Process Improvement in Precision Component Manufacturing: A Case Based Approach

Rajiv K. Srivastava and Debashish Jena

Abstract— **In spite of advancements in technology, the manufacturing of many small products and components continues to be labor intensive, and their assembly processes still rely on skill and craftsmanship. This paper describes operational problem solving through consultant-led intervention at one such manufacturer of watch dials, involving a combination of incremental and breakthrough improvements leading to significant performance gains in terms of cost, quality and delivery. Selected technical innovations in some significant areas are presented, along with an integrated approach for structuring and solving such process improvement problems systematically.**

Index Terms— **Manufacturing Processes & Methods, Process Improvement Approaches, Productivity & Quality Management**

I. Introduction and Problem Context

There have been considerable advancements in the use of technology and automation in the last few decades. However, the manufacturing operations of certain products and components like watch dials continue to be labor intensive, and their assembly processes still rely on painstaking skill and craftsmanship. Such items are characterized by miniature and irregular geometries, and are therefore not easily amenable to automation. Although computer controlled tools are used to carry out some of the production tasks, the watch dials are printed manually, and the markings and rings are still set by hand in a manner similar to jewelry manufacturing.

Thus while the product category itself has matured a long time ago, the processes have remained entrenched in human skills and traditional work practices. As a consequence, several inefficiencies and variabilities have crept into the operations over time. The industry as a whole seems to be in the Systemic stage [1], with relatively marginal scope for major innovation in the core manufacturing technologies. In particular, Research and Development on assembly processes of watches and dials has been limited. Though some process innovations do happen through the makers of the manufacturing equipment, such developments are not quite directed or controlled by the dial manufacturers themselves.

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This case study is based on MDDL, one of the few organized sector manufacturers of watch dials in India, with a client list which includes almost all domestic watch makers as well as some of the most prestigious international watch brands. The company was started in 1983, and now has an annual production capacity of 12 million dials across three production facilities in different parts of the country. It is also one of the only four companies in the world that manufacture high-precision watch hands, which now constitute about 15% of its turnover with 75-80% share of the domestic organized market, with exports growing at around 30% each year.

The watch dial industry is characterized by high product variety and fluctuations in product mix. Order sizes at the company vary from as low as 50 for some international brands, up to 10000 for more regular Indian brands. The number of models being manufactured at the factory could vary from 50 to 200 in a month, adding up to about 1000 over a year. Among these orders as many as 30% could be all-new models requiring fresh tooling, dies, fixtures, and process adjustments. The company relies on customer responsiveness, fast delivery, and innovative product development to drive its competitive strategy in domestic and overseas markets.

Dial manufacturing broadly consists of three stages:

- Blanking – the dial ‘blanks’ are first produced using Press and Welding operations
- Base Finish – various textures and effects are generated on dial faces using different finishing machines
- Assembly – this stage consists of pad/ screen printing, re-punching, index fixing, electro-deposited index fixing, gluing, backside cleaning, drop test, wrapping, and packaging. Most assembly is manual tweezers-based activity, with dials held in place by vacuum fixtures. Printing operations are performed on pad or screen printing machines, whereas gluing is done on gluing machines.

Large orders are split into smaller batches for production depending on monthly targets, which makes planning and control of production and manpower quite difficult. Further complications arise due to long setups of certain critical operations like Printing (30-45 minutes inline) and Electroplating. There were as many as 350-500 such setups in a month at one of the three factories studied. These complexities cause inefficiencies due to small lot production, line stoppages, starving, low resource utilization, and high WIP. In-process rejection levels used to be very high, up to as much as 50% in appliqués for luxury

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watch dials, and electroplating also gave rise to quality problems. Handling of indexes/ appliqués with metallic tweezers during dial assembly caused scratches, and different types of coated tweezers had been tried but without significant benefits.

II. ORGANISTIONAL CONCERNS AND PROBLEM SOLVING PATH

Management was very keen to increase productivity and show improvements in its operational performance on all three important manufacturing criteria i.e. quality, cost and delivery. However, since it was in a niche business no industry benchmarks were readily available. Hardly any systematic effort had been made in the past to establish norms, and without such standards it was difficult to gauge performance and improvements. Further, most of the existing operations standards were based entirely on historical data. Since plant operations are where the bulk of the value addition and differentiation takes place, management wanted to improve the yields and repeatability of various processes. They also felt that time standards would be a great help in more accurate production and manpower planning, for which they sought an external consultative intervention.

