January 01, 2006

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Surendra M. Gupta
Northeastern University

Kishore K. Pochampally
Northeastern University

Bibliographic Information

Pochampally, K. K. and Gupta, S. M., "Total Quality Management (TQM) in a Reverse Supply Chain", ***Proceedings of the SPIE International Conference on Environmentally Conscious Manufacturing VI***, Boston, Massachusetts, pp. 139-148, October 1-3, 2006.

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Contact Information

Dr. Surendra M. Gupta, P.E.
Professor of Mechanical and Industrial Engineering and
Director of Laboratory for Responsible Manufacturing
334 SN, Department of MIE
Northeastern University
360 Huntington Avenue
Boston, MA 02115, U.S.A.

(617)-373-4846 ***Phone***
(617)-373-2921 ***Fax***
gupta@neu.edu ***e-mail address***

http://www.coe.neu.edu/~smgupta/ ***Home Page***

Total Quality Management (TQM) in a Reverse Supply Chain

Kishore K. Pochampally[α] and Surendra M. Gupta[β]

[α]Department of Quantitative Studies and Operations Management
School of Business, Southern New Hampshire University, Manchester, NH 03106, USA
Phone: (603) 629-4685, Fax (603) 645-9737, E-mail: k.pochampally@snhu.edu

[β]Laboratory for Responsible Manufacturing, 334 SN, Department of MIE
Northeastern University, 360 Huntington Avenue, Boston, MA 02115, USA
Phone: (617)-373-4846, Fax: (617)-373-2921, E-mail: gupta@neu.edu

ABSTRACT

Six-Sigma is a newer version of Total Quality Management (TQM), and its fundamental principle is to reduce defects in processes. The traditional approach to calculate the value of *n* for an *n*-sigma process can be confusing to prospective six-sigma practitioners, because the three values of interest (viz., process capability ratio, process capability index, and *n*) are always different. In this paper, we present a new formula that is less confusing, and yet serves the purpose of checking how good a given process is. We apply this formula for a crucial issue (selection of potential recovery facilities) identified in the literature for reverse supply chain design. The CPC chart in the literature for selection of potential suppliers uses the process capability index alone. Since the process capability ratio too is required for judging the quality of a facility, we use the new formula for building a chart for selection of potential recovery facilities.

Keywords: Six-Sigma, Total Quality Management, Reverse Supply Chain, Supply Chain Quality, Supply Chain Design.

1. INTRODUCTION

Total Quality Management (TQM) is an approach to management that originated in the Japanese industry in the 1950's, and has been popular in the West since the early 1980's. TQM is a description of the philosophy of a company that aims to provide its customers with goods and services that satisfy the customers' needs. This philosophy requires quality in all aspects of the company's processes, with defects and waste eradicated from the processes (A process is any activity or group of activities that takes one or more inputs (raw material, people, machines, etc.), transforms and adds value to them, and provides one or more outputs (goods and/or services) to its customers [3]).

Six-Sigma is a newer version of TQM that originated at Motorola in the early 1980's, and employs many of the tried-and-true tools and techniques of TQM. Six-Sigma is a business-driven, multi-faceted approach to process improvement, cost reduction and profit increase. Its fundamental principle is to improve customer satisfaction by reducing defects in processes.

Statistical process control techniques help managers achieve and maintain a process distribution that does not change in terms of its mean and variance. The control limits on the control charts signal when the mean or variability of the process changes. However, a process that is in statistical control may not be producing outputs according to their design specifications because the control limits are based on the mean and variability of *sampling distribution*, not the *design specifications* [3].

Process Capability refers to the ability of the process to meet the design specification for an output. Design specifications are often expressed as a target value (τ) and a tolerance (*T*). For example, the administrator of an intensive care unit lab might have a target value for the turnaround time of results to the attending physicians of 25 minutes and a tolerance of $\pm$ 5 minutes because of the need for speed under life-threatening conditions. The tolerance gives an upper specification

(U) of 30 minutes and a lower specification (L) of 20 minutes. The lab process must be capable of providing the results of analyses within these specifications (See Figure 1 [3]); otherwise it will produce a certain proportion of “defects”.

