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Variability Reduction: A Statistical Engineering Approach to Engage Operations Teams in Process Improvement

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ABSTRACT A U.S. printing company successfully implemented a team-based variability reduction methodology to enable operations teams, primarily pressmen and bindery operators, to establish standard processes, identify and eliminate sources of variability, establish the daily disciplines necessary to sustain the productivity improvements over time, and create an environment to facilitate step-change productivity improvement through Six Sigma projects. This article shares the methodology and how it addressed the hallmarks of a problem requiring statistical engineering and incorporated key aspects of the theory of statistical engineering.

KEYWORDS Six Sigma, stability, standard process, statistical engineering, variability reduction

INTRODUCTION

Hoerl and Snee (2010a) defined *statistical engineering* as "the study of how best to use statistical concepts, methods and tools and integrate them with information technology and other relevant sciences to generate improved results" (p. 60). Hoerl and Snee (2010b) further identified five aspects of the theory underlying statistical engineering effectiveness:

1. A system or strategy to guide the use of statistical tools is needed to effectively use the tools.
2. The impact of statistical thinking and methods can be increased by integrating several statistical tools, enabling practitioners to deal with highly complex issues that cannot be addressed with any one method.
3. Linking and sequencing the use of statistical tools speeds the learning of the approach, thereby increasing the impact of the method.
4. Embedding statistical thinking and tools into daily work institutionalizes their application.
5. Viewing statistical thinking and methods from an engineering context provides a clear focus on problem solving to the benefit of humankind.

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Snee and Hoerl (2010) identify seven hallmarks of typical problems requiring a statistical engineering solution as:

1. The solution will satisfy a high-level need of the organization.
2. There is no known solution to the problem.
3. The problem has a high degree of complexity involving technical and nontechnical challenges.
4. More than one statistical technique is required for the solution. Typically, nonstatistical techniques are also required.
5. Long-term success requires embedding solutions in work processes, typically through using customer software and integrating with other sciences and other disciplines.
6. The whole is greater than the sum of the parts. The impact is greater than what could be achieved with individual tools.
7. A solid theoretical foundation is required to guide development of a solution. We understand why it works.
8. The solution can be leveraged to similar problems elsewhere. It is not just a one-off.

This article shares the experiences of one company in effectively implementing a structured variability reduction methodology with operations teams that incorporated the first four aspects of the theory of statistical engineering (referred to throughout this article as aspects 1–4). The methodology was developed to address manufacturing productivity needs that met the hallmarks of a problem requiring statistical engineering (referred to throughout this article as hallmarks 1–8). Over the course of 4 years, from 2000 to 2003, the company would see a 4–10% sustained increase in manufacturing productivity, as measured by throughput, across their manufacturing assets. The company would also extend the methodology into logistics, customer service, and finance operations. The lessons learned from the methodology's structured implementation approach were also extended to other improvement methodologies.

BACKGROUND

Beginning in the late 1990s, a U.S. printing company foresaw the coming changes in the demand for print media and recognized the need to maximize the utilization of its existing assets before strategically investing in new assets (hallmark 1. See Appendix for a high-level description of the printing process, key terminology, and roles in the process.) They began a journey to improve manufacturing productivity and quality. There was, however, no systematic approach or plan across the corporation. Various approaches were initiated at individual manufacturing facilities and product platforms, including ISO 9000 (ANSI/ISO/ASQ, 2008), 5S workplace organization and quick changeover (Levinson and Rerick 2002), and problem solving using basic quality tools (flowchart, check sheet, cause-and-effect fishbone diagram, Pareto chart, run chart, histogram, and scatter diagram). Efforts were highly dependent on local leadership. Success was often limited to one or two manufacturing lines. In 1998, a corporate decision was made to implement Six Sigma (Breyfogle 1999) to focus on problems with unknown solutions to obtain step-change improvements in manufacturing productivity and quality. Several waves of Black Belts and Green Belts were trained during 1999 with mixed project results. Projects were either taking nine or more months to complete or were not obtaining the desired improvement goals. Black Belts and Green Belts were finding little to no standard practices, limited data on process operation and performance, and little experience within the operations teams to collect and use the data needed for their Six Sigma projects. The Belts spent weeks, and sometimes months, working with operations teams (primarily pressmen and bindery operators) to develop and implement standard practices just to obtain reliable data they could analyze and use for identifying sources of variation and implement step-change solutions. In the past, pressmen typically went through an extensive and lengthy apprenticeship program that not only taught the art and science of printing, but best operating practices that resulted in process standardization and stabilization. By the late 1990s, these programs had mostly disappeared and the standard practices along with them. Having spent an average of $33,000 per Black Belt for training, associated travel, and external Master Black Belt coaching, members of the organization's leadership began to question the value of the investment when previous experience indicated that operations teams could implement and maintain standard practices and basic data collection.

Recognizing a need to share lessons learned and leverage resources, a corporate continuous improvement council was created at about this time. The council was led by the chief manufacturing officer and consisted of continuous improvement directors from each of the business units (books, magazines, etc.). Several council members realized that in order for Six Sigma to be successful in achieving the improvements desired, the Belts needed to be freed from process standardization and stabilization work in order to utilize the more advanced tools they were taught. It would take years, however, to see the benefits of any reinvigorated apprenticeship program. A different approach was needed to develop the capability of the operations teams to standardize and stabilize their own processes and to sustain the improvements on a daily basis—an approach that involved the technical aspects of operating the printing assets (i.e., presses and finishing lines) and developed the operations team members to continue to make improvements over time (hallmarks 3 and 4). The chief manufacturing officer had experience at another company with a similar situation and shared their training approach. With his leadership, one of continuous improvement directors developed training materials on process standardization and stabilization using the seven basic quality tools. The training was focused on standardizing the process and stabilizing performance of one common metric: run rate as measured by net good books per hour. The training was delivered to selected operations teams (primarily pressmen and bindery operators) from several manufacturing facilities. The teams were brought to corporate headquarters and trained collectively by the corporate continuous improvement director who developed the original materials. Follow-up coaching was provided to each team by this same continuous improvement director on a weekly basis. After two rounds of pilot studies in which variation in run rate not only decreased but the operations teams were actively engaged in sustaining the improvement, the council believed that they had the beginnings of an approach to develop the capability of the operations teams to standardize and stabilize their own processes and to sustain the improvements on a daily basis. The existing model of bringing the teams to corporate headquarters for training with one trainer and one coach, however, was not sustainable. A methodology that could be consistently deployed at the more than 20 North American manufacturing facilities, irrespective of equipment and product platform (books, magazines, etc.), with local resources was needed (hallmark 8). The chief manufacturing officer did not have experience with extending the approach across so many assets. The council knew of no other available structured methodology at the time (hallmark 2).

