A Three-Step Procedure (3SP) for the Best Use of Skilled Labor

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Abstract

As the manufacturing is becoming more and more globalization, the manufacturing jobs, especially low skilled jobs, have been moved to the developing countries for a lower production cost. For those jobs, such as skilled labor jobs, currently still kept in the developed countries, more and more cost pressure is experienced in these countries as those jobs will eventually be moved to the developing countries once their infrastructure, efficiency and skill level are improved.

Therefore one of the challenges currently faced by the Canadian companies is how to improve the manufacturing productivity. Currently those companies are using their own way to improve the productivity. As a result, a company may repeat what another company has already done for the improvement of the productivity, and waste the effort. In some cases, a company even has no idea how to pursue the action to improve its productivity.

In order to provide the Canadian companies some sort of systematic approach in the course of improving productivity, a systematic qualitative guideline for the best use of skilled labor, called as “Three-Step procedure” (3SA), is developed and described in detail in this paper.

Keywords: Manufacturing, Process analysis, Production, Productivity improvement, Skilled-labor, Skilled-labor intensive manufacturing, Three-step procedure.

1. INTRODUCTION

Canadian manufacturing companies are experiencing extreme challenges in retaining the production inside the country, since more and more manufacturing jobs, especially those low skilled labor intensive jobs, have been moved to developing countries such as China and India where the lower cost of labor significantly reduces the production cost. The jobs that are still remaining in Canada or other developed nations are mainly skilled labor or machine intensive jobs. Even for these jobs, they may eventually move to developing countries once their infrastructure, efficiency and worker skill level are improved.

In order to keep as many jobs as possible in Canada is now a major concern by Canadian companies. One of ways to reach this aim is to reduce production cost while maintaining the required quality, quantity and delivery time level. Currently most companies are using their own way to reduce the production cost through reducing the waste. This situation may cause the useless effort in the course of improving the productivity since a company may repeat the effort that has already been done by another company. In some cases, a company even does not know how to pursuit an action to improve its productivity. So it would be benefit for all companies if a systematic approach could be available to improve the productivity. However, no such way exists currently and maybe because of “Difficult to Recognize the Manufacturing Problem”, “Difficult to Locate the Root Cause”, “Difficult to Find the Solution” and “Unavailable Standard Procedure” [3].

- **Difficult to recognize the manufacturing problem** since the problems occur randomly with multiple symptoms. Randomly occurring means the problems could occur at anytime and at any location in the course of production; Multiple symptoms mean a problem could be presented in multiple ways and easily block the human being’s recognition process.

- **Difficult to locate the root cause** since the linkages between the problems and causes are extremely complicated, in some cases no information is available at all. Complicated linkages mean the links between problem and causes could be “One to one, One to many, Many to one and Many to many”; No information is available at all means the required information, such as electronic version of BOM, is missing since it may not be collected at first place.

- **Difficult to find the solution** since it is very difficult to find the root cause, and the attempt solution may not solve the root cause and the similar or the same problem may occur again in the future.

- **Unavailable standard procedure** since it is not developed so far and the different companies use the different procedures to solve their specific problems. It makes the solution searching procedure very subjective and less effective than it could be.

In order to provide a systematic approach to improve the productivity when skilled labor is used, a “Three-Step Procedure” (3SP) is developed and described in this paper.

2. LITERATURE REVIEW

The improvement of productivity is mainly related to the deduction of waste in terms of what is waste and how to reduce waste. Therefore, the literature review has focused on the “Definition of Waste”, “Identification of Waste in Manufacturing”, “Solution of Reducing Waste”, “Costing Process” and “Systematic Approach of the Best Use of Skilled Labor”.

2.1 Definition of Waste

In order to identify waste, it is necessary to know what the waste is. From an ecology point of view, everything on the earth has a purpose and no waste exists. So that the term “Waste” is a relative concept, for example, recycled paper is a waste for most industries, but not for the recycling industry since it is the source of its revenues.

Therefore waste is defined by many ways in the literature. Hesham K. Alfares et al. (2005) stated “The deteriorating items and deterioration of process are considered to be a kind of waste since both deteriorating items and deterioration of process cost money”; Kenne J.P. et al. (2000) [10] said “Inventory cost and back order penalties will affect the performance of production, and is considered to be a waste”.

Generally speaking, waste is any unwanted or undesired material left over after completing an activity such as a transformation of raw materials to semi-finished or finished products.

In this paper, “Waste” is defined as “Any unplanned loss in terms of quantity, quality and time in manufacturing”. Based on this definition, a “Planned loss” is not a waste since it is supposed to occur. In some literatures, this definition is called a “Pure waste”.

2.2 Identification of Waste in Manufacturing

Once the waste is defined, how to identify it in a manufacturing is the next question that is another topic in the literature review. The first attempt in the searching was focused on the identification of waste in skilled labor manufacturing, but no paper could be found. Then the searching was expanded to manufacturing and reviewed as follows.

Not many papers could be found related to the identification of waste in manufacturing, which was indicated by Britney, Brand and Lubicz, as “A relatively little work has been done to explore the process improvement on the cost saving by comparing to the research on the number and placement of inspection stations for the production costs like the costs associated with maintaining inspection stations, performing inspection tasks”. Some papers found are listed as follow:

Smith Marc (2008) [19] stated that the identification and elimination of waste is the core of any supplier development activity. He defined waste, and looked at possible causes and symptoms in a supply chain system.

Naruo et al. (1990) stated that expert system could be developed for diagnostic decision support, which transforms the cause-effect relationships into production rules and uses forward or backward chaining to infer fault causes from fault symptoms. Although the expert system overcomes the problem of computational complexity by employing heuristic knowledge, its ability to solve a problem is restrained to what is in the knowledge database due to the inability to learn and generalize knowledge.

Knapp and Wang, et al. (1992) presented in the paper “Neural networks for system fault diagnosis”. Another example was presented by Ye and B. Zhao (1996) [20] in the paper “A hybrid intelligent system that integrates the neural networks with a procedural decision making algorithm”.