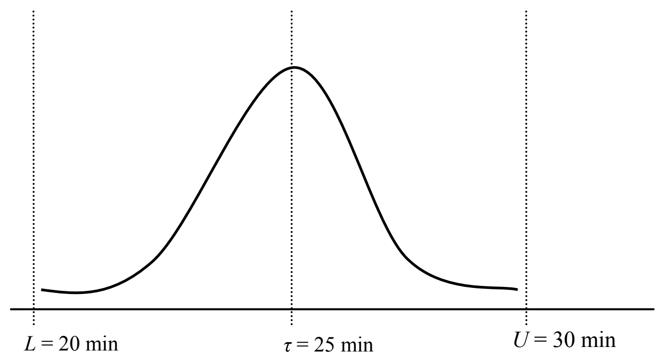

Figure 1. Capable Process

Note that in most situations, $T = \frac{U-L}{2}$ and $\tau = \frac{U+L}{2}$, and hence, we assume the same throughout this paper.

Two popular quantitative measures to assess the capability of a process are process capability ratio (C_p) and process capability index (C_{pk}).

1.1. Process Capability Ratio (C_p)

Assume that σ is the standard deviation of a process that produces a certain dimension of interest for an output (good or service). This certain dimension of interest will hereafter be called as critical dimension. Process Capability Ratio (C_p) is defined as

$$C_p = \frac{U-L}{6\sigma} \tag{1}$$

The numerator represents the specification width and the denominator captures the total width of the 3σ limits of the process distribution. We consider two examples, one for $C_p = 1$, and the other for $C_p = 2$.

If $C_p = 1$, it means that the specification width is equal to six times the process standard deviation. When the process mean (μ) is centered at $\frac{U+L}{2}$ without any shift from the target value, τ, the probability that the actual critical dimension is within the specification limits (assume that the process distribution is normal) is 0.9973 (i.e., 2700 parts per million (ppm) defect rate). Similarly, if $C_p = 2$, it means that the specification width is equal to twelve times the process standard deviation. When the process mean (μ) is centered at $\frac{U+L}{2}$ without any shift from τ, the probability that the actual critical dimension is within the specification limits is 0.999999998 (i.e., 0.002 ppm defect rate).

1.2. Process Capability Index (C_{pk})

Process capability ratio (C_p) is enough to find out whether the process is capable, only if μ is centered at $\frac{U+L}{2}$ without any shift from τ. For example, the lab process may have a good C_p value (i.e., more than the critical value of say, 1.5), but if μ is closer to U, lengthy turnaround times may still be generated. Likewise, if μ is closer to L, very quick results may be generated. Thus, in order to check whether μ is not far away from τ, there is a need for an additional capability ratio called process capability index (C_{pk}).

C_{pk} is defined in two different ways in the literature.

1.2.1. Definition I (see [2])

$$C_{pk} = MIN\left(\frac{\mu - L}{3\sigma}, \frac{U - \mu}{3\sigma}\right) \tag{2}$$

The minimum of the two ratios is taken because it gives the worst-case situation.

A process is said to be capable only if the process has good values (viz., more than the respective critical values set by the process manager) for both C_p and C_{pk}. If C_p is less than the critical value, it means that σ is too high. If C_{pk} is less than the critical value, it means that either μ is too close to U or L, or σ is too high.

1.2.2. Definition II (see [5])

$$C_{pk} = C_p(1 - k) \qquad \text{where } k = \frac{|\tau - \mu|}{T} \tag{3}$$

This definition allows consideration of a mean shift, i.e., shift of μ from τ. The fraction k is the fraction of tolerance consumed by the mean shift. The Motorola convention uses a one-sided mean shift of 1.5σ. This is motivated by common physical phenomena such as tool wear. If $C_p = 2$ and $C_{pk} = 1.5$ (i.e., mean shift consumes 25 percent of the tolerance), the probability that the actual critical dimension is within the specification limits is 0.9999966 (i.e., 3.4 ppm defect rate).