It was also a matter of concern for the organization that it had become dependent upon skilled workers, especially since it was intrinsically a labor intensive operation. This made it increasingly vulnerable to labor cost increases, potential labor trouble, absenteeism and other such challenges. The company was under further pressure to meet delivery schedules for a large range of customized products, with no tolerance on quality front from ever-demanding customers especially from global markets.

During preliminary discussions, management communicated to the consultants that the immediate objectives were to improve productivity of its three main assembly lines. The scope of the engagement needed to include a combination of methods improvements, work place redesign, scientific work measurement, line balancing, and review of production planning systems. The consulting team used the process assessment framework described by Kawase [2] to structure the improvement approach. In this framework, Control index represents the time utilization rate, and is a measure of availability of resources; Efficiency Index represents resource utilization rate; whereas Improvement Index pertains to effectiveness of methods and their improvement. The team envisaged that long-term effectiveness could be achieved by improving Control Index and Improvement Index, while short-term effectiveness could be achieved by improving Control Index and Efficiency Index.

The consultants were originally engaged to do time and method study of plant operations, and use the understanding and standards thus generated to help in production and manpower planning. Processes where major scope for improvement emerged, and/ or had significant implications for planning and resource utilization, were taken up for special treatment and given project orientation. The team chose to go beyond the literal mandate by expanding the scope of the improvement initiatives, to solve challenges posed by high product variety through attacking the major bottlenecks in printing setup processes.

Setups were examined and found to have a great bearing on the company's manufacturing flexibility, throughput improvement, and maximization of resource utilization. Major setup reduction opportunities were systematically identified. It was decided as a policy that as far as possible all long setup activities would be done off-line until major initiatives reached stable status. Work-holding fixtures for selected operations were redesigned to facilitate quick mounting and removal. Further, the consultants did not restrict themselves merely to conventional Single-digit Minute Exchange of Die (SMED) principles, but undertook fundamental design changes to achieve substantial setup reduction, for example from 45 minutes to below 10 minutes.

Methods improvement was carried out in conjunction with time study, and time standards were established only if the process was reasonably stable and being handled by a qualified worker. Incremental fine-tuning of work methods continued to be carried out on ongoing basis. Given the wide variety of models and their high obsolescence rate, selective time study was carried out to capture all possible elemental assembly operations. Following the Predetermined Time Standards (PTS) approach, standards for various operations from among existing product variants were consolidated and standardized, for synthesis of time standards for all existing and planned new models. Spreadsheet templates were devised to help supervisors in line balancing, manpower scheduling, monitoring and controlling. Additionally, simple computer-based tools were introduced for facilitating optimal use of shared resources.

All these changes were done collaboratively with process owners/ operators to ensure buy-in and learning for future improvements. The overall idea throughout the study was to look for breakthroughs by progressively redefining and enlarging the scope of the consulting engagement.

III. SELECTED IMPROVEMENT PROJECTS

A sample of selected process improvement projects executed during the study is described next to show the approach to problem analysis, solution, and implementation. More technically comprehensive descriptions of these innovations are documented separately in the case study based on the company [3].

A. Pad Printing

This is a printing process in which a flexible pad (mostly silicone) picks up a film of ink from an etched plate (cliché) and stamps (prints) it directly on to the surface of an object of any shape or size made of almost any material. The ink transfer can also be made in varnish, glue, powders, etc.; hence it finds application in varied high-tech industries. In this case it involved the printing of different markings (e.g. Roman, Arabic), symbols, and logos on dial surfaces based on design specifications using a semi-automatic, pneumatically-driven, single-color machine [example shown

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in Fig. 1]. Based on the assessment of the situation, it was decided not to recommend new machines which were expensive and did not offer enough flexibility. Accordingly efforts were concentrated instead on minimization of process setup times.