The continuous improvement council chartered a design team to construct such a variability reduction (VR) methodology. Believing that the methodology involved more than training and a deployment plan (hallmark 6), the council defined a continuous improvement methodology as "a structured set of tools, metrics, processes, and practices to drive results in one or more parts of a business" (1999). The design team consisted of continuous improvement managers from the three largest businesses, a pressroom manager, a bindery manager, VR team leaders from two of the pilot facilities, a representative from corporate human resources (HR), an organizational development consultant, and a process improvement consultant and trainer (the author). Pressmen and bindery operators from the pilot teams were also engaged in the development effort through the VR team leaders. The diversity of the team ensured that the resulting methodology would function appropriately across different assets and product platforms.

Over the course of a 5-day working session in mid-October 1999, the VR design team reviewed pilot implementation experiences and experiences with other improvement approaches, seeking to identify the elements required for successful implementation. The organizational development and process improvement consultants also shared and discussed the underlying concepts of employee engagement and continuous improvement (hallmark 7). The concepts included the following:

- All work is a process (Britz et al. 2000).
- Variation exists in all processes (Britz et al. 2000).
- Understanding and reducing variation are keys to success (Britz et al. 2000).
- The people closest to the process (the natural work team that operates the process on a daily basis) are best suited to address unmanaged sources of variation (Edelson et al. 1992).
- People can and will improve a process if the performance of the process is visible (Schonberger 1986).

- Understanding the context of the data and the variability in the process facilitates root cause analysis (Wheeler 1993).
- Capability of a process can best be improved after the process has been standardized (Edelson et al. 1992).
- Accountability is powerful: doing what we know we should do requires someone who will keep us on track, teach us, and encourage us (Crane 1998).
- Improvements can more easily be sustained when disciplined daily processes (e.g., defined roles and responsibilities, work instructions, and communication mechanisms) exist to support the continuation of the improvements (Joiner 1994).

By the end of the working session, the design team came to agreement on the intent of VR, the system elements needed for effective implementation, and an action plan for drafting materials in support of all elements for implementation by January 2000.

VR INTENT AND IMPLEMENTATION SYSTEM DESIGN

The result of the design team's efforts was a 12-week team-based, structured VR methodology that used data-based problem solving to reduce variability in a primary metric. The primary metric of focus for all manufacturing lines was run rate.

The intent of VR was to train the operations teams (primarily pressmen and bindery operators in manufacturing) to establish a standard process, identify and eliminate sources of variability within their control (stabilize the process), establish the daily disciplines necessary to sustain the improvements over time (hallmark 5), and create an environment to facilitate step-change improvement through Six Sigma projects. In other words, "squeeze the variability out of the process." See Figure 1 for a graphic representation of primary metric performance pre-VR, with VR, and with Six Sigma.

This approach, which aligns with Juran's trilogy (Juran and Godfrey 1999) of quality planning, quality control, and quality improvement, has many advantages (Edelson et al. 1992):

- Many people can participate in the work.
- Efforts to standardize and stabilize the process yield fast and efficient results as many, even hundreds of variables become more stable.

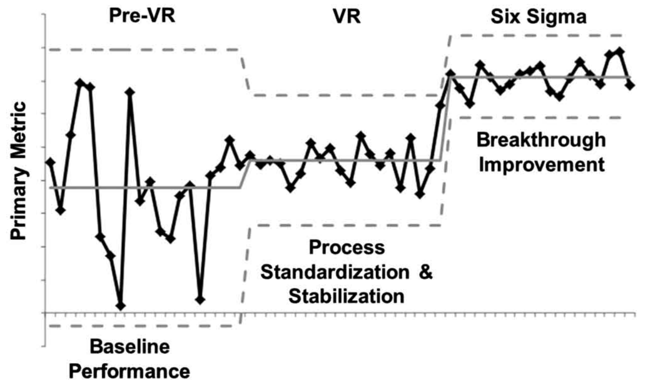

FIGURE 1 **Representation of primary metric performance pre-VR, VR, and Six Sigma.**

- It rarely requires capital or incurs risk.
- Standardization and stabilization of the process results in a lower noise environment for experimentation and more complex methods of understanding sources of variation (for which Six Sigma is well suited).

The VR design team recognized that in order to effectively deploy and sustain VR throughout the organization, a system would need to be defined and implemented to guide implementation. No such system currently existed within the organization. Based on the design team's understanding of employee engagement and continuous improvement concepts, past experiences with other improvement approaches, and back-and-forth discussion during the 5-day work session, the team identified and defined seven elements to be included in the methodology for effective implementation:

1. Linkage to the business strategy—Improvement opportunities using the methodology are prioritized based on linkage to the business strategy and annual plans.
2. Roles and responsibilities—An organizational structure to support the tasks associated with the methodology are defined and incorporated into daily work.
3. Performance tracking—The methodology includes metrics and reporting using a standard report card.
4. Documentation—A mechanism to capture, document, and share best practices associated with the methodology is incorporated into implementation plans.

5. Training—Deployment of the methodology includes a common training curriculum and certification of trainers.
6. Audit—The methodology includes an assessment process to hold individuals and teams accountable for results and ensure long-term sustainability.
7. Certification—A process to qualify and recognize individuals and teams for successful implementation is incorporated into the deployment of the methodology.

These elements provide a strategy to guide the use of the data-based tools in reducing variation (aspect 1). Details of how these seven elements were implemented in VR are discussed below.