Peng and Reggia (1990) stated that from an Operations Research point of view a diagnostic problem can be considered as an optimization problem that represents a solution in terms of optimization indicators that are subject to constraints such as the cause-effect structure of a target system. Operations research is basically mathematics and statistics based approach to analyze the data.

As a summery, the identification of waste is a complicated and subjective process, and few researches have focused on this topic so far.

2.3 Solution of Reducing Waste

Once the waste is identified, the next consideration in the literature review is the solution to reduce waste.

Many solutions can be found to reduce waste in manufacturing, for example, D. Challis et al. (2005) stated “TQM, JIT and Advanced manufacturing technology are important, however, the ‘soft’ human resource management practices such as leadership, teams, and employee performance is also significant in improving the manufacturing performance”. Other examples are:

Hallihan A et al. (1997) stated “Some types of waste could be eliminated by using JIT. This would be done with management support and by setting the JIT in a specific manufacturing context which is the combination of people, machines, materials, processes, products, and managerial policies”.

E. Houghton et al. (2005) stated “A cross-training of workers to perform multi-skilled jobs is one of the modern trends in job design for cost savings”.

Inderfurth K. et al. (2005) [8] noted that it is necessary to coordinate the production and rework activities with respect to the timing of operations, since the state of defective items may change in the course of time while they wait to be reworked. Such a deterioration of rework-able goods can result in increasing rework time and rework cost per unit, which increases cost.

Lin Z-C et al. (2002) [12] stated “A tolerance design, based on neural networks, in product components could produce a product with the least manufacturing cost possible, while meeting all functional requirements of the product”.

Lee B. (1999) [11] stated “Under the assumptions of profit maximization and cost minimization and ignoring the potential inefficiency in IT investment and management, the increase in the IT intensity will significantly reduce the technical, allocation and scale inefficiencies”.

2.4 Costing Process

Once waste and solution are found, they need to be assessed for the implementation in terms of cost since the trade off needs to be determined between cost of waste and cost of solution. In some cases, “Leave waste as is” maybe feasible if it is too expensive to implement solution unless it is a legal requirement.

The costing process in this paper refers to what and how to measure the cost, which is subjective and complicated, as stated by Jha N.K. (1996) [9], “Costing in manufacturing is a complicated process. The normal approach to costing is to estimate the cost based on time required for the production processes, and the costs for materials, and then add some profit margin on top that is pre-determined by the managerial judgment and experience”.

Many processes could be found in the literature, but most of them are case based. For example, Newnes L. B. et al. (2007) [14] mentioned an on-screen real-time cost estimation used in the early phase of design of injection moldings to identify the avoidable cost; Shehab E M et al. (2002) [18] used an object-oriented and rule-based system to estimate the product cost at an early design stage. The main function of the system, besides estimating the product cost, is to generate initial process planning, including the generation and selection of machining processes, their sequence and their machining parameters, to recommend the most economical assembly technique for a product and provide design improvement suggestions based on a design feasibility technique.

Some processes do provide a general approach, but no detailed “step by step” approach is available. For example, Michelle stated “There are basically four steps in assigning production resources to the end product in the costing process: 1) Define activity groups that have a direct relation with the end product; 2) Determine resource drivers that show the relation between production resources and activity groups and cost drivers that show the causal relation between an activity group and a type of end product; 3) Assign the costs and resources to activities based on the resource drivers; 4) Assign the costs of activity groups to the end product based on the Cost” (ABC Forum, 2008) [1].

Simon observed that it is essential to first make the decision about the level of detail that needs to be captured in the costing process. At the strategic level, about 100-150 activities are most commonly used to determine the profitability of a customer or a product. At an operational level the number goes up to 500+ activities to improve the costing process (ABC Forum, 2008) [1].

Park J. et al. (2005) [16] also stated that estimation of the production cost of a family of products involves both estimation of the production cost of each product in the family and the costs incurred by common and variant components/design variables in the family.

The way to determine cost includes: 1) Allocation, in which the production activities and resources needed to produce the entire product lines in a family are identified and classified with an activity table, a resource table, and a production flow statement; 2) Estimation, in which the production costs are estimated by cost estimation methods; and 3) Analysis, in which the components/design variables possible for the product family are investigated with resource sharing methods through activity analysis.

P.R. Roy et al. (2008) [15] developed a process "Function-based cost estimating" that links the commercial and engineering communities through a structured approach at the conceptual design stage. This process is to translate the un-quantified terminology and the requests associated with the product specifications by using a standardized approach.

It starts with functional decomposition, and then identifies product parameters that are related to a top level function, and finally associate product costs to the function using past knowledge and data. It is validated in two case studies from the automotive and aerospace industries.

Sharma Rajiv Kumar et al. (2007) [17] presented a quality costing in process industries through QCAS: a practical case, which is to implement, sustain and manage a quality-costing program in a process industry by attaching fuzziness to the notion of "quality".

2.5 Systematic Approach of the Best Use of Skilled Labor

A systematic approach of the best use skilled labor is another focus in the literature review. However, unfortunately no paper could be found related to the topic of "Systematic Approach of the Best Use of Skilled Labor" in the literature.

3. Three-Step Procedure (3SP)

When the field managers or industrial engineers were deciding how they would improve manufacturing productivity, the first thought in their mind was, "How do I proceed this task in terms of 1st step, 2nd step and so on?" and "Was there any procedure in reality or the literature that can be followed by field personnel?" Based on an extensive literature search, although many manufacturers do variations of improvement of the productivity informally or set up a rigorous structure for parts of the improvement for themselves, the whole statement has not been found anywhere. The papers found so far are either for a specific problem or for an overall problem without detailed approach.

