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On using Six-Sigma Principle for Quality Improvement in Construction

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Abstract
The Gaussian distribution and Six-σ principle have been widely used in the field of construction quality management with great success. Even though the Gaussian distribution has been solely used as the most dominant distribution, there exist other distributions which can be even more effective than the Gaussian distribution. This paper gives a theoretical study on a new Hyperbolic distribution using the Six-σ principle to improve quality in construction management. The Hyperbolic and Gaussian distributions are then numerically compared by estimating their important statistical properties such as population in range, number of defects, yield percentage and defects per million opportunities. The impacts of these factors are briefly discussed to give guidance to organisations in the construction industry on how to lower cost and to improve project quality by prevention. To illustrate the theory behind these distributions and the Six-σ principle and to also show their reliability and effectiveness, a case study using cost data from a hydro-seeding industry is presented. From that, in this particular case, the Hyperbolic distribution is shown to be more effective in quality improvement by prevention than the Gaussian distribution. This validates the Hyperbolic distribution as a suitable distribution for construction quality management.

Keywords
Hyperbolic distribution, Gaussian distribution, quality management, construction, Six-σ principle.

1 Introduction
Poor quality of activities is commonly occurred in the construction industry, for example, short-piling and unsuitable use of materials (Construction Industry Review Committee, 2001). Although the quality management is implemented by many organizations, serious problems can still be found in construction sites (Construction Industry Review Committee, 2001). Thus, there is an urgent need to improve the quality performance in the construction industry.

There are various methods, which have been used by organisations in the construction industry to improve quality, employing mainly two major techniques: management techniques such as quality control, quality assurance, total quality management; and statistical techniques such as cost of quality, customer satisfaction and Six-σ principle (Prasad, 1998). The Six-σ principle has been widely employed by organisations around the world because of its effectiveness in improving quality by prevention and in lowering production costs. A Gaussian distribution's probability density function has been used as the main distribution with great success employing the Six-σ principle because of its ideal bell shape. From that, important factors such as population in range, number defects in the population, yield percentage and defects per million opportunities can be numerically estimated.

The Gaussian distribution has been widely used in many fields of science such as medicine, civil engineering, construction management, signal processing, astronomy, physics and optics (Cohen, 1989). In the field of signal processing, a Hyperbolic kernel which is used to generate a Hyperbolic distribution, has been shown to be more effective and robust than the Gaussian distribution, which has been known as Laplace of Gaussian (LoG) (Cohen, 1989) or Choi and Williams kernel's study (Choi and Williams, 1989). Inspired by encouraging results obtained in Le's studies (Le *et al.*, 2003, Le *et al.*, 2003), more work toward the use of the Hyperbolic distribution in the field of construction management has been carried out to see whether the same success can be achieved in the field of construction management.

This paper therefore focuses on the following main objectives:

- To investigate the importance of quality in construction;
- To statistically show the effectiveness of the Hyperbolic distribution to the Gaussian distribution in improving quality using the Six-σ principle;
- To demonstrate that there exist more than one suitable distribution for use with the Six-σ principle to improve quality performance in construction activities; and
- To validate the Hyperbolic and Gaussian distributions for quality improvement by using a hydro-seeding case study.

2 The Importance of Quality

The purpose of project quality management is to ensure that the project satisfy the needs for which it was undertaken (Schwalbe, 2006). It should be noted that project management involves meeting or exceeding stakeholder needs and expectations. The project team must develop good relationships with key stakeholders, especially the main customers for the project, to understand what quality means to them. After all, the customers ultimately decide if the project quality is acceptable. Many technical projects fail because the project team focuses only on meeting the written requirements for the main products being produced and ignores other stakeholder needs and expectations for the project.

Quality management plays a major role in construction companies (Harris and McCaffer, 2004). The quality of processes producing products is crucial to the delivery of quality products. Quality, therefore, must be on an equal level with project scope, time and cost (Schwalbe, 2006). If a project's stakeholders are not satisfied with the quality of the project management or the resulting products of the project, the project team will need to adjust scope, time and cost to satisfy stakeholder needs and expectations. Meeting only written requirements for scope, time, and cost is not sufficient. To achieve stakeholder satisfaction, the project team must develop a good working relationship with all stakeholders and understand their stated or implied needs.