1. Linkage to business strategy. Opportunities for using the VR methodology (initially press and finishing lines) were prioritized based on savings potential, capability to meet current and future customer demand, capability to meet other business demands, and the availability of resources. The continuous improvement director in each business unit was charged with leading this prioritization process with plant management during the annual budget planning process. Implementation at a single plant was typically staggered so as not to task common resources (for example, HR, engineering, maintenance, and information technology).
2. Roles and responsibilities. Management commitment and involvement was recognized as a key component to VR success. The manufacturing vice president for each business unit was identified as the VR sponsor and coached by the continuous improvement director for the business unit. The department manager was the VR champion and the process supervisor was the VR team leader and coach. In keeping with the concepts that the natural work team that operates the process on a daily basis is best suited to address unmanaged sources of variation because they understand the context of the data and the variability in the process, members of the operations team (for instance, pressmen from each shift) formed the VR team. A plant Six Sigma Green Belt was assigned to the VR team as a data analysis resource. Support was also provided from HR, engineering, maintenance and information technology (IT) as needed. Roles, responsibilities, and deliverables were integrated with daily work

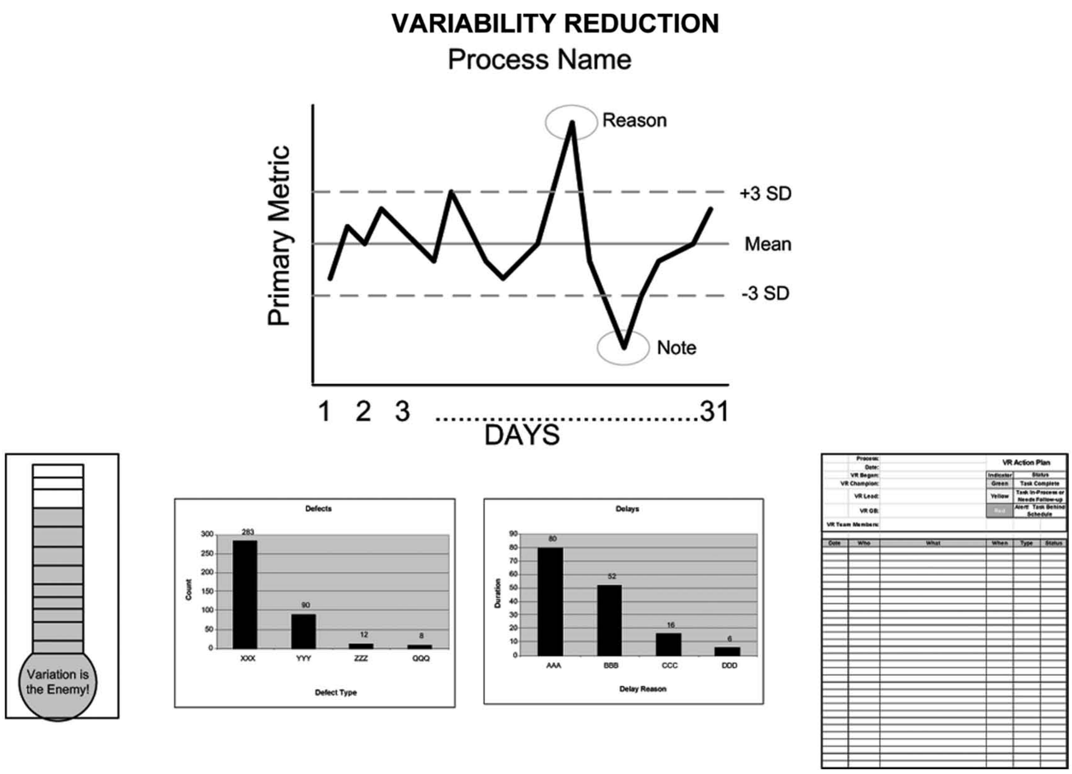

FIGURE 2 Graphical representation of VR visual display.

TABLE 1 **VR roles and responsibilities**

Role	Responsibilities
VR sponsor	Understand and commit to using VR within the function/facility Prioritize VR opportunities Review VR scorecard for each team weekly Review progress monthly with VR champions Help teams and champions overcome barriers Follow up on VR audit corrective actions
VR champion	Understand and commit to using VR within the department Participate in VR champion training Assist sponsor to prioritize VR opportunities Provide resources to begin and sustain VR within the department Review visual display and scorecard for each team at least weekly Ensure VR teams follow the roadmap and utilize the tools to make data-based decisions Help team(s) overcome barriers Conduct work instruction audits
VR team leader	Understand and commit to leading VR within their operation Participate in VR team training Guide the VR team through the roadmap and utilization of the tools to make data-based decisions Engage other process team members in VR implementation Communicate team progress and concerns to leadership and key stakeholders Conduct work instruction audits
VR team members	Understand and commit to leading VR within their operation Participate in VR team training Use the VR roadmap and tools to make data-based decisions to continuously improve process • Record accurate and timely data • Adhere to agreed work instructions • Take positive action to address sources of variation Engage other process team members in VR implementation
Six Sigma green belt	Assist team with data analysis and making data-based decisions Coach the VR team leader on use of data analysis tools

(hallmark 5 and aspect 4), thus helping to institutionalize VR. See roles and responsibility descriptions in Table 1.

3. Performance tracking. In keeping with the concept that people can and will improve a process if its performance is visible, a visual display, typically a white board containing graphical summaries of the primary metric and status of VR efforts (see Figure 2 for a graphical representation), was required at each piece of equipment or in the process area associated with a VR team. The VR visual display was a highly visible focal point for teams to communicate the performance of the manufacturing process and results of their VR efforts across shifts and with others supporting their efforts, including management. Shift turnover meetings were typically held in front of the visual display. Standard scorecards were also developed and automated with the assistance of IT resources (hallmark 5). The scorecards included baseline statistics for the last 12 months for both run rate and throughput; statistics for the last 60 days of production; histograms of the baseline and last 60 days of production; run charts of the last year and last 60 days of production; and a Pareto chart of the top 10 delays contributing to low run rate the last 30 days of production. The scorecards were updated weekly and visible through the company intranet at the plant, business unit, and corporate levels.
4. Documentation. To ensure consistent rollout of VR across multiple manufacturing facilities in North America, a VR implementation guide was developed that detailed the VR roadmap and tools (see next section), roles and responsibilities, audit processes, certification levels, and incorporated the examples from the VR pilots (hallmark 8 and

aspect 1). A VR Web site was also established on the company intranet for sharing best practices and success stories.