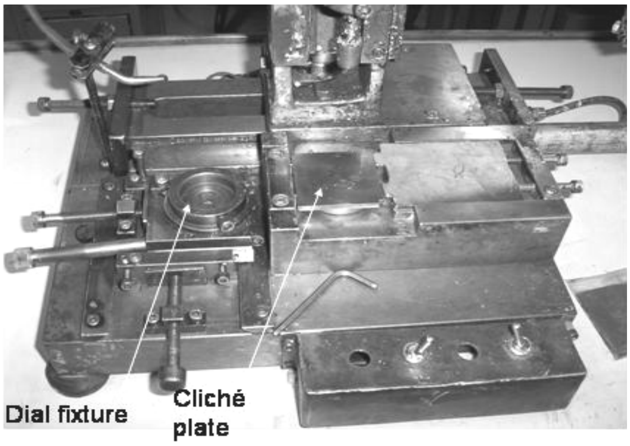

Fig. 1: Pad Printing Machine

Three broad setup activity areas were identified: *Cliché plate preparation, Machine adjustments, and Ink mixing*. First, preparation of the Cliché plate involved multiple trial and error adjustments to bring the system into position for proper printing. Next, adjustments of the machine for set up of the plate and fixture tool took a relatively long time (as much as 15-20 minutes) to achieve accurate alignment. Further, mixing of ink took more than five trials (consuming 10-15 minutes) to get the color right. Efforts to locate commercially available standard clamping and quick-changeover mechanisms for retrofitting turned out to be unsuccessful.

The first step was to apply SMED principles [4] to all internal task elements and attempt to make them external to the extent possible. To reduce the work content itself in terms of aggregate time required to complete all tasks, further process improvement was taken up using task-based techniques like methods improvement, 5S and waste reduction. This resulted in incremental improvement to the tune of 10%, which translated into improved Control Index and Efficiency Index. However far more significant improvements, of around 60% reduction in setup time, were achieved by a conscious adoption of focused design changes to the system, and relevant changes in work practices. This included reference/datum generation, standardization and standard operating procedures, and pushing the boundaries of existing setup reduction and quick changeover practices [5]. All together, these changes added up to aggregate breakthroughs, and as a net result the setup times came down from over half an hour to only about 6-7 minutes.

B. *Screen Printing*

Screen printing is one of the most versatile printing processes, which can be performed on a wide variety of material such as textiles, ceramics, metal, wood, paper, glass, and plastic. The process is used to print markings, symbols and patterns on dial surfaces as follows [see Fig. 2]: the screen is positioned on top of the dial face; ink is applied on top of the screen; a 'squeegee' (wiper blade) is used to spread the ink evenly into the screen and on to the dial through the open pores in the screen; finally the screen is peeled away. The basic process elements that determine the productivity and quality of image printing are frame, fabric, stencil, ink, and substrate.

Fig. 2: Screen Printing Machine

The major problem under consideration was reduction of long setup time for model changeovers, which broadly comprised three stages: *Screen preparation, Ink preparation, and Machine adjustments*. The set-up of the screen and dial fixture for a new model used to take a very long time (15-20 minutes) for alignment. In addition, Ink preparation took more than five trials to get the color right. The time taken for first trial screen print on the dial was also found to be unacceptably high (about 25 minutes), as well as being highly variable. Absence of reference/ datum on the screen frame and its clamping device, and lack of suitable alignment mechanism, made such lining up very difficult. All these resulted in high variability in set-up time, apart from the problem of patterns getting transferred at erratic locations on the screen during preparation. Besides, lack of standard color mixing procedure and measuring devices caused further delays in ink preparation.

To begin with, the sizes of all screen frames were taken up for standardization, with perpendicular fine notches introduced to run through the middle of the screen frame so as to provide reference lines. Various methods were introduced to aid alignment, clamping, fixing the film on the screen, and transfer of pattern to the right location - for example use of backing sheets, plumb lines, frame locating arrangements etc. On completion of every job, colors were catalogued for repeatability in future runs. In addition, dispensers of appropriate size were introduced to get color mixing right in a single trial. Exact base colors and blending ratios for different colors from different manufacturers were properly standardized and documented, so as to enable operators to get the correct shades within 5 minutes. Additionally, adoption of Ultra Violet curing was able to greatly reduce curing time. All these improvements together reduced changeover time from about 40-45 minutes overall to just 7-8 minutes.

