. She is a co-inventor of the SpencerMetrics methodology and system. Ms. Fiasconaro has expertise across the spectrum of printer testing, including Focus Group moderation and management. A Microsoft Certified Systems Engineer, she earned a BA in Economics at Stony Brook University.

Vishal Sahay

In addition to his expertise in Color management, Vishal Sahay leads projects analyzing print quality, ink/toner cost-per-print, and psychometric statistical analysis of central location focus group testing as well as throughput performance – he is a co-inventor of the SpencerMetrics methodology and system. He earned an MS in Print Media from the Rochester Institute of Technology and a BE in Printing Engineering Technology from B.M.S. College of Engineering in India.