In Section 2, we present the traditional approach to investigate whether a process is a 6-sigma process (i.e., an efficient process). In Section 3, we present a new formula that is simpler than the traditional approach, yet can check whether a process is a 6-sigma process. This new formula is used in Section 4, for selection of potential recovery facilities in a region where a reverse supply chain is to be designed. Finally, in Section 5, we give some conclusions.

2. TRADITIONAL APPROACH TO SIX-SIGMA INVESTIGATION

Traditionally, one needs both C_p and C_{pk} values, in order to investigate whether the process of interest is a 6-sigma process. We illustrate this by calculating C_p and C_{pk} values (using (1) and (3), respectively) for a given n-sigma process (n is any positive real number; the higher the value of n, the better the process is). We consider three different cases, viz., $n = 3$, 4.5, and 6. It must be noted that the mean shift in each case is allowed to be <u>up to</u> 1.5σ.

2.1. 3-Sigma Process

See Figure 2.

$$C_p = \frac{U - L}{6\sigma} = \frac{6\sigma}{6\sigma} = 1$$

$$C_{pk} = C_p(1 - k) \geq 1\left(1 - \frac{1.5\sigma}{3\sigma}\right) = 0.5$$

Hence, if $C_p = 1$ and $C_{pk} \geq 0.5$, it is considered a 3-sigma process.

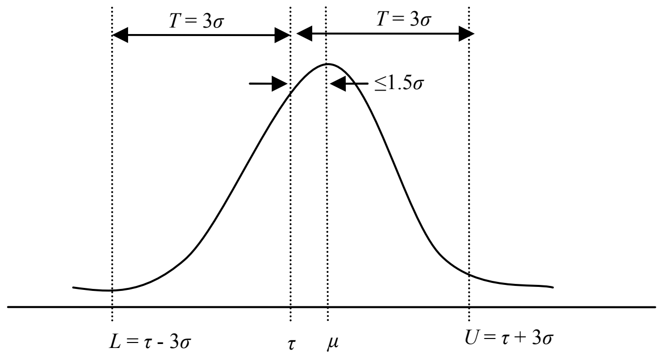

Figure 2. 3-Sigma Process

2.2. 4.5-Sigma Process

See Figure 3.

$$C_p = \frac{U - L}{6\sigma} = \frac{9\sigma}{6\sigma} = 1.5$$

$$C_{pk} = C_p(1-k) \geq 1.5\left(1 - \frac{1.5\sigma}{4.5\sigma}\right) = 1$$

Hence, if $C_p = 1.5$ and $C_{pk} \geq 1$, it is considered a 4.5-sigma process.

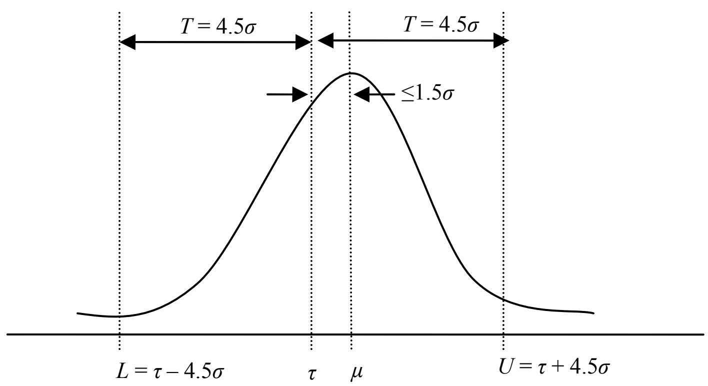

Figure 3. 4.5-Sigma Process

2.3. 6-Sigma Process

See Figure 4.

$$C_p = \frac{U - L}{6\sigma} = \frac{12\sigma}{6\sigma} = 2$$

$$C_{pk} = C_p(1-k) \geq 2\left(1 - \frac{1.5\sigma}{6\sigma}\right) = 1.5$$

Hence, if $C_p = 2$ and $C_{pk} \geq 1.5$, it is considered a 6-sigma process.