5. Training. The concepts and tools of VR were new to most VR team members, process supervisors, and even some champions. Hence, training played a critical role in deployment. The training curriculum included half-day champion training, 2 days of interactive training on the VR roadmap and tools for the VR team leader and team members, half-day VR team team building, and half-day VR team chartering and project management training. Supplemental tool training was also available on an as-needed basis. Champion training occurred at the plant level prior to the first VR implementation. VR team members were removed from their daily responsibilities for three consecutive days to participate in the training. Depending on plant implementation plans, one to three VR teams were trained simultaneously. Given that implementation was prioritized and scheduled as part of the annual budget planning process, there was little resistance to conducting the training. The training was provided on site by a VR trainer. VR trainers were identified for each facility and worked closely with the department managers and process supervisors to ensure that each VR team had the training and skills needed to be effective. VR trainers were required to have VR experience as a VR team member or team leader, and experience in the process (i.e., press, finishing). VR trainers were certified to conduct VR training through a three-stage process of observation, co-training with an experienced VR trainer, and finally leading with observation and feedback from an experienced VR trainer.
6. Audit. Following the concept that doing what we know we should do requires someone who will keep us on track, teach us, and encourage us, audits were integrated into the VR roadmap at 4-week intervals (weeks 4, 8, and 12). The primary purpose of the audits was to assess team progress andprovide firm, honest feedback to the team and champion. The audits served to hold the VR teams accountable for results and to ensure long-term sustainability of VR practices. The audits were conducted by a second party appointed by the business unit continuous improvement director. The VR auditors were usually continuous improvement managers or VR team leaders from another facility within the business. Audits were scheduled and monitored at a business level as part of a continuous improvement scorecard. Audit reports were shared with the VR champion at a closing meeting and corrective actions and timing agreed upon. The VR sponsor (typically at the vice president level) also received a copy of the audit report and corrective action plans for further follow-up. Once a VR team was certified (see next element), the audits were reduced in frequency to quarterly.
7. Certification. Individual and team recognition was provided at two levels: silver certification and gold certification. Teams that demonstrated effective application of VR at the completion of the 12-week roadmap were silver certified. This involved completion of all steps in the VR roadmap, demonstration of knowledge and application of the VR tools by the team (individually and collectively), and elimination or reduction of a major source of variation. Upon certification, team members received individual recognition and a VR silver certification banner was hung over the equipment/in the process work area. Teams that demonstrated sustained improvement could qualify for gold certification. To achieve gold certification, a team had to demonstrate all VR elements were sustained for a minimum of 90 days after silver certification; an ongoing sustainability plan through audits was in place with records of audit findings and actions taken; data integrity; and a minimum 15% improvement in the average of their primary metric and reduction in process standard deviation of at least 10%. The improvements had to be statistically validated using the appropriate hypothesis tests. Hence, the purpose of gold certification was not only to sustain VR but to encourage mature VR teams to become engaged with Six Sigma Green Belt or Black Belt projects associated with their process and achieve step-change productivity improvement.

VR ROADMAP AND TOOLS

The original VR training (as developed by the corporate continuous improvement director) included a 12-week implementation plan. The majority of the pilot VR teams were able to complete the implementation in the 12 weeks. Although the design team believed that more time was needed to effectively create sustainable change in daily work, business demands to predictably improve productivity in less time were strong. Also, there was anecdotal evidence that those VR pilot teams that had undergone team building either prior to or soon after the VR training were able to come together faster and meet the 12-week timeline. The design team believed that 12 weeks was an acceptable compromise with the addition of team building.

The original VR implementation plan was loosely defined and did not specify a sequence for the use of the tools. Nor did it include upfront work to prioritize the process versus business need. The continuous improvement director had instead coached the business unit continuous improvement directors and pilot VR teams through these activities. Given the plan to deploy VR across multiple facilities simultaneously with local resources, the VR design team believed that more structure was needed to ensure a consistent deployment across the corporation. The resulting structure consisted of six phases that were documented in a matrix that identified the objectives, deliverables, tools, metrics, and reports required for each phase; this matrix was referred to as the *VR roadmap*. The roadmap was included in the VR implementation guide and referenced extensively during VR team training. See Table 2 for key components of the roadmap.

The 12-week roadmap was also aligned with the Six Sigma define–measure–analyze–improve–control (DMAIC) phases. See Figure 3.

The original VR training materials were updated to reflect the more structured roadmap and to incorporate examples from the pilot VR teams. The design team was careful to use similar language and examples that were used in Six Sigma training to help Belts and VR teams view Six Sigma and VR as complementary methodologies rather than as competing methodologies.

The key tools used throughout the 12-week roadmap included tools to understand and standardize the process, analyze the sources of variation, and communicate and manage the project (hallmark 4). The process understanding and standardization tools were primarily used during weeks 2 through 4 and the process analysis tools were primarily used throughout weeks 5 through 12. The communication and project management tools were used throughout the entire 12-week VR roadmap and helped to build teams that could work together across shifts to address sources of variation (hallmark 5). See Table 2 for more detail.

In general, the tools were sequenced to allow the VR team to understand the work flow using process maps/flowcharts, streamline and standardize the work flow, then to collect data and to explore it statistically and graphically to identify and verify sources of variation before implementing a potential improvement. The sequence was relatively easy for the design team to implement given that a common primary metric was chosen for all manufacturing assets. The sequence of tools provided the VR teams with a common language, allowed the teams to see their operation more holistically, and deal with more complex issues than they had been able to deal with previously (aspect 2). For instance, a press VR team would first establish a standard process that they all agreed to follow by using process maps/flowcharts, value-added analysis, and spaghetti diagrams. The standard process would include the sequence of steps to set up and run the press as well as specific machine settings (i.e., line speeds, paper tension, dryer temperatures, roller position, etc.) to produce different types and sizes of products. The standard process would then be documented as a work instruction and used to train all operations personnel working on the line. The VR team would also create a check sheet to collect data on the delays (machine breakdowns, jams, product quality issues, etc.) contributing to low run rate. They used these data to create a "delay Pareto" to identify the top delays that they would explore in more detail using histograms and run charts to understand whether the delay was due to a special cause or was a chronic delay. These data, along with their action plan and progress against the VR roadmap (represented as a thermometer), would be displayed on the visual display daily. Further investigation using brainstorming, the cause-and-effect fishbone diagram, and/or "5 whys" was used to identify potential root causes for further data collection and analysis. The scatter plot was used to verify potential relationships between a potential cause and effect. Once potential root causes were identified, potential solutions were then identified, selected, and implemented. New data were collected on the process with the solution(s) in place and analyzed to verify improvement.

