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Performance Assessment for Sunlight Radiation Resistant Coating Manufacturers

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Abstract. It is of great significance to select suitable manufacturers to improve the ability to respond to the final customer demand. Establishing a strategic partnership with manufacturers is an effective way to increase profits and improve the process efficiency for better connectivity across the supply chain. Therefore, manufacturer performance evaluation and selection is one of the most important decision-making problems in enterprises. This study proposes a manufacturer capability index M_{CI} and gives the uniformly minimum-variance unbiased estimator (UMVUE) of the variance and probability density function (PDF) for index M_{CI} . Finally, an example of performance assessment for sunlight radiation resistant coating (SRRC) manufacturer is given to illustrate the application of the proposed index M_{CI} .

1. Introduction

In the traditional sunlight radiation resistant coating (SRRC) supply chain management, the SRRC members are in a situation of antagonism and competition, and the supply and demand sides play a zero-sum game. Therefore, the traditional manufacturer performance evaluation index is mainly focused on the cost. However, when enterprises (buyers) choose SRRC manufacturers (sellers), they only pay attention to the short-term behaviour of cost, which leads to a decline in product quality and service capacity and aggravates the hostile relationship between seller and buyer, such as: delivery time, pre-sale and post-sale service, etc[1-2]. Therefore, there is an inseparable relationship between the enterprises with its SRRC manufacturers.

In general, enterprises decision makers decide on the basis of past personal experience or their subjective perception, or use the Likert scale to calculate the sample mean for selecting SRRC manufacturers, but ignore the degree of variation of the sample, resulting in a failure to accurately grasp and judge the SRRC manufacturer's service capacity and performance [3-4]. Therefore, a systematic method should be used to analyse and quantify the qualitative and quantitative criteria of these uncertainties and contradictions. This study presents a manufacturer capability index M_{CI} to assess the level of SRRC manufacturer capabilities, and gives some statistical properties of the index M_{CI} and derives the uniformly minimum-variance unbiased estimator (UMVUE) of the variance and probability density function (PDF) for index M_{CI} . The ability levels of multiple SRRC manufacturers can be assessed by values of M_{CI} . Finally, a performance assessment for SRRC manufacturer is used to exemplify the applicability and usefulness of the proposed index M_{CI} .



2. Manufacturer capability index M_{CI}

In general, enterprises require SRRC manufacturers to provide high quality products/services with low cost [5-7]. For product quality assurance and quality control testing, enterprises usually use some expert tools and techniques to measure the quality of the products. In practice, however, it is difficult to obtain overall total data, most of the samples are taken by sampling, then the sample data is measured using the sample estimation method. Based on the concept of [8], a manufacturer capability index M_{CI} was defined as follows:

$$\hat{M}_{CI} = (b_n) \times \tilde{M}_{CI} \quad (1)$$

where $\tilde{M}_{CI} = \bar{X} - LPS / 3S$ is the expected value of naive estimator for index M_{CI} equals to $(b_n)^{-1} M_{CI}$, LPS is the lower performance score for each SRRC manufacturer, \bar{X} estimates the mean μ and sample standard deviation S estimates the standard deviation σ and the constant b_n is a correction parameter to an unbiased estimator and determined by:

$$b_n = \sqrt{\frac{2}{n-1}} \times \left(\frac{\Gamma[(n-1)/2]}{\Gamma[(n-2)/2]} \right), \quad n > 2 \quad (2)$$

Obviously, by multiplying the value of b_n , the unbiased estimator \hat{M}_{CI} for M_{CI} can be obtained as follows:

$$\hat{M}_{CI} = (b_n) \times \tilde{M}_{CI} \quad (3)$$

In fact, unbiased estimator \hat{M}_{CI} is a function of the complete sufficient statistics $(\bar{X}, (S)^2)$. Due to the distribution of $(3\sqrt{n}/b_n)\hat{M}_{CI}$ has a non-central t -distribution with a degree of freedom with $n-1$, and the non-central parameter is $\delta = 3\sqrt{n}M_{CI}$, noted as $t_{n-1}(\delta)$, and $Z = \frac{\sqrt{n}(\bar{X} - LPS)}{\sigma}$ obey $N(3\sqrt{n}S_{po}, 1)$, and $K = \frac{(n-1)S^2}{\sigma^2}$ obey χ_{n-1}^2 . Therefore, \hat{M}_{CI} can be rewritten as follows:

$$\hat{M}_{CI} = \left(\frac{b_n}{3} \right) \times \sqrt{\frac{n-1}{n}} \times (K)^{-1/2} \times (Z) \quad (4)$$