For example, Park J. et al. (2005) [16] stated the procedure in the design phase could be: 1) Identify and classify the production activities and resources needed to produce the entire product line in a family with an activity table, a resource table, and a production flow statement; 2) Estimate the production costs; and 3) Investigate the components/design variables possible for the product family with the resource sharing methods through activity analysis.

Therefore it was necessary to develop a new procedure to provide field personnel with a new standard qualitative procedure for the best use of skilled labor.

Based on the extensive interview with field personnel, the steps in the procedure should be, in order, "Whether skilled labor should be used in the first place?" "What is the maximum potential achievement to be set as a benchmark if skilled labor is selected?" and "How could the defined benchmark be attained and maintained?"

In order to facilitate the above questions, a "Three Step Procedure (3SP)" is developed in this paper, which includes: "Step 1: Determine whether to use skilled labor"; "Step 2: Define the most suitable specifications for using skilled labor" and "Step 3: Attain and maintain the defined productivity", as shown in Figure 1.

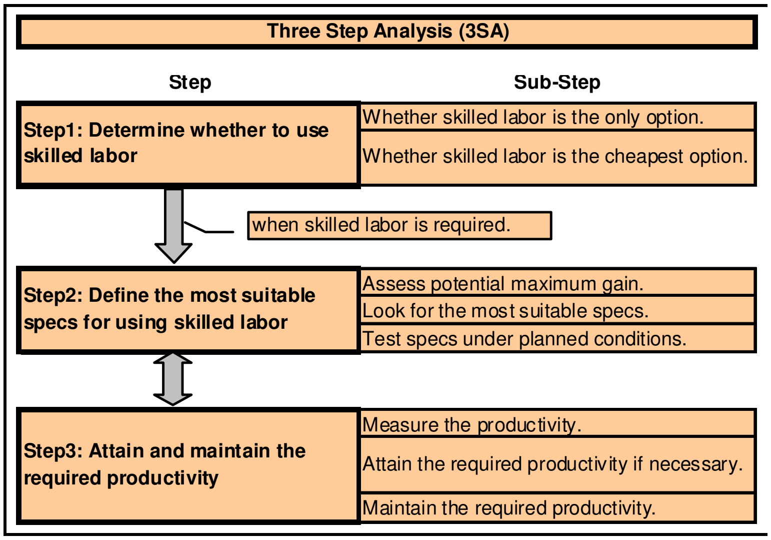

FIGURE 1: Three-Step Analyses (3SP)

3.1 Step1: Determine whether to Use Skilled Labor

Many production options such as skilled labor, un-skilled labor and machine are used in manufacturing to complete an order. The question is which one is the best one for the required job in terms of effectiveness and efficiency. Thus two issues are raised here: "Whether skilled labor is the only option" and "Whether skilled labor is the cheapest option". If skilled labor is chosen to be used, the issue will go to Step 2 otherwise no further discussion is needed in this paper.

- **Whether Skilled Labor Is the Only Option.** The purpose to check this issue is to reduce the decision effort since it is unnecessary to go through the cost procedure if skilled labor is the only option to do the required job effectively and efficiently.

  A list of situations is identified where skilled labor is the only option, which includes "Small volume of orders; Non existent machine; Unavailable documents; Complex item with small volume; Uncertainty in process; Extreme accuracy, Extensive measurement and adjustment required; and Significant judgment required".

  - **Small volume of orders** addresses the case when the order is small. In such a case, expensive machines cannot be justified, since each operation would have to carry a large part of the capital cost. If the machine also requires a significant setup time, the setup cost per operation for a small volume run would be large. For example, when only milling 100 cases of the radial aircraft engines per year, it will be very expensive per case if a NC machine is used because of its high capital cost.

  - **Non existent machine** addresses the case when no machine exists to do the required job, and the only way is to use skilled labor. For example, for aligning the metal sheet on the body of an old type of aircraft with an extreme surface smoothness, no machine currently exists to handle this job, and the only way is to use skilled labor. Another example is that an extremely accurate alignment is required when joining two sheets together to avoid "Oil canning" (a situation when two sheets do not fit perfectly together and cause a slightly curved rather than a flat surface, and with slight force the curve pops in or out easily). However, no machine could be found to perform this job since the machine does not exist and using skilled labor becomes the only way to do this job.

  - **Unavailable documents** address the case when the required documents are unavailable to do the required job, and skilled labor is the only option. For example, "Bill of Material

(BOM)" of an old type of engine with many variations is not available, and causes significant difficulty to determine which parts fit where. The solution could be recreating a BOM or use skilled labor with the knowledge of BOM for this type of engine.

- **Complex item with small volume** addresses the case when the requested item is complicated and the order volume is small as well, and skilled labor is the only option to do the job in terms of cost effectiveness. For example, a customized motor cycle requires many unique assembling operations such as "Fitting and aligning", which requires a sophisticated process that could only be done by skilled labor.

- **Uncertainty in procedure** addresses the case when the next step is unknown until the current step is completed. For example, when cutting a diamond, the placement of the next cut can't be known before the current cut is completed because of the variations in physical properties throughout the natural diamond. In such a case, skilled labor is the only option.

- **Extreme accuracy, extensive measurement and adjustment required** addresses the case where intelligence is required. For example, two pieces of thin metal sheet are often aligned very accurately when assembling the aircraft. Because of the combination of the extreme accuracy requirement and the flexibility of the sheets, no machine could be found to do this job, and skilled labor is the only choice.

- **Significant judgment required** addresses the case where good knowledge and judgment is required for doing the job. For example, when sorting the worn parts for useable, rework and scrap, good knowledge is required to do a correct sort; otherwise a good part may be treated as a bad one or vice versa if non-skilled labor is used; when lapping a cylinder valve, significant judgment is required for determining the smoothness of surface.