TABLE 2 **VR roadmap key components: objective, deliverables, and tools by phase**

VR phase	Phase objective	Phase deliverables	Tools
Prework	Prepare for VR implementation	1. Select team 2. Collect baseline data 3. Graph baseline data	Basic statistics Histogram Run chart
Week 1	Develop capable VR team	1. Attend VR training 2. Participate in team building 3. Establish VR charter, goal, and project plan	Team charter Goal setting worksheet VR project plan
Week 2	Initiate standard process, communication, and data collection	1. Identify standard process 2. Initiate work instruction 3. Develop and implement delay check sheet 4. Erect visual display 5. Initiate action plan	Process map/flowchart Value-added analysis Spaghetti diagram Work instructions Check sheet Visual display Action plan
Weeks 3 and 4	Implement standard process and collect data	1. Finalize work instruction; train and implement 2. Collect delay data 3. Initiate daily meetings	Work instructions Check sheet Basic statistics Visual display Action plan
Weeks 5 and 6	Eliminate sources of variation using data	1. Analyze delay data 2. Investigate top delays 3. Identify and verify root cause 4. Implement solution(s) 5. Initiate VR scorecard	Basic statistics Histogram Run charts Cause-and-effect fishbone diagram Pareto diagram 5 Whys Brainstorming Scatter plot Visual display Action plan Scorecard
Weeks 7–12	Refine standard process and elimination of sources of variation; institute process controls	1. Continue to analyze delay data, investigate top delays, identify and verify root cause, and implement solution(s) 2. Refine standard process, work instructions, and data collection 3. Implement process controls	Process map/flowchart Value added analysis Spaghetti diagram Work instructions Basic statistics Histogram Run charts Cause-and-effect fishbone diagram Pareto diagram 5 Whys Brainstorming Scatter plot Visual display Action plan Scorecard

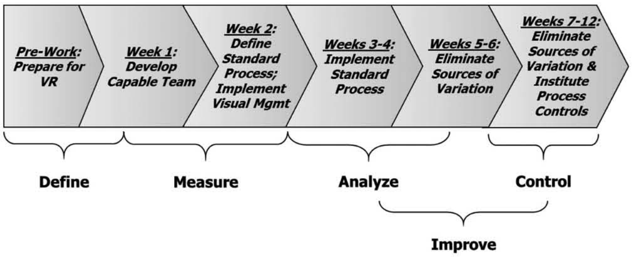

FIGURE 3 **Alignment of VR phases with Six Sigma DMAIC phases.**

Once verified, methods were put in place to control the improvement over time. The control methods included additional work instructions and training, workplace organization, mistake proofing, new gauging, and, where practical, automation.

Given the educational and statistical background of the majority of VR team members, simple analysis and graphical tools that could be quickly and easily created by hand and/or with Excel were used. In fact, during the pilots and initial year of VR implementation, the operations teams were not even introduced to standard deviation. Variation was measured using a ratio of the first quartile and the third quartile (Q1/Q3), referred to as *VR ratio*. The VR ratio could easily be calculated by hand or with the use of a calculator or Excel. VR teams understood that the smaller the ratio, the larger the variation in the process; the larger the ratio, the smaller the variation in the process. As the organization matured in its use of statistical tools, limitations of the VR ratio as a measure of improvement became apparent, especially its lack of sensitivity to removal of special causes of variation. With the help of IT resources, the calculation of the standard deviation was automated as part of the creation of a common VR scorecard (hallmark 5).

If more advanced statistical analysis tools (e.g., hypothesis testing, regression, design of experiments, etc.) were needed to identify a source of variation, the opportunity was identified as a potential Six Sigma project, prioritized by plant management and given to a Green Belt or Black Belt (depending on the complexity and scope of the opportunity). The Green Belt or Black Belt could then focus on the analysis and solution of the problem knowing that the operations team, through VR, had standard practices and data collection in place to assist with the analysis. Some members of the VR teams became Six Sigma Green Belts, expanding their tool kit, and worked with their fellow team members to broaden the scope of issues on which they could work.

Once silver certified, a VR team was expected to continue to sustain the behaviors and to continue to improve performance, either on their primary metric and/or a secondary metric, alone or in partnership with a Six Sigma Black Belt or Green Belt. This ongoing improvement in performance was planned and budgeted during the annual budgeting process.

EXAMPLE OF VR ON A BINDERY LINE

VR was initiated on a bindery line in one of the magazine plants in mid-2000. The VR team created flowcharts of line startup and operation, analyzed for non-value-added activities and different practices between shifts and individuals, and agreed to a standard process for startup and operation of the line, including line speed for different types of magazine jobs. This standard process was documented in work instructions that were used to train all line employees on the agreed-upon standard process. The team also identified and defined categories of downtime that negatively impacted line run rate. With the help of IT resources, the VR team was able to incorporate these downtime categories into newly developed software to capture and report downtime and create the delay Pareto shown in Figure 4 for the last 30 days of production.

From the delay Pareto, the VR team could see that the downtime that consumed the most hours during the 30 days was a "binder infeed high book jam" and that missing signatures (abbreviated as *sigs* in the Pareto) at several packers were identified as eight of the remaining nine top downtimes in both hours

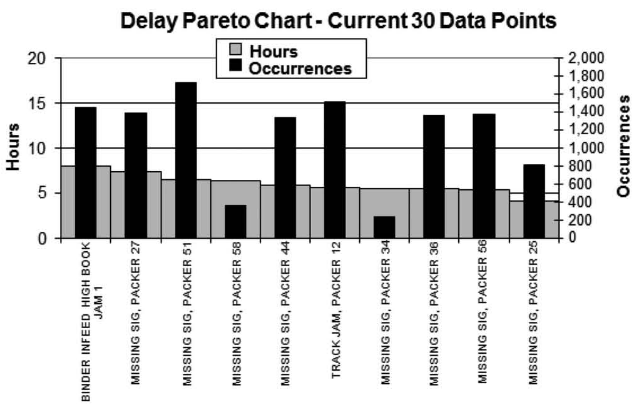

FIGURE 4 **Bindery line delay Pareto 30 days after standard process implementation.**