3 Hyperbolic vs. Gaussian: A Six-σ approach

The Gaussian distribution has been widely and effectively employed using the Six-σ principle to estimate important factors such as the population in range (PIR), the number of defects and the number of defects per million opportunities (DPMO). These estimations give satisfactory guidance for organisations in the construction industry on how to improve project quality. The main aim of this section is to mathematically introduce the Hyperbolic distribution and some of its properties, which are compared with those of the Gaussian distribution. From that, the crucial mentioned-above factors can be estimated and compared with those obtained using the Gaussian distribution. The effectiveness of each distribution is then assessed which enables organisations to judge which one is best use for a particular population. It should be noted that not all populations are Gaussian distributed. Thus, by having more available distributions for use under the Six-σ principle, more choices are made available to organisations yielding lower production cost and higher product quality.

For many years, the Gaussian distribution, or Gaussian kernel as in the field of time-frequency signal processing, has been widely and successfully used as the main tool in statistics and in design of quality management. Many important concepts have been proposed and studied with great success. The Gaussian distribution has been effectively employed in many fields of science with different names, such as Laplacian of Gaussian (LoG) and Mexican-hat wavelet. However, the link of these names, which uniquely and mathematically describe one function, has never been clearly explained and clarified. In addition, there are many functions possessing the ideal bell curve which can be used in applications where the Gaussian distribution has been successfully employed. The above ideas have motived further work on the Hyperbolic distribution to determine its effectiveness in improving quality in the field of construction management.

The purpose of introducing the Hyperbolic distribution in this paper is to further explore possible tools that are available for design of quality management. The Gaussian distribution can be used first as a performance benchmark and the effectiveness of new distributions, such as the Hyperbolic distribution, can be measured and compared. From that the best distribution can be used for particular management processes or systems as it has been shown that the Gaussian distribution is not always the most effective distribution in describing a set of random data of a population (Lathi, 1998). The Hyperbolic and Gaussian distributions are mathematically given by Eqs. (1) and (2) respectively

$$H = \frac{\beta \cdot \operatorname{sech}(\beta x)}{\pi}, \text{ with the variance of } \operatorname{var}_H \approx \frac{2.4674}{\beta^2}, \tag{1}$$

$$G = \frac{\exp\left(-\frac{x^2}{2\sigma^2}\right)}{\sigma\sqrt{2\pi}}, \text{ with the variance of } \operatorname{var}_G = \sigma, \tag{2}$$

where β and σ are the distribution parameters. The normalised Gaussian and Hyperbolic distributions are plotted in
Figure 1.

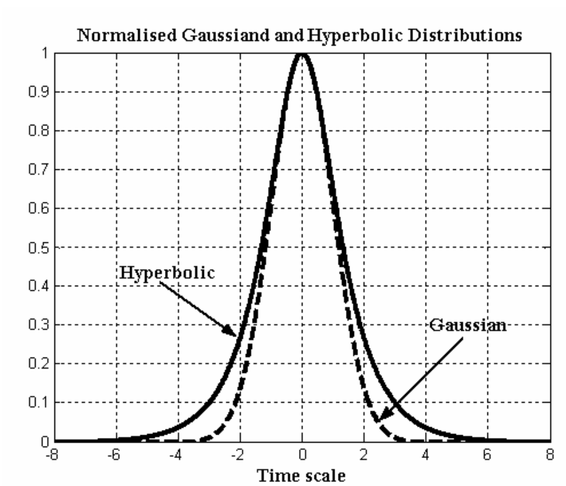

Figure 1: Normalised Hyperbolic and Gaussian distributions with $\beta = \sigma = 1$

4 Case Study

This section outlines one typical case study using cost data of a hydro-seeding company in which it is found that the Hyperbolic and Gaussian distributions are effective tools for analysing the company's overall performance and quality. From the estimated PIRs and DPMOs, possible further improvement on the company's performance and quality can be made.

4.1 Background on the company

This research uses a pilot study approach to enhance the quality performance in Hong Kong hydro-seeding industry. A landscape hydro-seeding company is selected to review and to analyse the projects quantitatively. All staff members were also responsible for quality on site through self-monitoring and observation. The supply chain employees, including suppliers, subcontractors, designers, client, project manager, site agent, quantity surveyor and junior staff, were all involved in recording and collecting data such as being responsible for filing incidents and suggesting possible causes for manifested effects.