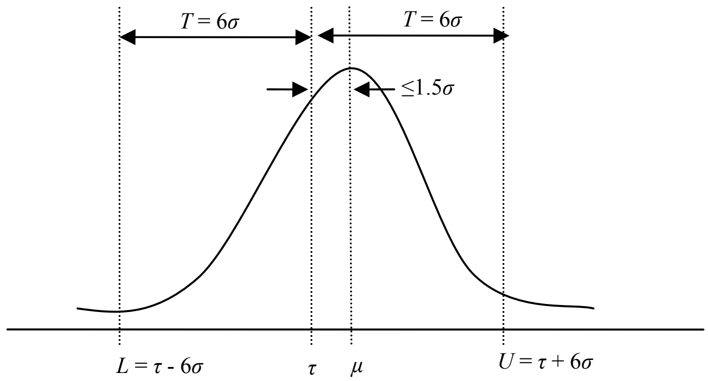

Figure 4. 6-Sigma Process

3. NEW FORMULA FOR SIX-SIGMA INVESTIGATION

Evidently, in the traditional approach to six-sigma investigation (see Section 2), the three numerical values (viz., C_p, C_{pk}, and n) are always different, and hence, the investigation procedure might be confusing to prospective six-sigma practitioners. Here, we propose the following new formula that is simple and less confusing, and yet serves the purpose of checking how good a given process is:

$$\frac{U-L}{2\sigma} = n \le \frac{0.75(U-L)}{|\tau-\mu|} \quad (4)$$

Any n-sigma process must satisfy the above relationship. Obviously, by using (4), one can directly calculate the value of n, unlike in the traditional approach. We illustrate this for n = 3, 4.5, and 6. In each case, we take two different mean shifts that are less than or equal to 1.5σ.

3.1. 3-Sigma Process (See Figure 2)

$$\frac{U-L}{2\sigma} = n \le \frac{0.75(U-L)}{|\tau-\mu|}$$

For mean shift = 1.5σ,

$$\frac{U-L}{2\sigma} = \frac{6\sigma}{2\sigma} = 3 \le \frac{0.75(U-L)}{|\tau-\mu|} = \frac{0.75(6\sigma)}{1.5\sigma} = 3$$

For mean shift = 1.2σ,

$$\frac{U-L}{2\sigma} = \frac{6\sigma}{2\sigma} = 3 \le \frac{0.75(U-L)}{|\tau-\mu|} = \frac{0.75(6\sigma)}{1.2\sigma} = 3.75$$

3.2. 4.5-Sigma Process (See Figure 3)

$$\frac{U-L}{2\sigma} = n \le \frac{0.75(U-L)}{|\tau-\mu|}$$

For mean shift = 1.5σ,

$$\frac{U-L}{2\sigma} = \frac{9\sigma}{2\sigma} = 4.5 \le \frac{0.75(U-L)}{|\tau-\mu|} = \frac{0.75(9\sigma)}{1.5\sigma} = 4.5$$

For mean shift = 1.2σ,

$$\frac{U-L}{2\sigma} = \frac{9\sigma}{2\sigma} = 4 \le \frac{0.75(U-L)}{|\tau-\mu|} = \frac{0.75(9\sigma)}{1.2\sigma} = 5.625$$

3.3. 6-Sigma Process (See Figure 4)

$$\frac{U-L}{2\sigma} = n \le \frac{0.75(U-L)}{|\tau - \mu|}$$

For mean shift = 1.5 σ ,

$$\frac{U-L}{2\sigma} = \frac{12\sigma}{2\sigma} = 6 \le \frac{0.75(U-L)}{|\tau - \mu|} = \frac{0.75(12\sigma)}{1.5\sigma} = 6$$

For mean shift = 1.2 σ ,

$$\frac{U-L}{2\sigma} = \frac{12\sigma}{2\sigma} = 6 \le \frac{0.75(U-L)}{|\tau - \mu|} = \frac{0.75(12\sigma)}{1.2\sigma} = 7.5$$