- **Whether Skilled Labor Is the Cheapest Option.** When more than one option is available to do the job, a cost comparison is necessary. For example, both NC welder and skilled labor are available to do a "Welding" job and the question is which one is the cheapest. When the batch size is small, using skilled labor is usually the cheapest because the setup cost of the NC welder is normally very higher per part welded. Some rules are summarized in the analysis in order to reduce the analysis effort, which are:

  - **Rule 1:** Machinery is always considered as the first option to do the job when the unit cost is acceptable since the machine always provides the least production time, the greatest quantity, the best and most consistent quality. Considering whether to use the machine usually depends on the unit cost determined by the production volume.

  - **Rule 2:** Non-skilled (un-skilled or semi-skilled) labor is the second option to do the job when the worker has the minimum required skill since the wage is medium. But, it is expected that other costs may be increased, such as longer production time or more defects.

  - **Rule 3:** Skilled labor is the least desired option to do the job if other options are available because of high labor cost.

  - Rule 4: Contract is a possible option to do the job if the cost is acceptable.

  In summery, in an industrialized country, machinery is always the first option, un-skilled labor is the second option, and skilled labor is the last option. Contract may be an option.

  The comparison in this step means to determine whether skilled labor has the least cost, which includes four steps: 1) Analyze production flow, 2) Determine factors to measure, 3) Identify losses and 4) Estimate cost, as briefly described as follows.

1) **Analyze production flow** is to understand how the production is done in terms of information and material flow.

The information flow includes the static information (e.g. aim, task, penalty policy, throughput, scrap, delay and cost) and dynamic information (e.g. where the value is added or lost and how the involved steps are linked).

The material flow shows where the material or part comes from and goes to.

One example of production flowchart is shown in Figure 2, which is a real process of "Grind and Lap Valves" performed in Aero-Recip (Canada) Ltd. This process is one of processes in rebuilding the cylinder of P&W R985 engine. The reasons for performing this process is that the ring on the valve seat in the cylinder is a soft metal part and needs to be replaced if it is worn and out of specifications. When a new ring is installed, it must seal with the valve without gas leaking otherwise engine power will be lost significantly if this process is not performed.

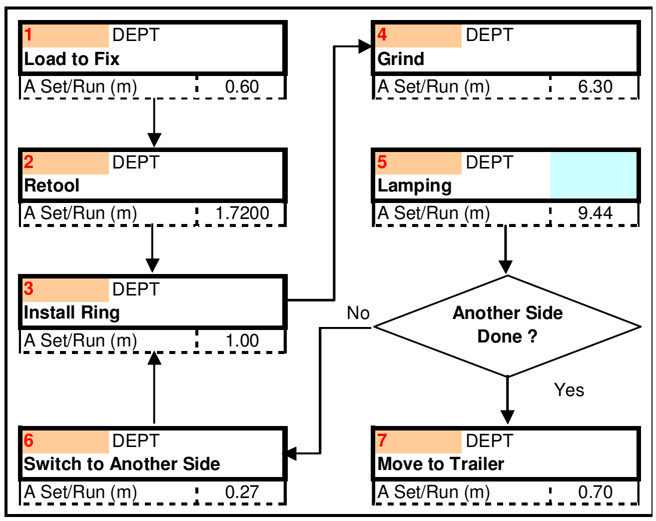

FIGURE 2: Grind and Lap Valves (Cylinder, P&W R985)

The details of the process are: Operator moves a cylinder in which new rings have been installed, from a trailer and loads and secures it on a fixture. He sharpens the sand stone (used for grinding) to the correct angle if necessary. He grinds the area on the ring where the valve will touch (called "Contact area") and checks the result several times until enough material is removed, and then cleans the grinding area with a cloth.

Next, he does a "fine" operation (called "Lap") to smooth the "contact area" to make sure no gas will be leaked through this area when the valve seals with the ring. The way to do this is: He takes the valve, which is specifically used for the valve seat being lapped, from a case and puts the lapping compound on the contact area on the valve. He takes a pole with a suction cup on the bottom (lapping tool) and mounts it on the flat side of the value seat, and puts the valve on the ring of the valve seat 1, then he starts lapping by rotating the pole. After rotating a while, he cleans the contact area and visually checks the smoothness. If the lapping is not completed, he repeats these pasting, rotating, cleaning and checking steps until the smoothness level which gives a good seal level is reached. Then he turns the cylinder to the second side that is valve seat 2 and repeats the above operations done for valve seat 1. Once both sides are completed, the operator removes the bolts and takes the cylinder off the fixture and places it on the trailer. The operation time is also shown in Figure 2.

In order to create a correct flowchart, it is crucial to use a knowledgeable person, obtain management approval and get all involved parties to agree to the flowchart. The tools used in creating the flowchart include observation, video, interview, questionnaire, process analysis and data analysis.

2) **Determine factors to measure** is to decide what to measure in terms of cost spent on “Quantity, Quality and Time”, which is related to “Input, Control, Doing and Output” and listed as follows.

a. Input

i. **Material:** Quantity (from actual measure) and unit cost (per piece, from accounting book).

ii. **Labor:** Number and unit cost (per unit of time, from accounting book), which includes wages, salary, fringe benefits and support cost.

iii. **Machine (including tool, fixture and computer):** Quantity, unit cost including the capital cost and maintenance cost (per piece or unit of time, from accounting book) and depreciation period.

iv. **Space:** Size and unit cost (per area or per unit of time, from accounting book), which includes the deposit and renting cost.

v. **Contract:** Quantity and unit cost (per part or unit of time, from accounting book).

vi. **Tied cost:** Interest paid for the stored material, which depends on the “Interest rate” (from accounting book), “Time stored” and “Quantity of material” (from actual measure).

vii. **Energy:** Amount of energy used (electricity, water and compress air, from actual measure) and unit cost (per watt, volume or unit of time, from accounting book).

b. Control

i. **Penalty:** Payment (determined by the penalty rates and quantity involved) for dissatisfaction of the customer in terms of quantity, quality and time. The penalty is usually pre-set (from accounting book).

ii. **Organizing:** Cost for scheduling, meeting and etc, which depend on the “Cost per unit of time” (from accounting book), and “Time spent for those efforts” (from actual measure).

c. Doing

i. **Time:** Time spent for doing the job which includes the planned time (from production statement) and actual time spent (from actual measure).

d. Output

i. **Quantity:** Quantity produced (from actual measure).

ii. **Quality:** Quality produced such as scraps and reject items (from actual measure).

iii. **Time:** Time spent to complete the job (from actual measure).