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These two printing solutions demonstrate application of multiple principles and practices of Quick Changeover and SMED approaches. The general approach evolved was to first make basic design modifications in order to achieve minimal adjustments and to deskill the operations; this was then followed by systematic conversion of internal tasks to external; and the final thrust was on simplifying the residual internal tasks while also reducing effort and time on external tasks. The guiding principle was to improve the existing semi-automatic machinery to build in more flexibility in terms of changeovers, with low investment, instead of employing new state of art computer/ servo-controlled machines requiring heavy capital expenditures.

C. Dial Index Assembly

Index assembly is a labor-intensive and high-skill operation in which indexes (appliqués) are fixed manually, one at a time, on a dial face held up by vacuum (Fig. 3). Tweezers are used to pick-up the index and insert its feet into designated holes on the dial face. Use of metallic tweezers for handling causes the bulk of the quality problems, with rejection of appliqués to the tune of 50%, and this also leaves scratches on the dial surface. The projects taken up were to first find a substitute for metallic tweezers, and then if possible eliminate the need for any gripping device altogether.

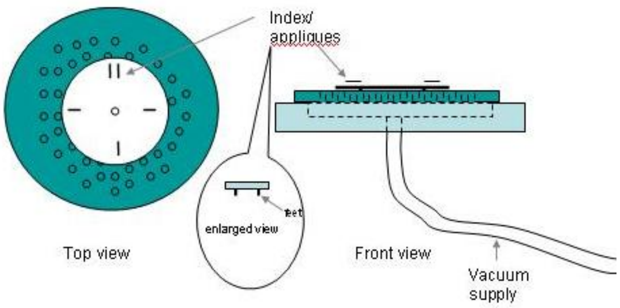

Fig. 3: Index Assembly Operation

The search for possible substitutes for tweezers spanned industrial product finders, trade journals, patent publications, and the internet. Alternatives available from watch tool catalogues were limited, and mostly offered only traditional tweezers. Non-metallic and silicone-tipped tweezers were tried, but without significant success since the sharpness of pick-up and manipulation ability of metallic tweezers proved difficult to match. Due to the miniature and irregular size of objects to be handled, very few advanced tools and possibilities for automation actually emerged. The team also searched through medical device and life sciences technology, numerous applications of smart grippers, literature on micro/ mini tools, and assembly technology. However, because of the different scaling of gravity and adhesion, such tools were not found to be fully suitable for micro-manipulation.

It was then decided to explore the potentially promising approach of utilizing adhesion forces or vacuum [6]. Innovative methods and apparatus for handling semiconductor wafers, which use Bernoulli principle to provide non-contact manipulation, or vacuum-lifting principles, also seemed to be an attractive prospect. The team also used the principles of TRIZ (*Theory of inventive problem solving*) for systematic idea generation [7], specifically the “Merging” and “Multiplication” principles, along with the “Combine” and “Eliminate” principles from Method study. This finally culminated in two solution possibilities: an alternative device for metallic tweezers to prevent scratch defects; and an innovative application (for select models) that completely eliminated the need for any gripping device and reduced operation cycle time to one-third during pilot runs.

Although the above process changes are potentially radical in terms of impact, not all kinds of markings, appliqués and indexes can be assembled that way. More ideas came from micro-tools used in the electronics industry, the most significant being vacuum tools for handling micro-objects. Standard tools called Vacuum Pens are available as substitutes for tweezers, but the standard units come with minimum tip dimension of 3 mm, whereas most dial marking sizes are below 1 mm. Further, larger tool-tip diameters compromise precision assembly since this prevents a clear view of the punched holes on the dial.

Hence, it was decided to fabricate a vacuum pen of under 1 mm tip internal diameter, with the tip beveled to provide a proper angle for picking up the indexes and then locating them on the dial face. These new devices require much less visual concentration on the worker’s part, and moreover the plastic tips do not leave scratches on indexes. The overall impact was the reduction in quality defects by 30%, which was considered quite a substantial improvement.