Under the normal distribution assumption, since \bar{X} and $(S)^2$ are independent of each other, we have:

$$E(\hat{M}_{CI})^2 = \left(\frac{b_n}{3} \right)^2 \times \left(\frac{n-1}{n} \right) \times E(K)^{-1} \times E(Z)^2 = \left(\frac{b_n}{3} \right)^2 \times \left(\frac{n-1}{n} \right) \times \left(\frac{\Gamma[(n-3)/2]}{2\Gamma[(n-1)/2]} \right) \times [9n(M_{CI})^2 + 1] \quad (5)$$

$$Var(\hat{M}_{CI}) = E(\hat{M}_{CI})^2 - E^2(\hat{M}_{CI}) = \left(\frac{\Gamma[(n-1)/2]\Gamma[(n-3)/2]}{\Gamma^2[(n-2)/2]} \right) [(1/9n) + (M_{CI})^2] - (M_{CI})^2 \quad (6)$$

Let $T = (3\sqrt{n}/b_n)\hat{M}_{CI} = \frac{Z}{\sqrt{K/(n-1)}}$ obey $t_{n-1}(\delta)$, and $Y = \hat{M}_{CI} = \frac{b_n}{3\sqrt{n}} \times T$, then Y and T have a one-to-one mathematical relationship, therefore, we have:

$$f_Y(y) = f_T(t) \left| \frac{d_T}{d_Y} \right|, \text{ where } \left| \frac{d_T}{d_Y} \right| = \frac{3\sqrt{n}}{b_n} \quad (7)$$

and

$$f_T(t) = \frac{2^{-(n/2)}}{\Gamma[(n-1)/2]} \int_0^\infty x^{\left(\frac{n-2}{2}\right)} \exp \left\{ -0.5 \left[x + \left(\frac{\sqrt{x}}{(n-1)} t - \delta \right)^2 \right] \right\} dx, \quad t \in R \quad (8)$$

then

$$f_{\hat{S}_{pl}}(y) = f_T\left(\frac{3\sqrt{n}}{b_n}y\right)\left(\frac{3\sqrt{n}}{b_n}\right) \\ = \left(\frac{2^{-(n/2)}b_n^{-1}\sqrt{n}}{3\Gamma[(n-1)/2]}\right)\int_0^\infty t^{\left(\frac{n-2}{2}\right)} \times \exp\left\{-0.5\left[t + \left(\frac{\sqrt{nt}}{(n-1)b_n}\left(\frac{1}{3}\right)y - \delta\right)^2\right]\right\} dt, \quad y \in R \quad (9)$$

Under the normal distribution assumption, \hat{M}_{CI} is the UMVUE of M_{CI} . The variance and PDF of the UMVUE for M_{CI} can be derived as follows:

$$Var(\hat{M}_{CI}) = \left(\frac{\Gamma[(n-1)/2]\Gamma[(n-3)/2]}{\Gamma^2[(n-2)/2]}\right)\left[(1/9n) + (M_{CI})^2\right] - (M_{CI})^2 \quad (10)$$

$$f_{\hat{S}_{po}}(y) = \left(\frac{2^{-(n/2)}b_n^{-1}\sqrt{n}}{3\Gamma[(n-1)/2]}\right)\int_0^\infty t^{\left(\frac{n-2}{2}\right)} \times \exp\left\{-0.5\left[t + \left(\frac{\sqrt{nt}}{(n-1)b_n}\left(\frac{1}{3}\right)y - \delta\right)^2\right]\right\} dt, \quad y \in R \quad (11)$$

where $x \in R$ and R is real number.

To facilitate the calculation of the \hat{M}_{CI} , table 1 shows the corresponding value b_n with different value n .

Table 1. Values of b_n with different n

n	b_n	n	b_n	n	b_n
3	0.580	8	0.888	13	0.936
4	0.725	9	0.903	14	0.941
5	0.798	10	0.914	15	0.945
6	0.841	11	0.923	16	0.949
7	0.869	12	0.930	17	0.952

According to the manufacture capability assessment guide (see table 2) proposed by [9], it is shown that 60 is a threshold for re-ordering by the enterprise. When the manufacture's performance is lower than 60, the enterprise will refuse to order. Therefore, this study sets 60 as the *LPS* of M_{CI} to assess the manufacture's ability level and performance.