4. REVERSE SUPPLY CHAIN DESIGN

Traditionally, a supply chain consists of all stages involved, directly or indirectly, in *fulfilling a customer desire*. The supply chain not only includes manufacturer and suppliers, but also transporters, warehouses, retailers, and customers themselves. Today, many supply chains are no longer limited to *fulfilling a customer desire*. The reason being that the growing desire of customers to acquire the latest technology, along with the rapid technological development of new products, has led to a new environmental problem: "waste", consisting of products that are discarded after their useful lives and the products that are discarded prematurely (Hereafter, we refer to the "waste" as *used products*). Reprocessing (processing of used products) is essential for (i) *saving natural resources*: we conserve land and reduce the need to drill for oil and dig for minerals, by making products using reprocessed goods (viz., goods obtained from reprocessing), instead of virgin materials, (ii) *saving energy*: it usually takes less energy to make products from reprocessed goods than from virgin materials, (iii) *saving clean air and water*: making products from reprocessed goods creates less air pollution and water pollution than from virgin materials, (iv) *saving landfill space*: when reprocessed goods are used to make a product, they do not go into landfills, and (v) *saving money*: it costs much less to make products from reprocessed goods than from virgin materials. Besides the above motivators, an important driver for companies to engage in reprocessing is the enforcement of environmental regulations by local governments.

Reprocessing of used products requires a series of activities (collection, disassembly, recycling, remanufacturing, disposal, etc.) that are performed by multiple parties known together as a reverse supply chain (See Figure 5). In the past decade, there has been an explosive growth of reverse supply chains, both in scope and scale.

Reverse supply chain design is a relatively new area of research, and a few case studies (with application of quantitative models) have been reported in the literature about the same (see [1]). In this section, we address the selection of potential recovery facilities in a region where a reverse supply chain is to be designed (this is one of the crucial issues (see [6]) identified in the literature for reverse supply chain design).

Linn et al. [6] present an approach for selection of suppliers in a traditional supply chain, using C_{pk} and Price Comparison (CPC) chart. The CPC chart (see Figure 6), which integrates the process capability and price information of multiple suppliers (assuming every other criterion value is either unimportant or the same for all suppliers), provides a method to consider quality and price simultaneously in the supplier selection process.