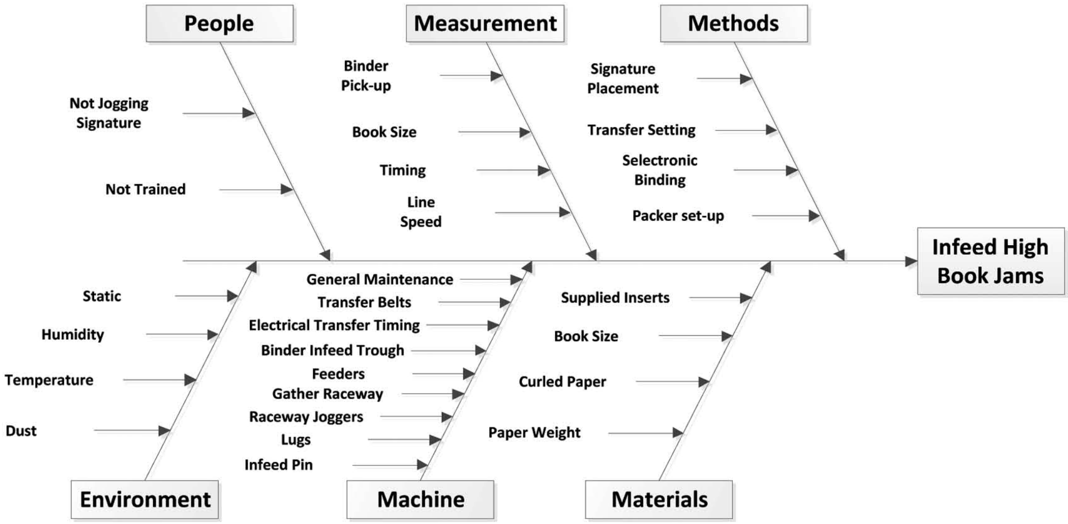

FIGURE 5 **Infeed high book jam cause-and-effect fishbone.**

and occurrences. These two delay types became the focus of the team's VR efforts.

To understand the binder infeed high book jam delay, the VR team created a cause-and-effect fishbone diagram. See Figure 5.

Through multivoting, the VR team prioritized the investigation of the potential causes. See Table 3. The infeed trough received the highest number of votes. Investigation by the VR team and maintenance found the current trough to be worn. The trough was replaced by a stainless steel trough, which not only addressed the current issue but eliminated future wear concerns. The second highest vote concerned not jogging the signature, which was a training issue. More detail on how to properly jog a signature was added to the work instruction and all bindery line operators trained on the method.

With respect to the missing signatures, the VR team worked with their Green Belt resource to measure and analyze several machine parameters, including the vacuum drop at the sucker cups used to grab individual signatures for collation at the packers. The vacuum drop was found to significantly affect the number of missing signatures and associated downtime. Further testing by engineering and maintenance quantified the allowable vacuum drop at the sucker cups. In order to give bindery operators the ability to measure and control the vacuum drop on-line during production, engineering and maintenance developed and installed new gauges on the line and worked with the VR team to train the operators on their use. Once the results of these new gauges were verified on this line, they were added to the remaining lines at the plant. The design was also shared with other plants with similar equipment.

The improvements to the trough, training, and sucker cup vacuum gages took approximately 6

TABLE 3 **Infeed high book jam effect multivoting results**

Effect	Multivote count	% of Total
Infeed trough	90	19.48
Not jogging signature	72	15.58
Infeed pin	68	14.72
Transfer setting	60	12.99
Curled paper	56	12.12
Packer setup	48	10.39
Feeders	36	7.79
Book size	32	6.93

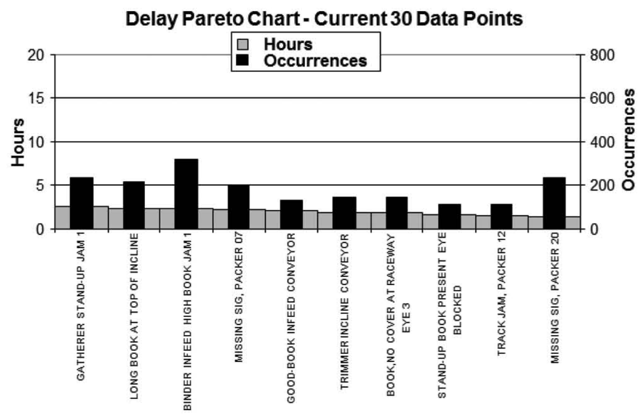

FIGURE 6 **Bindery line 30-day delay Pareto after VR improvements.**

TABLE 4 **Bindery line productivity before and after improvements**

Metric	Before	After
NGBPH average	5,561	7,886
NGBPH standard deviation	1,893	1,588

weeks to investigate and implement. Figure 6 shows the resulting delay Pareto 30 days after implementation. Note that infeed high book jams is now the third highest and approximately half of its previous value. Also note that only two missing signatures now appear in the top 10 delays.

Table 4 compares the bindery line productivity before and after the improvements as measured by net good books per hour (NGBPH) average and standard deviation.

This effort earned the bindery line VR team silver certification. The team was able to sustain the improvements and make further reductions in infeed high book jams and missing signatures and receive gold certification five months later.

LESSONS LEARNED AND REVISIONS TO VR IMPLEMENTATION

Eighteen months after roll-out across the more than 20 manufacturing plants, the continuous improvement council chartered a second team (referred to as v2.0 VR design team) to identify lessons learned and to update the VR methodology accordingly. Data were collected on VR team performance and feedback was obtained from VR sponsors, VR champions, VR team leaders, VR trainers, and VR auditors through surveys and interviews.

Key patterns from the data and feedback included the following:

- The majority of manufacturing VR teams could successfully implement VR in 12–16 weeks.
- Though not originally designed for nonmanufacturing process teams, VR was found to work in transactional processes (e.g., logistics, customer service, and finance). The primary metric for transactional processes was either cycle time or defect rate. However, due to the fact that transactional processes do not always operate every day, transactional VR teams required 16–20 weeks to meet the deliverables.
- Transactional VR teams requested that the VR training and VR implementation guide be revised to minimize manufacturing-specific terminology and to incorporate transactional examples.
- VR teams felt penalized by the use of the VR ratio as a measure of variation reduction when they reduced special cause sources of variation that were not reflected in the VR ratio for up to 2 months (due to the 60-day moving calculation). VR teams were increasingly comfortable with the use of standard deviation.
- VR team leaders and teams requested additional information on roles and responsibilities by phase to supplement the VR matrix.
- Area or process supervisors were often selected to serve as the VR team leader. Because most manufacturing supervisors were promoted into the role from a lead pressman or lead binding operator role, few had training in team building, conflict resolution, and other team-based dynamics. Not all supervisors were comfortable serving as VR team leader and guiding such a team-based effort. Since the original VR design, corporate HR had developed a 5-day workshop on change management and teambuilding for supervisors. VR team leaders who participated in the workshop highly recommended that all VR team leaders attend the workshop prior to serving as a VR team leader.
- VR trainers who were not Green Belt certified struggled to support VR teams that required training and coaching on the tools beyond that included in the VR 2-day training.
- The discipline required to perform root cause analysis versus jumping to solutions had not previously been a part of most plants' cultures. VR teams lost time and energy implementing changes to their process when they did not first verify the root cause(s).
- Due to the number of manufacturing VR teams, it had become increasingly difficult for the continuous improvement directors to manage requests for and schedule VR audits within their business. VR sponsors and champions also questioned consistency of VR audits from one auditor to another.
- Some VR teams did not sustain performance after achieving silver certification. VR sponsors and

champions requested more frequent follow-up for such teams.

- A compliance management system that provides mechanisms for document management and control, maintaining training and audit records, and tracking nonconformances provides the infrastructure to sustain improvements long-term and frees the VR team from such administrative tasks. Such a compliance management system had been purchased and implemented at several of the plants in conjunction with ISO 9001 registration.

Based on these patterns and other recent corporate activities, the v2.0 VR design team identified improvements to the VR methodology and updated the implementation guide and training materials accordingly. Key improvements included the following:

- A separate VR roadmap was developed for use in transactional processes. The roadmap was extended to 16 weeks to deal with the fact that transactional processes do not always operate every day. Separate transactional VR training materials were also developed that removed manufacturing language and incorporated transactional examples. The implementation guide was edited to incorporate both manufacturing and transactional roadmaps and examples.
- The VR roadmap was reformatted into a cross-functional flowchart and roles and responsibility matrices created by phase. Both were incorporated into the VR implementation guide and VR training.
- The VR ratio was removed from VR training and the VR scorecard and communications drafted and provided to the continuous improvement council to use throughout the organization. An appendix on the use of standard deviation versus VR ratio was added to the VR implementation guide.
- The VR team leader role description and training requirements were updated to include the corporate HR change management and team building workshop for supervisors as prerequisite training for all new VR team leaders.
- The VR trainer role description and training requirements were updated to require that VR trainers be Green Belt certified. This helped ensure that the VR trainers had more training on the tools than that included in the VR training and had demonstrated their knowledge through application on a minimum of two Green Belt projects.
- Supplemental root cause analysis training was developed and provided to VR trainers and teams. The training was developed in partnership with corporate environmental health and safety (EHS) resources. VR auditors were also trained to look for VR team difficulties in conducting root cause analysis and to work with the plant VR trainer to coach the VR team leader on using the data-based tools to identify and verify root causes before identifying and implementing solutions. More emphasis was placed on root cause analysis for silver certification.
- Detailed VR audit checklists and definitions of conformance were developed and documented in the VR implementation guide. Existing auditors were retrained to use these checklists and definitions. The VR auditor role description and training requirements were also updated to require audit training. Such audit training had recently been developed by corporate EHS resources and corporate ISO 9001 resources. VR auditor certification was also defined. After receiving audit training, a VR auditor was required to participated on a minimum of two VR audit teams prior to being certified to lead VR audits.
- Manufacturing VR audits were scheduled and monitored at a corporate level as part of a continuous improvement scorecard. Recent changes in the organization's structure created a process management function to coordinate continuous improvement support activities such as training and auditing. This included the scheduling of monthly audits while corrective actions were taken for those VR teams whose run rate performance deteriorated or whose VR audit scores fell below a threshold value two consecutive quarterly audits.
- Best practice samples of using the new compliance management system for work instructions, VR training plans and records, and VR audit reports were identified in partnership with corporate ISO 9001 resources and posted on the VR intranet site. The team also recommended to the continuous improvement council that roll-out of the system be expanded to the remaining sites within the next one to two years.

Version 2.0 of the VR implementation guide and training materials were released to the corporation in January 2002. Version 2.5 was released at the end of 2002 and further integrated transactional processes into the VR materials. VR deployment continued at least through mid-2004 when the author's work with the organization ended.

BENEFITS OF VR

An analysis at the end of 2003 of the 485 silver certified manufacturing VR teams yielded an average sustained improvement in throughput of 4% and 2% reduction in throughput variation versus pre-VR levels. A similar analysis of the 95 gold-certified manufacturing VR teams yielded an average sustained improvement in throughput of 10% versus pre-VR levels. Gold certified presses saved an average of $57,600 and finishing lines an average of $73,600 per year in labor costs alone. Additional savings included reductions in paper, ink, utilities, and waste expenditures.

In addition to the productivity improvements and cost savings, the organization saw the following anecdotal benefits through the implementation of VR:

- Operations teams owned daily process improvement activities, including work instructions, daily performance tracking, and problem resolution using data-based problem solving. Operations team members from the process supervisor to pressmen and bindery operators were the heart of VR. They identified where improvement was most needed, identified and verified the root cause(s), and identified and implemented solutions within their control. An external team did not come in and do it for them (or to them).
- Improvements lasted longer as the operations teams owned the results and had the team discipline and tools to sustain the improvements over time.
- Capital expenditures for the improvements were minimal.
- Conformance to schedule for VR manufacturing assets improved with the reduction in variability. This in turn allowed customer service to commit to new work within a specified time period with more confidence.
- ISO 9001 activities involving document management and control, training, and auditing were integrated into daily work on VR assets.
- The efficiency of Six Sigma resources was increased. Black Belts and Green Belts were able to focus on problems with unknown solutions beyond the skill and control of the operations team. The average savings per Black Belt project increased from $258 K in 2002 to $299 K in 2003. With over 70 Black Belts completing at least two projects per year, this had the potential for generating approximately $5.6 million in additional savings per year.