These novel and low-cost applications of vacuum technology show that it is quite feasible to exploit moderate rather than highly advanced technology. This helps to bring about breakthrough process improvements in manual operations of industries where technology penetration is low, and activities are not readily amenable for automation. Although advanced automation is possible in these industries, its economic viability, requisite flexibility under small batch production scenario, and demand for high-quality workmanship, are some challenges which need to be addressed adequately first.

IV. DEVELOPMENT OF INTEGRATED PROCESS IMPROVEMENT APPROACH

The company’s management was interested in institutionalizing the analysis and improvement approach developed during the study for ongoing and further use. In particular, it wanted to harness the ability to blend appropriate technology with sound managerial practices. The consultants were also keen on documenting their approach, especially the combination of incremental improvements and breakthrough innovations, and incorporating it into their own overall techno-managerial problem solving framework.

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More generally, there is a need to incorporate innovation perspectives into process improvement models, which would help to make breakthrough improvement viable and realize maximum synergy through coordinated initiatives. Prominent works in literature [1], [6], [8], [9], [10] discuss the objectives, enablers, product lifecycle linkages, key drivers, competitive priorities, critical success factors, learning effects etc. in the context of product and process development.

However, most documented case studies in this area tend to be in technologically mature industries. Further, most existing models are more oriented towards product development, with relatively few aimed specifically at process development. Process development is technically difficult, time-critical and competitively important, and thus worth being explored as a distinct unit of analysis. The process development frameworks suggested by authors such as Pisano [10] tend to be at broader, conceptual level in the context of product development as an integral approach and as a framework for capability building. However in scenarios of the type seen in the case, we need to balance the perspectives between managerial and technological aspects, the complexities and trade-offs underlying which have been acknowledged by researchers.

In light of these observations as well as the experiences from various aspects of the case, the proposed model [Fig. 4] has been visualized as an attempt to bridge the gap between technically oriented tools (such as TRIZ, Six Sigma), and Business Process Redesign (BPR) oriented models in Clark et al [11]. The framework provides an integrated and hierarchical plan for going about process improvement initiatives in multi-project situations. It systematically plans for synergy realization from the concept level down to execution level. Based on this approach, a series of improvement projects were successfully implemented with a view to addressing the larger operations management problems confronting the organization.

The approach is likely to be most beneficial in a multiple project environment, especially when third-party led retrofitted process improvement initiatives are involved. Pushing the boundaries of existing setup reduction and quick changeover practices for breakthrough improvements would be one such fertile area for its application. However, the approach may be relatively more suitable for improvement oriented projects, rather than for purely new product development especially in very high technology research domains.