3) **Identify loss** is to get the loss information including planned and unplanned losses.

4) **Estimate cost** is to evaluate the cost includes a total cost, value added and value loss.

The sources for obtaining the above information are “Production Statement”, “Accounting Book” and “Actual Measure”. The tools used to collect the above information are video, interview and observation. In this step, estimates of times and losses may be used instead of actual measure if the measurement is very difficult.

If skilled labor is chosen, the analysis process will go forward to Step 2 for further evaluation, otherwise no further discussion will be undertaken in this paper.

3.2 Step2: Define the Most Suitable Specifications for Using Skilled Labor

After skilled labor is chosen to do the job, it is necessary to know how to use skilled labor to obtain the maximum output rate with the least manufacturing error. Therefore, “Define the most suitable specifications for using skilled labor” is identified as the task of Step2 and discussed under two topics: 1) Assess maximum potential gain and 2) Determine the most suitable specifications.

- **Assess maximum potential gain** is to estimate the potential maximum gain with the least loss under the planned condition (e.g. the required materials are always ready for use and the operation is not delayed). The analysis here is based on the ideas of operation designers who are experienced in designing skilled labor manufacturing operations. In order to get the least loss, four general directions are identified in this thesis: 1) Optimize the utilization of resources; 2) Minimize the process time; 3) Minimize the error occurrence and 4) Maximize workplace safety.

    - **Optimize the utilization of resources** such as raw material, skilled labor and machine. For example, assign one operator to operate on two or more machines, rather than have one operator per machine; carefully define the used part acceptance level in overhauling process, rather than use an unnecessarily accurate specification that rejects useful parts; have unskilled labor perform some steps to reduce skilled labor involvement; keep defined scrap low, especially related to cutting parts from a piece of material.

    - **Minimizing the process time** includes setup and run. For example, run a larger batch to reduce setup time per part if setup time is long; eliminate unnecessary steps by carefully analyzing the job to determine the minimum work to be done; reduce skilled labor waiting time for parts or tools to become available, or for a machine driven process to finish; use assisting tools to increase process speed.

    - **Minimizing the error occurrence** is very important because some errors always occur when skilled labor is used to perform complex tasks. For example, design the workstation for easy access to check the operation and parts whenever required; set more inspection stations in place if cost effective; provide more instructions for trouble-shooting when an error occurs; use assist tools, fixtures and machines for better accuracy; design the operation and the parts to keep the possibility of mistakes low.

    - **Maximize the workplace safety**, for example, add sensors to suitable locations of machines to prevent operators’ hands from entering the work area during an operation; redesign the workplace using ergonomic techniques to decrease the potential work risk. However, this issue is not a focus in this thesis since it is a more legal issue than cost issue.

  Note that the information related to how the maximum potential gain is achieved is described above for the reader’s ease of understanding. This information can be found in many articles.

Also most skilled labor manufacturers have operation designers that are experienced in this area (Nahmias Steven, 2004) [13].

- **Determine the most suitable specifications** after the general structure and techniques for the operation have been worked out, the operation is designed in detail and run to see how well it works. With complex operations using skilled workers, a major consideration is the reduction of operational errors and smooth recovery when errors are created.

  If improvements can be made to the operation, an iterative procedure of improving and running is used until a suitable result is achieved. To obtain the best results the following procedures are used: 1) Analyze production flow, 2) Determine factors to measure, 3) Determine production design weak points, reasons for weak points and potential solutions, and 4) Estimate cost.

  - **Analyze production flow** is the same as the one in Step 1.

  - **Determine factors to measure** is the same as the ones in Step 1.

  - **Determine production design weak points, reasons for weak points and potential solutions** means any errors that occur under expected conditions. For example, as expected conditions, everything supporting the job is as it is supposed to be, including material with the correct specifications available at the expected time and, operators with the required skill levels performing the operation; a detailed statement of the job is used as a reference, and all inputs to the job, control of the job, and running of the job must fit this detail job statement. If this statement does not exist, it will have to be created.

    - **Production design weak points** are any errors that occur under expected conditions. For example, as expected conditions, everything supporting the job is as it is supposed to be, including material with the correct specifications available at the expected time and operators with the required skill levels performing the operation; a detailed statement of the job is used as a reference, and all inputs to the job, control of the job, and running of the job must fit this detailed job statement. If this statement does not exist, it will have to be created. To find the weak points, all measures are under close observation, noting everything of importance in production, including: exactly how long each step in the production takes; the likelihood of material being used improperly; and the likelihood of out of specification product being created.

    - **Reasons for weak points** are the possible causes for the errors. For example, labor with less than the required skill is used to determine the reusability of a part from the engine to be overhauled may reject a good part or accept a bad one because the labor's skill or training is too low.

    - **Potential solutions** are the possible solutions to eliminate the cause. For example,

      - Use a step improvement approach, which is to use a very different approach than is presently being used. For example, designing a new product in a way that the manufacturing process will be easier, or that will allow the use of more machinery. This solution is desirable in manufacturing but associated with a high product development cost.

      - Re-design the processes to simplify the work, do less work, or wait for less time, by splitting, combining and merging. For example, waiting could be eliminated by changing the operation sequence or production schedule; the distances of a tool movement could be reduced by changing the operation sequence or combining the tasks.

- Re-design the layout to reduce loss, for example, unnecessary travel distance between two machines. Another example is that if a hot gun is used, the operation should always be kept away from a cold environment; e.g. never near doors that may be opened in the winter time.

- Re-design the information system to add extra data, such as information related to Loss, cause and solution.