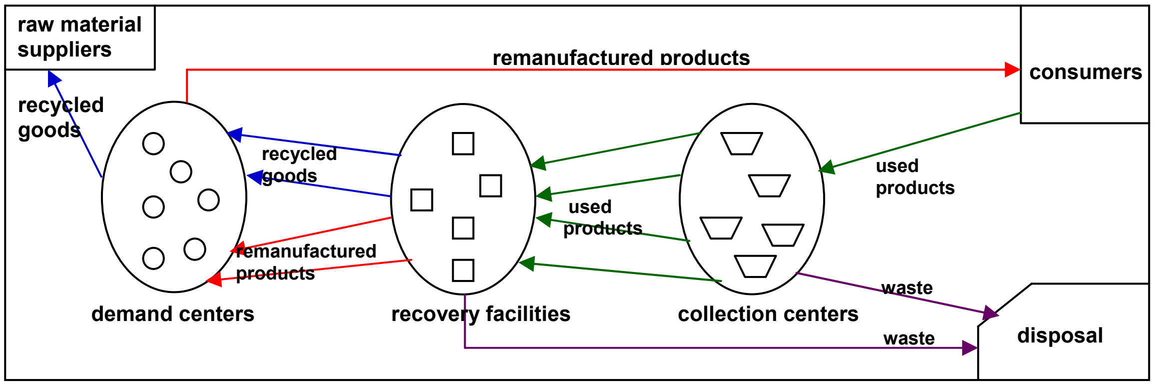

Figure 5. Generic Reverse Supply Chain

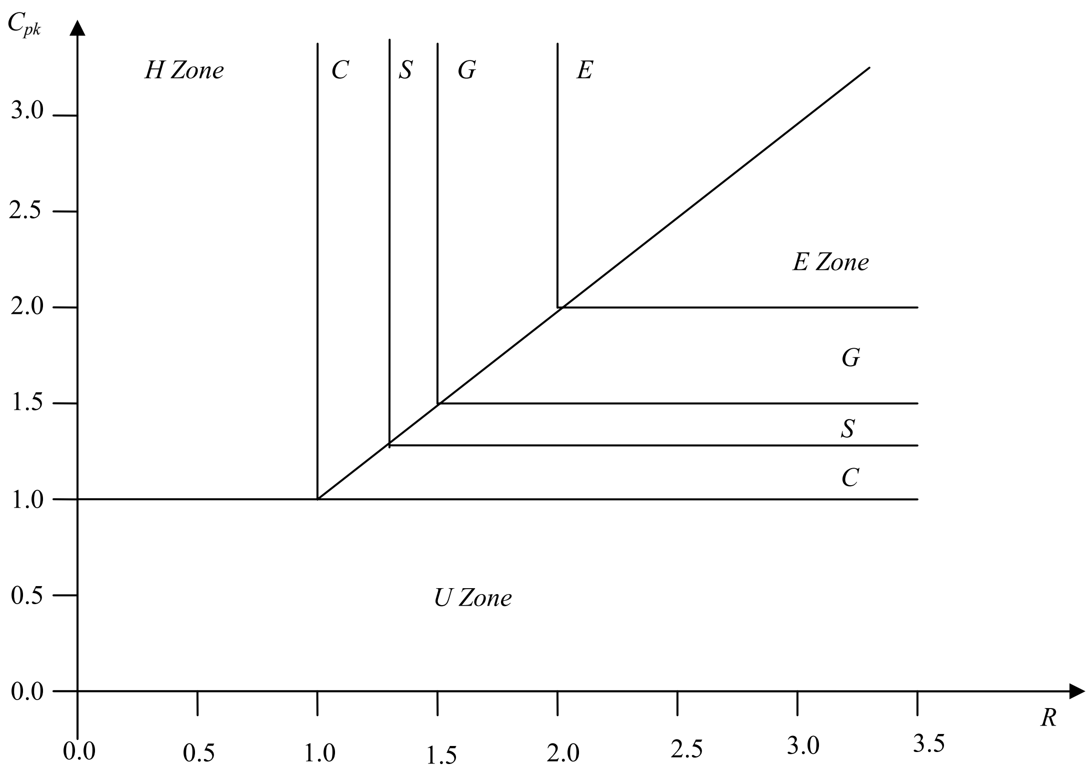

Figure 6. CPC Chart

C_{pk} is drawn on the Y-axis, and the 'target price desired' to 'price quoted by supplier' ratio (R) is drawn on the X-axis. C_{pk} and R of each supplier are then plotted in the chart. The chart is partitioned into six different zones representing the quality performance and price levels. The zones are defined as follows:

E Zone: excellent zone, $E = \{(R, C_{pk}) \mid C_{pk} > 2.0 \text{ and } R > 2.0\}$

G Zone: good zone, $G = \{(R, C_{pk}) \mid C_{pk} > 1.5 \text{ and } R > 1.5\}$ - E

S Zone: satisfactory zone, $S = \{(R, C_{pk}) \mid C_{pk} > 1.33 \text{ and } R > 1.33\}$ – G - E

C Zone: capable zone, $C = \{(R, C_{pk}) \mid C_{pk} > 1.0 \text{ and } R > 1.0\}$ – G – E - S

H Zone: high price zone, $H = \{(R, C_{pk}) \mid C_{pk} > 1.0 \text{ and } R < 1.0\}$

U Zone: unacceptable zone, $U = \{(R, C_{pk}) \mid C_{pk} < 1.0 \text{ and } R > 0\}$

Because of their high-quality performance and low-cost quotation, those suppliers falling into the *E* zone are considered the best group of suppliers to choose from. Those falling to the *U* zone are simply not acceptable because their C_{pk} value is too low. The supplier selection should start from the *E* zone and follow the sequence of *E* – *G* – *S* – *C*- *H* – *U*. Within the same zone, those falling into the lower half zone (below the 45^0 line) has better cost performance. In contrast, those in the upper half zone (above the 45^0 line) have better quality performance. Therefore, if the objective is to select a better cost performer, those in the lower half of the zone should be selected. If the objective is to find a better quality performer, those in the upper half zone should be selected. If quality and cost are equally important, those close to the 45^0 line should be selected.