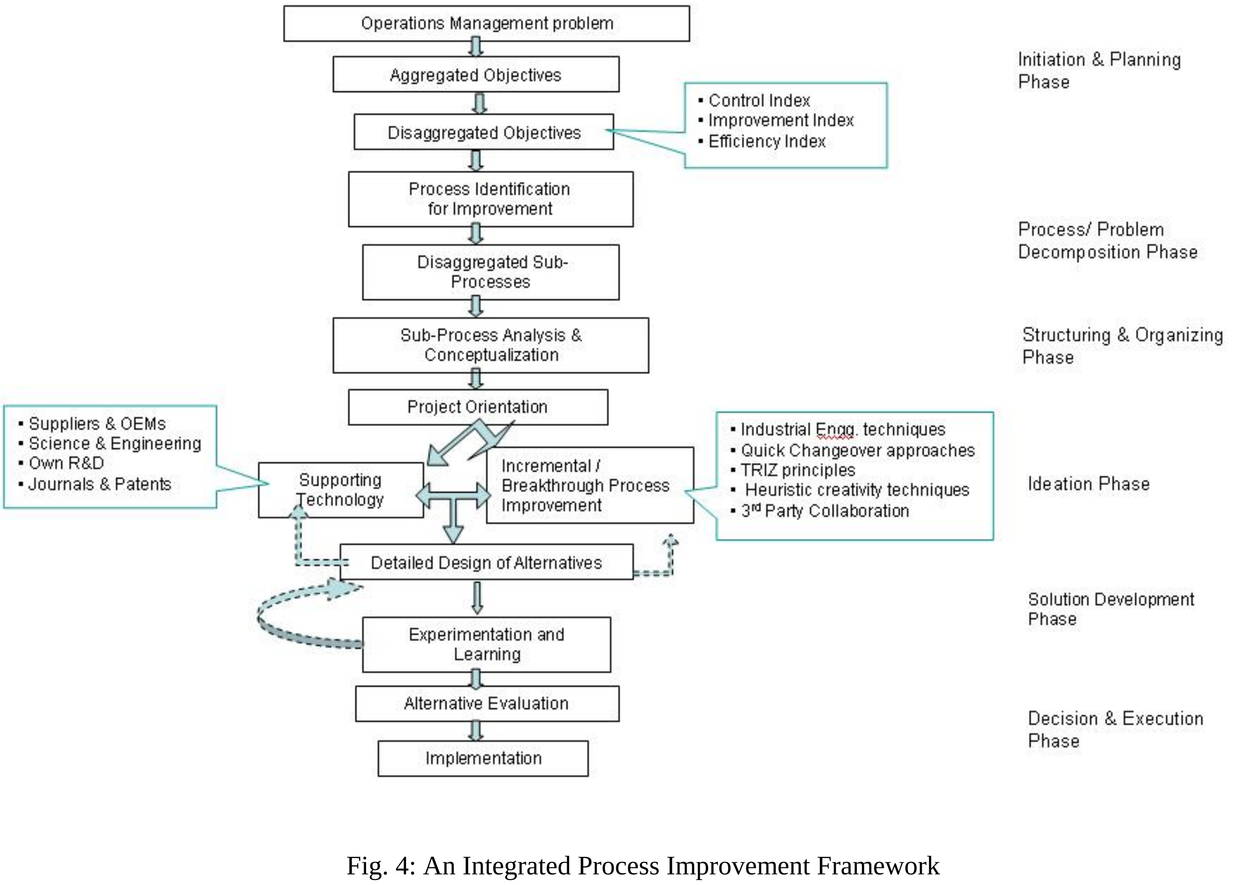

Fig. 4: An Integrated Process Improvement Framework

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V. DISCUSSION AND FUTURE WORK

The matching of process strategy with technology deployment in relatively niche and under-researched industries needs further refinement and focus. Marrying process ideas with enabling technology can get quite complex, but there is still significant scope for process innovation without having to use very sophisticated technological process design. From an industrial automation perspective, streamlining assembly processes of watch dials is a big challenge in itself. Extending the radical process innovation concepts to all kinds of appliqués or indexes is an area for further exploration, and needs additional technological breakthroughs and commercial viability.

In setup reduction, design modification offers an attractive alternative approach when potential for major improvement through traditional approaches begins to stagnate. Expansion of the scope of SMED with introduction of modularization and other technological improvement is another avenue worth further exploration. It would greatly benefit the manufacturing industry at large, if equipment manufacturers were to incorporate Design for Quick Changeover features. Accordingly, a triadic collaboration between manufacturing organizations, operations management/ industrial engineering consultants, and equipment designers may be useful to incorporate consideration of manufacturability aspects.

The prospects of achieving radical process innovation can be greatly improved by making concerted use of enabling technological innovations. However, major technological change should generally be taken up only after exploring other options, since this brings along challenges of implementation and technology absorption. The relationship between the extent of technology adoption and process improvement/ innovation could therefore be another fruitful area for further research.

Process management techniques, by design and intent, are oriented towards exploiting current capabilities incrementally. However, such an approach could limit significant exploratory activity and inhibit learning outside the existing technological trajectory. Accordingly, more work on integration of general creative thinking principles with process improvement would be beneficial for understanding and managing process innovation.

Finally, study of the use and impact of process improvement as a strategic weapon for different product lifecycle needs could generate further insights. Available literature indicates that process development generally lags product development significantly [6], and it is said that process improvement matures only after the new product reaches adequate maturity. The approach and solutions described in this paper, developed and implemented collaboratively, have been found to be successful in infusing fresh ideas into process design to achieve considerable improvements on all manufacturing criteria. Hence it would be short-sighted to underestimate the potential of process improvements even in the most established and mature product industries.

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