The successful deployment of VR across the organization led to the seven continuous improvement methodology system elements being extended to other continuous improvement efforts. Though today we recognize that linking projects to strategic business needs, defined roles and responsibilities, performance tracking, best practice documentation, a common training curriculum, and recognition through certification are keys to successful Six Sigma deployment (see Snee and Hoerl [2003] and Zinkgraf [2006]), such a structured approach was not part of many Six Sigma deployments in 1999–2002. The initial implementation of Six Sigma at this organization consisted primarily of training and certification. Beginning in 2003, the seven elements were extended to Six Sigma, 5S, quick changeover, and ISO 9001 deployments. Projects for all continuous improvement efforts were strategically selected and scheduled during the annual budgeting process, roles and responsibilities were defined for each methodology and documented in methodology implementation guides, performance was monitored and tracked via scorecards available through the company intranet, training curricula were developed and delivered using certified trainers, audits were systematically conducted using certified auditors at critical points of implementation, and individuals and teams were recognized for various levels of achievement.

SUMMARY

A U.S. printing company faced productivity improvement challenges typical of the eight hallmarks of a problem requiring statistical engineering.

A structured variability reduction methodology that used data-based problem solving to reduce variability in a primary productivity metric by standardizing and stabilizing daily operations was developed and implemented across the company's assets and work processes. The primary metric of focus for all manufacturing processes was run rate; the primary metric for transactional processes was either cycle time or defect rate. The methodology engaged operations teams (pressmen and bindery operators in manufacturing; technicians in prepress; clerks in logistics; and customer service representatives in customer service) to establish a standard process, identify and eliminate sources of variability within their control (stabilize the process), establish the daily disciplines necessary to sustain the improvements over time, and create an environment to facilitate step-change productivity improvement through Six Sigma projects. The methodology included seven elements that addressed aspects 1 through 4 of the theory underlying statistical engineering effectiveness. Documentation, training, audits, defined roles and responsibilities, and certification embedded the methodology into daily work, provided the structure for consistent implementation across multiple facilities, and sustained results over time. The statistical and nonstatistical tools of VR were sequenced to enable operations teams to learn the tools and methods and to quickly attack sources of variation within their daily control. Over the course of 4 years, the company would see a 4–10% increase in sustained throughput of its manufacturing assets and evidence of improvement in their Six Sigma deployment.

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REFERENCES

ANSI/ISO/ASQ Q9000–2008 Series Quality Standards. (2008). Milwaukee, WI: ASQ Quality Press.

Breyfogle, F. W. (1999). *Implementing Six Sigma*, 2nd ed. New York: John Wiley & Sons.

Britz, G. C., Emerling, D. W., Hare, L. B., Hoerl, R. W., Shade, J. E. (2000). *Improving Performance through Statistical Thinking*. Milwaukee, WI: ASQ Quality Press.

Crane, T. G. (1998). *The Heart of Coaching*. San Diego, CA: FTA Press.

Edelson, N. M., Ellis, M. L., Kharkar, A. N., Stutts, B. E., deTreville, S. (1992). *A Sequential 3-Phase Process Improvement Strategy*. Nashville, TN: ASQC Quality Congress Transactions.

Gravure printing. Available at: http://www.pneac.org/printprocesses/gravure/ (accessed September 28, 2011).

Hoerl, R. W., Snee, R. D. (2010a). Closing the gap: Statistical engineering links statistical thinking, methods, tools. *Quality Progress*, 43(5): 52–53.

Hoerl, R. W., Snee, R. D. (2010b). Tried and true: Organizations put statistical engineering to the test, see results. *Quality Progress*, 43(6):58–60.

How offset printing works. Available at: http://computer.howstuffworks.com/offset-printing2.html/ (accessed September 29, 2011).

Introduction to the offset printing process. Available at: http://www.psprint.com/resources/printing-tips-and-techniques/general/introduction-to-the-offset-printing-process.asp (accessed September 28, 2011).

Joiner, B. L. (1994). *Fourth Generation Management*. New York: McGraw-Hill.

Juran, J. M., Godfrey, A. B. (1999). *Juran's Quality Handbook*, 5th ed. New York: McGraw-Hill.

Levinson, W. A., Rerick, R. A. (2002). *Lean Enterprise: A Synergistic Approach to Minimizing Waste*. Milwaukee, WI: ASQ Quality Press.

Schonberger, R. L. (1986). *World Class Manufacturing: The Lessons of Simplicity Applied*. New York: The Free Press.

Snee, R. D., Hoerl, R. W. (2003). *Leading Six Sigma: A Step-by-Step Guide Based on Experience with GE and Other Six Sigma Companies*. Upper Saddle River, NJ: Prentice Hall.

Snee, R. D., Hoerl, R. W. (2010). Further explanation: Clarifying points about statistical engineering. *Quality Progress*, 43(12):68–72.

Wheeler, D. J. (1993). *Understanding Variation: The Key to Managing Chaos*. Knoxville, TN: SPC Press.

Zinkgraf, S. (2006). *Six Sigma: The First 90 Days*. Upper Saddle River, NJ: Prentice Hall.

APPENDIX

Printing Process, Key Terminology and Roles (Printer's National Environmental Assistance Center, 2011; HowStuffWorks, 2011; PsPrint, LLC, 2011)

Most commonly used printing processes consist of three steps: pre-press, press, and finishing.

Pre-press involves converting the digital document into the proper format for transfer onto either a metal plate (offset printing) or etching into a metal cylinder (gravure printing). Offset printing is the most common method; gravure is limited to large runs of magazines and direct-mail catalogs. Multiple pages are typically included on one plate or cylinder. The resulting printed sheet with multiple pages on it, called a signature, is folded during finishing so that the pages are in their proper sequence. The personnel that work in pre-press are often called pre-press technicians.

At an offset press, the plate is mounted on a roller and ink and water are applied to the plate. The ink binds to the part of the plate that contains the image; the water keeps the ink off the non-image areas of the plate. Oil is mixed with the ink to ensure that the ink and water repel each other and there is no smearing on the final product. The plate transfers, or offsets, the image onto a rubber blanket roller which in turn transfers the image onto paper. In four-color printing, this process is repeated three times, once for each color.

At a gravure press, the cylinder rotates in a bath of ink. As the cylinder rotates, excess ink is wiped off the cylinder by a flexible steel blade. The ink remaining in the recessed cells of the cylinder form the image by direct transfer to the paper as it passes between the printing cylinder and an impression cylinder. Like off-set printing, this process is repeated three times for four-color printing. Often, the wet paper is run through an oven to dry before finishing. The personnel that work on the press are often called pressmen.

Finishing includes such activities as folding, cutting, collating, binding, and covering. The personnel that work in finishing are often called operators.