- Redefine the process to reduce the overall cost of some operations. For example, since labor intensive operations always have losses caused by the operator, change the operation in a way that slightly increases the time, but reduces the chance of damaging the part.

- Redefine the specifications where possible, for example increase the allowance of a hole to allow a bolt to be installed more easily.

- Redefine the specification to accept more used parts by carefully considering the maximum wear of used parts that will not hurt the product being rebuilt.

- Add plan to consider savings not normally considered, such as energy saving, when defining the operation.

- Assist with machine, tool and fixture to improve the consistency of quantity, quality and time. Machine assistance can add speed and accuracy and reduce "out of specification parts". For example, a fixed caliper is used to make a common measurement rather than requiring the operator's skill and extra time to use an adjustable caliper. The automatic equipment is used as much as possible to perform the load, unload, inspection and locating.

- **Estimate cost** is the same as the one in Step 1.

All above determinations can be thought as "Define the process requirement". One key issue that has to be addressed is that the person to do the above determinations should have significant training and experience with manufacturing operations. The developed procedure must be tested under tightly controlled conditions to determine how well the design actually works. It is an iterative determination process, going between design and test until the best result is found. The testing also uses an extensive video recording, data analysis and discussion with operators to determine what runs smoothly and what gives problems. The result of this determination is used as the production baseline of measurement for the next step: Step 3.

3.3 Step3: Attain and Maintain Required Productivity

After skilled labor is chosen and the most suitable specifications are defined, it is necessary to know how to attain and maintain the defined productivity which is identified as the aim of Step 3 and supported by three sub-steps: 1) Determine the productivity level; 2) Locate the cause; and 3) Find a solution.

- **Sub-Step1: Determine the Productivity Level.** In order to improve the productivity that is defined as the "Inverse of cost" in this paper (Strong, 2003) [2], it is necessary to understand the current productivity level to see whether any waste exists.

  In terms of waste, everything on the earth has a purpose and no waste exists from the ecology point of view. Therefore the term "Waste" is a relative concept since waste for one person may not be waste for another. For example, recycled paper is a waste for most industries, but not for the recycling industry since it is the source of its revenues. Generally speaking, waste is any unwanted or undesired material left over after completing an activity such as the transformation of raw materials to semi-finished or finished products.

In this paper, **"Waste" is defined as "Any unplanned loss in terms of quantity, quality and time in manufacturing"**. The main point in this definition is that the waste is measured against the "Planned" quantity, quality, time and cost. For example, an unplanned idle is a waste, but is not a waste if the idle is planned. Based on this definition, this "Waste" is also referred to as "Pure waste" in some literature.

This sub-step is supported by the further 4 steps: 1) Analyze production flow; 2) Determine factors to measure; 3) Identify waste and 4) Estimate cost, which are basically the same as the ones in Step 1. The tools used to collect the information include interviews with the foreman and operators and independent observation of the operation, and obtaining information from reliable production information system. The only difference is "Identify loss" in Step 1, while "Identify waste" in this step.

The waste here is defined as "Unplanned loss", such as excessive availability, excessive capability and unplanned busy.

- **Excessive availability** indicates the quantity of resources is greater than planned, such as two workers doing a job that actually requires only one worker and causes over payment.
- **Excessive capability** indicates the capability of resources is greater than planned, such as a skilled worker is doing a low skilled job and causes an over paid wage.
- **Unplanned busy** indicates the time spent is for unnecessary activity like doing an inspection twice.

A detailed "step by step" approach to implement this sub-step will be submitted for the publication.

- **Sub-Step 2: Locate Cause of Waste.** Once the waste is roughly identified in the sub-step 1, the cause of waste has to be located, which is defined as the aim of sub-step 2.

The **cause of waste is defined in this paper as "Any issue to create waste"**. For example, an unskilled worker causes a higher reject rate; the parts received with inconsistent quality causes a longer operation time; a slightly incorrect shape of fixture may cause part damage.

In order to provide an exact direction to locate the related causes of waste, a detailed investigation is required, which includes: 1) Analyze production flow and 2) Locate cause of waste.

- **Analyze production flow** is the same as the analysis in Step 1 with the major focus on the cause of waste. For example, for a particular waste such as a waiting time for a part coming to a drilling operation, a specific production flow (A kind of inserted mapping chart to show the detailed linkages between this drilling operation and other operations) is created to show the causes from up stream, which may reveal a labor shortage in the upstream operation resulting in an inability to deliver the required part on time.
- **Locate the cause of waste** is to map waste to the related cause, which sometimes requires a great detailed investigation and data analysis. For example, an inconsistent quantity of the parts received between batches causes extra time to handle the different batch sizes since the resources structured for one batch may not easily handle a significantly large or smaller batch size, and cause an increase in loading and unloading

time; lack of a required part causes the operator to wait for the part coming instead of working on the part; a part received with a missing hole causes a reject; A higher fuel price causes a higher material cost.

- **Sub-Step 3: Find a Solution.** Once the cause(s) is located, a solution should be found, which includes short-term solution and long-term solution.

  A short-term solution is the solution to make the customer happy through restoring the customer satisfaction as soon as possible, in terms of Quantity, Quality and Time. For example, adding more inspectors at the blocked inspection station to speed up the inspection operation to decrease the level of jam; repair or rework on the defects as soon as possible. The way to find the solution includes an interview with foreman, supervisor, manager, expert; data analysis and simulation.

  For the short-term solution, cost to implement the solution is not main concern since the satisfaction of the customer is the highest priority.

  A long-term solution is the solution to maintain the productivity level as long as possible once the customer satisfaction has been restored through a short-term solution. For example, when determining the reusability of a part core, a less skilled worker may sort a good part as a bad part, or vice versa. This causes the purchasing of the extra part if a good part is sorted as a bad one or the creation of a defective product if a bad part is sorted as a good one. The "Less skill level" is identified as a root cause in this case, and more training is required as a long-term solution. The way to find the short or long solution includes the interview with foreman, supervisor, manager, expert; data analysis and simulation.