Table 2. Manufacturer capability assessment guide

Score	Level	Result
Score > 75	High	Enterprises will order again
$60 \leq \text{Score} \leq 75$	Medium	Manufacturers should prevent their quality levels from falling continuously
$30 < \text{Score} < 60$	Insufficient	Enterprises will refuse to order

3. Numerical example

A performance assessment for SRRC manufactures is selected as an empirical example. The five managers of the enterprise decided to use the proposed method of this study to evaluate the capability levels of the three SRRC manufactures based on two benefit criteria as: quality and service, and two cost criteria as: delivery time and price. The semantic assessment was set as {very bad; bad; medium; good; very good}. Since the semantic assessment is a qualitative description, each semantic variable of the evaluator will be converted into a score (quantification), for example: the benefit criteria semantics {very bad; bad; normal; good; very good} will be converted to scores as {(10), (30), (50), (70), (90)} and the cost criteria semantics {very low; low; normal; high; very high} will be converted to scores as {(90), (70), (50), (30), (10)}. After using the proposed method, the results of the three SRRC manufactures are shown in tables 3, 4 and 5.

Table 3. Score of Manufacturer A

Criterion Manager	Quality	Service	Delivery time	Price	Average
Manager 1	Low (70)	Good (70)	Very low (90)	Very low (90)	80
Manager 2	Normal (50)	Normal (50)	Low (70)	Low (70)	60
Manager 3	Good (70)	Good (70)	Low (70)	Low (70)	70
Manager 4	Very good (90)	Normal (50)	Low (70)	Very low (90)	75
Manager 5	Good (70)	Very good (90)	Low (70)	Very low (90)	80
					$\bar{X} = 73$
					$S=13.416$

Table 4. Score of Manufacturer B

Criterion Manager	Quality	Service	Delivery time	Price	Average
Manager 1	Good (70)	Good (70)	Very low (90)	Low (70)	75
Manager 2	Good (70)	Good (70)	Low (70)	Low (70)	70
Manager 3	Good (70)	Good (70)	Low (70)	Very low (90)	75
Manager 4	Good (70)	Very good (90)	Low (70)	Low (70)	75
Manager 5	Normal (50)	Good (70)	Low (70)	Normal (50)	60
					$\bar{X} = 71$
					$S=10.208$

Table 5. Score of Manufacturer C

Criterion Manager	Quality	Service	Delivery time	Price	Average
Manager 1	Normal (50)	Good (70)	Very low (90)	Low (70)	70
Manager 2	Good (70)	Normal (50)	Low (70)	Normal (50)	60
Manager 3	Good (70)	Good (70)	Very low (90)	Low (70)	75
Manager 4	Good (70)	Good (70)	Low (70)	Normal (50)	65
Manager 5	Good (70)	Very good (90)	Very low (90)	Very low (90)	85
					$\bar{X} = 69$
					$S=8.367$

Using the \bar{X} and S values obtained in tables 3, 4, and 5 and equation (2), the scores of three SRRC manufactures are obtained as $\tilde{M}_{CI1}=0.323$, $\tilde{M}_{CI2}=0.359$, and $\tilde{M}_{CI3}=0.267$. Then, table 1 shows that when $n = 5$, b_n is 0.798. Hence, by using equation (4), we obtained $\hat{M}_{CI1}=0.258$, $\hat{M}_{CI2}=0.287$, and $\hat{M}_{CI3}=0.213$. The result shows that manufacture B is superior to other manufactures in the SRRC manufacture performance evaluation. Therefore, manufacture B is the best choice for the enterprise with respect to four criteria.

4. Conclusion

Each SRRC enterprise in the supply chain is a community of interests, which cannot be generated when the enterprise is independent by complementary advantages and synergistic effects, for example: improve productivity, save resources, reduce costs, create greater customer value, etc. Therefore, how the enterprises (buyers) to evaluate and select SRRC manufacturers (sellers) is a very important issue. In general, when enterprises evaluate, screen, and decide suppliers, they often use the Likert scale to ignore sample variability, resulting in an inability to accurately determine the level and performance of manufacturer. To solve this problem, this study proposes a manufacturer capability index M_{CI} , and

gives the UMVUE of the variation and PDF of the index M_{CI} . This method not only meets the technical requirements, but also improves the rationality of decision-making for SRRC enterprises. Finally, this study uses a performance assessment for SRRC manufactures as an empirical example to prove the effectiveness of the proposed method. The method proposed in this study can be extended to other industries as a performance appraisal tool in the agreements for the supply of goods and services between buyer and seller.

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