Although the above approach can integrate both quality and price, it must be noted that C_{pk} value is not enough to judge quality; one needs C_p value too. To overcome this problem in the selection of potential recovery facilities, we use *n* value (instead of C_{pk}) on the Y-axis of our chart. Also, the criterion for the X-axis is not so obvious in the case of a recovery facility, due to the following primary challenges in a reverse supply chain:

- Uncertainty in supply of used products
- Unknown condition of used products
- Imperfect correlation between supply of used products and demand for reprocessed goods

We consider the following two special criteria (one at a time) for the X-axis:

- Throughput / Supply
- Throughput * Disassembly Time

Criteria such as cost (fixed + variable) and customer service level (if quantifiable using techniques such as fuzzy logic [7]) are obvious, and hence, we do not address them here.

4.1. Throughput / Supply

The only driver to design a traditional supply chain is the demand for new products, and so, if there is low demand for new products, there is practically no traditional supply chain. However, this is not the case in some reverse supply chains where even if there is low supply of used products (*SU*), reverse supply chain must be administered due to the possible drivers discussed earlier. In supply-driven cases like these, it is unfair to judge a recovery facility without considering *SU*. Though throughput (*TP*) is a criterion that can compare two or more candidate recovery facilities, it is not justified to use *TP* as an independent criterion because *TP* depends on *SU*. However, *SU* must not be taken as an independent criterion because it cannot compare the candidate facilities. Since a low *SU* might lead to a low *TP* and a high *SU* might lead to a high *TP*, the idea is to take (*TP*)/(*SU*) as a criterion for the X-axis. Thus, we compensate for the effect of a low *TP* by dividing *TP* with a possibly low *SU*, in order not to underestimate the facility under consideration. Similarly, we dampen the effect of a high *TP* by dividing *TP* with a possibly high *SU*, in order not to overestimate the facility under consideration.

Figure 7 illustrates our chart that integrates *n* and *TP*/*SU* of multiple recovery facilities.

The chart is partitioned into five acceptable regions (I – V) and an unacceptable region. These zones are defined as follows:

Zone I = $\{(n, TP/SU) \mid n \geq 5.0 \text{ and } 0.9 \leq TP/SU \leq 1\}$

Zone II = $\{(n, TP/SU) \mid n \geq 4.0 \text{ and } TP/SU \geq 0.8\}$ – Zone I

Zone III = $\{(n, TP/SU) \mid n \geq 3.0 \text{ and } TP/SU \geq 0.7\}$ – Zone I – Zone II

Zone IV = $\{(n, TP/SU) \mid n \geq 2.0 \text{ and } TP/SU \geq 0.6\}$ – Zone I – Zone II – Zone III

Zone V = $\{(n, TP/SU) \mid n \geq 2.0 \text{ and } TP/SU \geq 0.5\}$ – Zones I – Zone II – Zone III – Zone IV

Unacceptable Zone = $\{(n, TP/SU) \mid n < 2.0 \text{ and/or } TP/SU < 0.5\}$

Because of their high-quality performance and high *TP*/*SU* value, those recovery facilities falling into Zone I are considered the best group of recovery facilities to choose from. Those falling into the unacceptable zone are simply not acceptable because either their *n* value is too low, or *TP*/*SU* value is low, or both. The recovery facility selection should start from the Zone I and follow the sequence of I – II – III – IV - V.