  For the long-term solution, cost to implement the solution must be assessed for whether the solution should be implemented. In some cases, "Leave the loss as is" may be the best solution if the cost of implementing the solution is too significant.

The implementation of the solutions is not a focus of this paper since it is really another big issue.

4. Flow of Using 3SP

The flow of using 3SP provides a fairly detailed idea on how to use 3SP for making decisions for the best use of skilled labor, which is shown in Figure 3.

For a "New production process", the flow includes: 1) Analyze process; 2) Step 1: Determine whether to use skilled labor; 3) Step 2: Define the most suitable specifications for using skilled labor; 4) Step 3: Attain and maintain the defined productivity defined in Step 2, which is the benchmark.

1) **Analyze process** is to understand the process designed, for example, product name, production volume, planed time and throughput.

2) **Step 1: Determine whether to use skilled labor** is to compare skilled labor with other production alternatives such as unskilled labor, machine or contract. Two routes are involved in this determination: 1) Whether skilled labor is the only option; and 2) Whether skilled labor is the cheapest option. If skilled labor is not selected, no further discussion is required; otherwise the issue goes to the next step.

3) **Step 2: Define the most suitable specifications** is for effective and efficient use of skilled labor. These specifications represent "No unnecessary losses exist related to quantity, quality and time while performing the activity", which means the maximum potential gain. These

specifications can be considered the process requirements to be achieved and used as benchmarks to assess the productivity of the actual production.

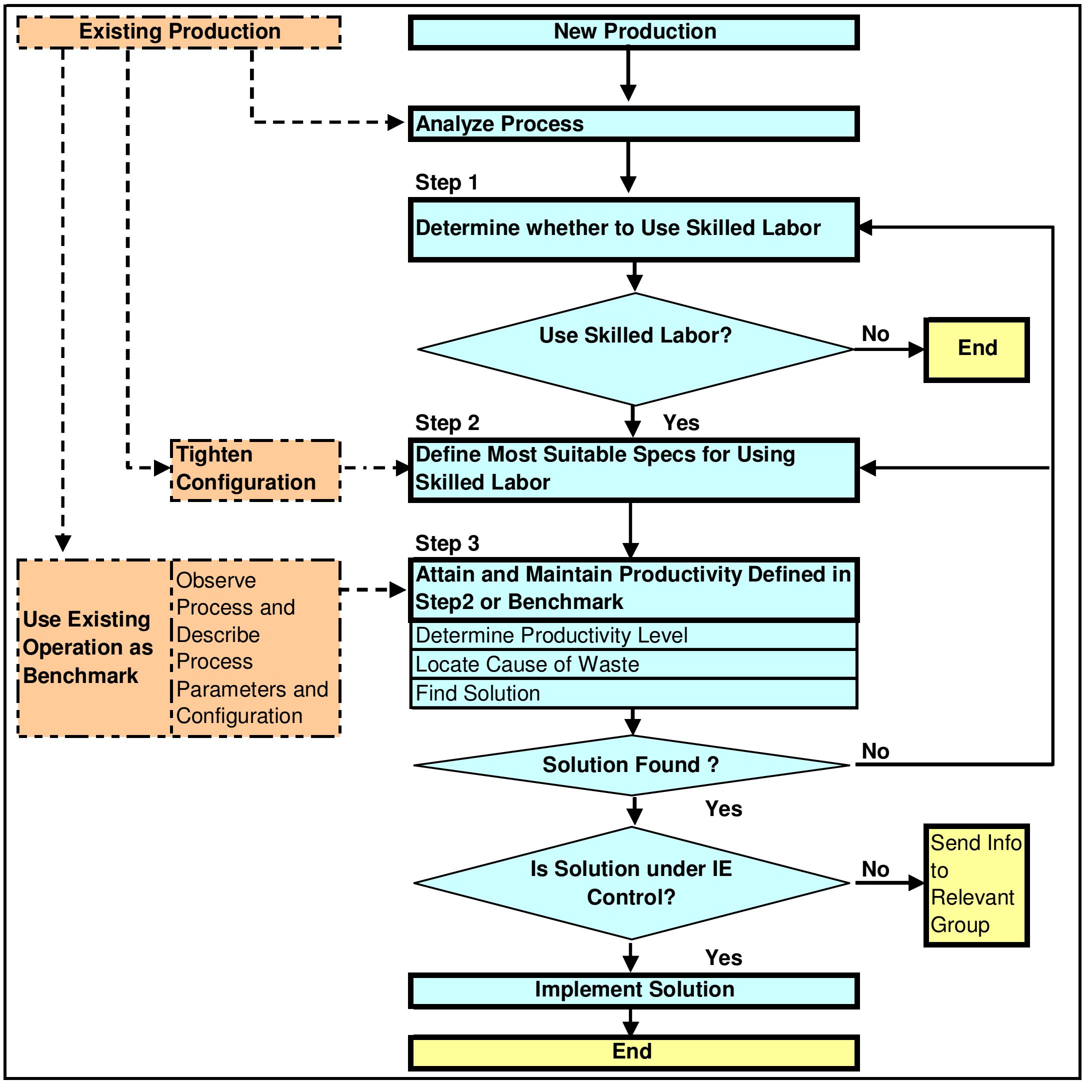

FIGURE 3: Flow of Using 3SP

4) **Step 3: Attain and maintain the defined productivity defined in step2 or benchmark** is supported by three tasks: 1) Determine the productivity level; 2) Locate the cause; 3) Find a solution.

Determine the productivity level means to determine waste in the process based on the cost analysis.

Locate the cause is to map waste to related cause(s), which requires a detailed investigation. For example, an unskilled worker causes a high reject rate; the part received with inconsistent quality causes a longer operation time; a slightly incorrect shape of fixture causes the part to be damaged.
If the causes located are under the control of the Industrial Engineer, the issue goes to the next decision point; otherwise it is handled over to relevant groups for further decision. For example, a cause of "Higher wage" is handled over to a union for further decision.