In this research, projects implemented in the financial years from April 2003 to March 2004 and from April 2004 to March 2005 are analyzed using the Hyperbolic and Gaussian distributions. Costs in adopting Hyperbolic and Gaussian distributions are divided into costs of prevention and costs of failure. For the hydro-seeding company surveyed in this research, costs of prevention mean the costs used to reduce further failures, including monthly review meetings with a foreman to understand the progress and quarter monthly review meetings with workers to assess their working techniques. Except the review meetings held in this company, seven major elements of costs of prevention include: *i)* training of the engineering clerk and site engineer for the site "information collection of site condition by telephone" which was introduced in December 2002; *ii)* introduction of the new and advanced hydro-seeding machine in February 2002; *iii)* upgrading computer systems and introducing an internal e-mail system; *iv)* using a digital camera system to record all the work and site conditions during the site operation or the site investigation by the engineers; *v)* consulting and meeting with professionals by joining seminars and conferences, which can provide up-to-date information on hydro-seeding activities; *vi)* providing related books and magazines in the library for improving the knowledge of employees; *vii)* employing one part-time engineer to help and improve the quality; *viii)* inspection of hydro-seeding work within 100 days; *ix)* undertaking digital photos by engineers during inspection in monitoring the growth condition of grass and site conditions; and *x)* carried out ISO 9001 auditing every six months, which includes checking, inspecting, filing, recording all reference information in the required format.

The company's costs of quality failures are divided into two major items: costs of handling and costs of rework. Upon completion of the project, if the vegetation is not satisfactory after 100 days, the clients may orally and/or formally lodge a complaint about the situation. Engineers should examine the situations of ungrown grass for the particular projects, such as site conditions, working environment and others. The costs used by engineers in understanding and investigating the situations, are classified as costs of handling. After the engineers have investigated the situation of ungrown grass, rework may be required. Therefore, the costs of rework includes: *i)* extra time spent by engineers in office; *ii)* extra time for site meeting and site investigation in work failures; and *iii)* material, labour and machine for the rework.

4.2 Estimation of PIRs and DPMOs

The procedure of estimating the PIRs and DPMOs is outlined as follows. First, the mean and variance of the data are estimated by using a MATLAB program. From that, values of β and σ are estimated. For this particular set of data, β and σ are very small in the order of 10^{-5} and large in the order of 10^{4} respectively. As shown earlier, for extreme cases of small β, it is possible that the Hyperbolic distribution can outperform the Gaussian distribution which is true in this case. With the appropriate values of β and σ obtained from the given data, the PIR and DPMO of each distribution can be approximately worked out up to 15 decimal digits. In this paper, only two decimal digits are shown of simplicity.

The estimated Hyperbolic and Gaussian PIRs of the total prevention cost and total failure cost are plotted in Figure 2 and Figure 3 respectively in which it is clear that the Hyperbolic PIR is slightly lower than the Gaussian PIR. It should be noted that the PIR reflects the population percentage which obeys a particular distribution, however, it does not directly affect the performance of the company. Thus, to correctly assess the company performance, it is necessary to estimate its DPMO based on the given data. Table 1 shows the PIR of the data using the Hyperbolic and Gaussian distributions in which it is clear that the PIRs of both distributions are at acceptable levels. This suggests that these distributions can be used to model the data, in other words, they can be used to theoretically assess the performance of the company. It should be noted that the Gaussian distribution has been widely employed to manage quality and to monitor performance. By using the results shown in Table 1, it can be said that the new Hyperbolic distribution can be used for quality and performance monitoring as effective as the Gaussian distribution. This provides a new dimension in the field of construction quality management which enables managers and organisations to further improve quality.

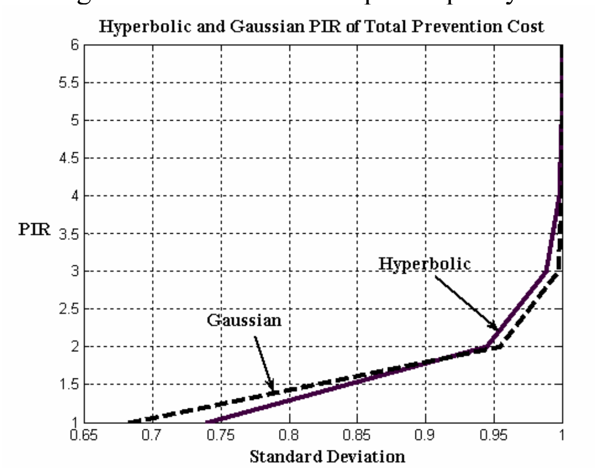

Figure 2: Population in range of the total prevention cost using the Hyperbolic and Gaussian distributions