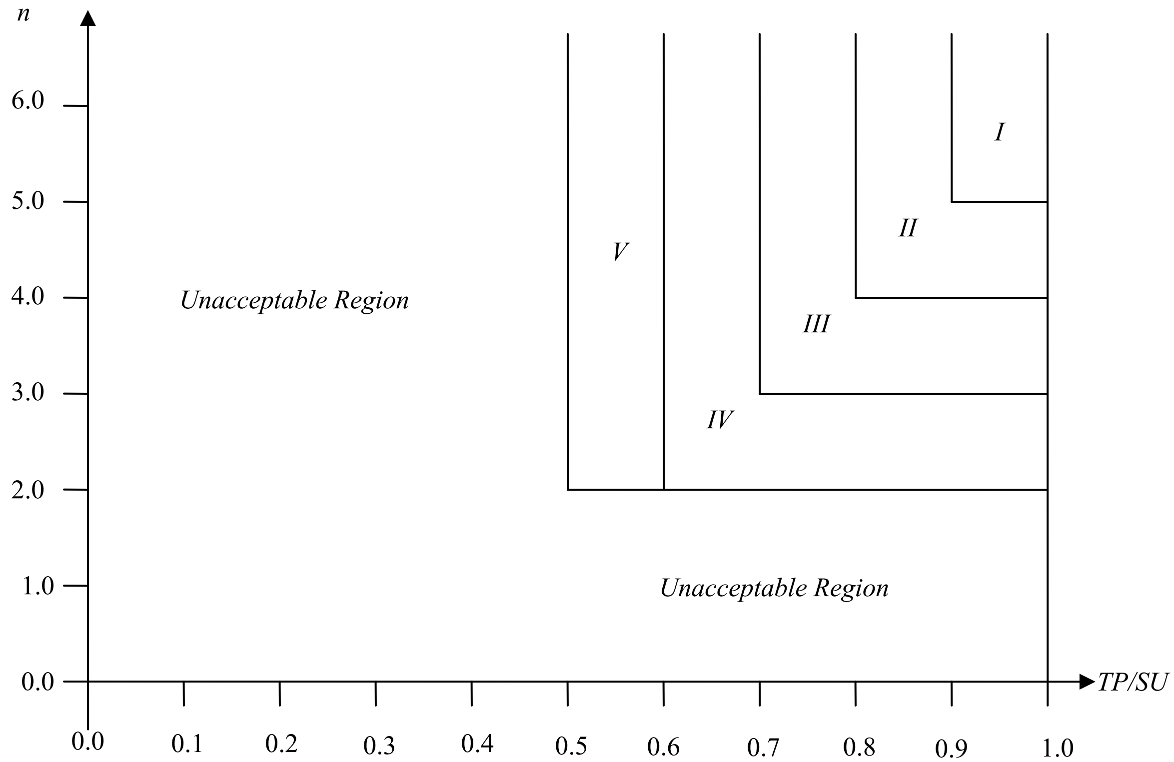

Figure 7. *n* & *TP/SU* Chart

4.2. Throughput * Disassembly Time

Unlike in a traditional supply chain, components of incoming goods (used products) in a recovery facility are likely to be deformed and/or broken and/or different in number even for the same type of products. Hence, incoming products of the same type might have different disassembly times, unlike in a traditional supply chain where assembly times are pre-determined and equal for products of the same type. Since *TP* of a recovery facility depends upon the average disassembly time (*DT*), it is unfair to not consider *DT*. However, *DT* must not be taken as an independent criterion because it cannot compare the candidate facilities. Since a high *DT* might lead to a low *TP* and a low *DT* might lead to a high *TP*, the idea is to take (*TP*)*(*DT*) as a criterion on the X-axis. Thus, we compensate for the effect of a low *TP* by multiplying *TP* with a possibly high *DT*, in order not to underestimate the facility under consideration. Similarly, we dampen the effect of a high *TP* by multiplying *TP* with a possibly low *DT*, in order not to overestimate the facility under consideration.

The chart for this criterion can be drawn like in Section 4.1.

5. CONCLUSIONS

The traditional approach to calculate the value of *n* for an *n*-sigma process can be confusing to prospective six-sigma practitioners, because the three values of interest (viz., process capability ratio, process capability index, and *n*) are always different. In this paper, we presented a new formula that is simple, and yet can be used for investigating the quality of a process. We applied this formula for selection of potential recovery facilities in a region where a reverse supply chain is to be designed.

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