Find a solution including both short-term and long-term solution.

A short-term solution is to satisfy the customer as soon as possible in terms of the quantity, quality and time that the customer requests. For example, if the inspection slows down the production flow, an additional inspector should be in position to speed up the inspection operation.

A long-term solution is to maintain the defined productivity for a long-term. For example, train the low skilled worker, who should not have been assigned to do the job, to a level that he can perform the job effectively and efficiently. The long-term solutions can be classified as four possible routes: 1) Return the situation to the specifications as defined; 2) Go back to Step 2 to redefine the specifications; 3) Go back to Step 1 to reassess whether using other production alternatives such as machine and unskilled labor etc; 4) Leave as is.

3SP can be used flexibly in reality since it has three independent steps. As a summary, Step 1 concerns the general structure of the activity and determines which manufacturing method is the most suitable one; Step 2 organizes the activity to make it as productivity as possible and uses this productivity as a benchmark to measure the production; Step 3 looks at the indicators to see whether the activity runs as expected, and if not, finds short-term and long-term solutions to attain and maintain the productivity level.

These steps could be used in several different ways. For example, if the issue is to determine which production method is the most suitable way to produce the required items, Step 1, 2 and 3 must be done one by one; If skilled labor is already used, only Step 2 and 3 should be done; If skilled labor is in place and the most suitable specification are already reached, only sub-step 3 (Maintain productivity) in Step 3 should be done. For “Existing production process” as shown as dashed line in Figure 3, the possible decision points are: 1) “Analyze process” if required; 2) “Define the most suitable specs for using skilled labor” if “Tightened configuration” is required; 3) “Attain and maintain the defined productivity” if “Use existing operation as benchmark” can be done.

The details of the implementation of the solutions are very important, but too big and extensive to be covered in this paper.

5. CONSLUSION

3SP (Three-Step Procedure) provides **a standard procedure** to determine whether skilled labor should be used and how to attain and maintain high productivity with skilled labor.

3SP is basically **a qualitative procedure** to guide the user on how to proceed when the best use of skilled labor is required.

If 3SP is used for a more complex system, its structure will be similar but the contents in the structure need to be modified for fitting the new situation.

3SP has been used to improve the productivity in Bristol Aerospace Limited and Aero-Recip (Canada) Ltd, which are two labor intensive manufacturing companies.

3SP could be used not only in manufacturing to improve the productivity, but also in other industries such as banking, health or government. The author is using this approach to improve the efficiency in a law enforcement organization.

More validations need to be done to prove its usefulness in improve the productivity.

6. REFERENCES

1. ABC Forum, Recent User Comments. http://www.12manage.com/methods_abc.html, 2008

2. Deo Balbinder S. and Strong Douglas. *"Operation Based Cost Measurement Model"*. In Proceedings of the IER Conference, 2002

3. Ding Youmin. *"A Systematic Approach for the Best Use of Skilled Labor in Manufacturing"*. Ph.D. Thesis, The University of Manitoba, Canada, August 2009

4. Ding Youmin, Strong Doug and Deo Balbinder. "*Communicating Cost and Performance*". Industrial Management, Vol. 51 (4), pp. 22-25, July/August 2009

5. Ding Youmin, Strong Doug and Deo Balbinder. "*Function Based Standard Activity Structure (FBSAS) for Measuring Productivity in Manufacturing*". In Proceedings of the ASAC, 2009

6. Ding Youmin, Strong Doug and Deo Balbinder. "*Application of Function Based Costing*". In Presenting of the ASAC Annual Meeting, 2008

7. Harmon Paul and King David. "*Expert Systems*". John Wiley & Son. Inc., 1985

8. Inderfurth K. et al. "*Lot Sizing in a Production System with Rework and Product Deterioration*". International Journal of Production Research, vol. 43, pp. 1355-1374, 2005

9. Jha N.K. "*Probabilistic Cost Estimation in Advance of Production in a Computerized Manufacturing System through Stochastic Geometric Programming*". CIE, vol.30 (4), pp. 809-821, 1996

10. Kenne J.P. et al. "*Production Planning Problem in Manufacturing Systems with General Failure and Repair Time Distributions*". Production Planning & Control, vol. 11, pp. 581-588, 2000

11. Lee B. "*An Integrated Assessment of Productivity and Efficiency Impacts of Information Technology Investments*". Journal of Productivity Analysis, vol. 12, pp. 21-43, 1999

12. Lin Z-C et al. "*Cost - Tolerance Analysis Model Based on a Neural Networks Method*". International Journal of Production Research, vol. 40, pp. 1429-1452, 2002

13. Nahmias Steven. "*Production and Operations Analysis*". 3rd edition, Irwin McGraw-Hill, 2004

14. Newnes L. B. et al. "*On-Screen Real-Time Cost Estimating*". International Journal of Production Research, vol. 45 (7), pp. 1577-1594, 2007

15. P. R. Roy et al. "*Function-Based Cost Estimating*". International Journal of Production Research, vol. 46 (10), pp. 2621-2650, 2008

16. Park J. et al. "*Development of a Production Cost Estimation Framework to Support Product Family Design*". International Journal of Production Research, vol. 43, pp. 731-772, 2005

17. Sharma Rajiv Kumar et al. "*Quality Costing In Process Industries through QCAS: a Practical Case*". International Journal of Production Research, vol.45 (15), pp. 3381-3403, 2007

18. Shehab E M et al. "*A Design to Cost System for Innovative Product Development*". JEM, vol. 216 (7), pp 999-1019, 2002

19. Smith Marc. "*Identification of Waste in Manufacturing and Other Business Systems*". www.elsmar.com/Identify_Waste, 2008

20. Ye and Zhao B. "*Fault diagnosis of highly automated manufacturing systems*". International Journal of Production Research, vol. 34, pp 555-576, 1996