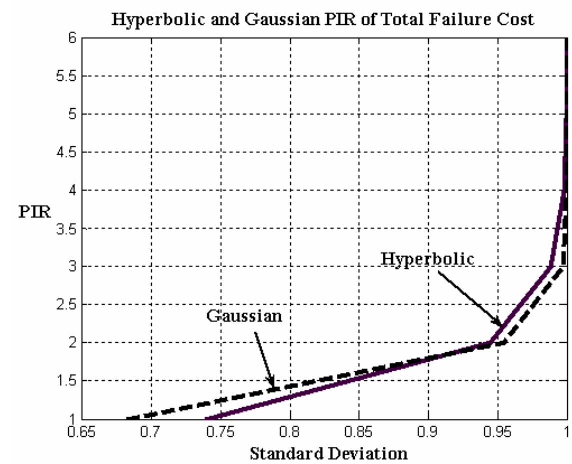

Figure 3: Population in range of the total failure cost using the Hyperbolic and Gaussian distributions

Table 1: PIR using the Hyperbolic and Gaussian distributions for the total prevention and failure costs

	Population in range (PIR)			
	Using Hyperbolic distribution		Using Gaussian distribution	
Standard deviation	Total prevention cost	Total failure cost	Total prevention cost	Total failure cost
One	0.7390356	0.7390356	0.6826889	0.6826888
Two	0.9450125	0.9450123	0.9544997	0.9544994
Three	0.9885624	0.9885624	0.9973002	0.9973002
Four	0.9976223	0.9976223	0.9999367	0.9999367
Five	0.9995057	0.9995057	0.9999943	0.9999994
Six	0.9998973	0.9998972	0.9999999	0.9999999

Table 2 gives the approximate estimated DPMOs by applying the two distributions in which the Hyperbolic DPMO is lower than that of the Gaussian, except when the standard deviation is one. It should be noted that the lower the DPMO, the better the quality. In this case, the company can expect to reduce the number of DPMO from 3.4 to 1.9 using the 6-σ principle which is an improved performance. This means that out of one million products, there could theoretically be about 1.9 defects. It is clear that by reducing the DPMO, the company's performance can be theoretically improved by about 1.5 times than before. In practice, its overall performance is also dependent on other factors such as sub-contractor performance, weather conditions and employee skills. As a result, the overall performance may not be as high as theoretically predicted using the Hyperbolic and Gaussian distributions. It is important to stress that the actual number of defects is very difficult to measure as there are many external factors such as weather conditions, different client perceptions on standard and geometrical conditions, which significantly affect this measurement. Therefore it is not possible to compare it with the theoretical values of 3.4 (using the Gaussian distribution) and 1.9 (using the Hyperbolic distribution). However, by examining the PIRs and DPMOs given in Table 1 and Table 2, it is clear that the company has appropriately invested to its prevention activities with the main aim of avoiding failures. To check on the progress of the company activities and performance, detailed data need to be collected on a regular basis, the PIR and DPMO of the data are then estimated using the Hyperbolic and Gaussian distributions. From that, decisions can be made by managers whether an activity or a group of activities should be ceased to achieve better PIRs and DPMOs. It should also be noted that the process of estimating the PIRs and DPMOs is not time consuming and therefore should be employed by every company in the industry to closely monitor quality and overall performance. As for this case study, more data are currently being collected to show the consistency between the theoretical figures reported in this paper and the real figures obtained in practice. In conclusion, it is crucial that the DPMOs and PIRs of data at different values of the standard deviation should be estimated by using Hyperbolic and Gaussian distributions to improve quality and overall performance.

Table 2: Approximate Defects Per Million Opportunities (DPMO) using the Hyperbolic and Gaussian distributions for the total prevention and failure costs

	DPMO			
	Using Hyperbolic distribution		Using Gaussian distribution	
Standard deviation	Total prevention cost	Total failure cost	Total prevention cost	Total failure cost
One	818642.23	848642.22	697677.22	697676.04
Two	151932.13	151932.13	308770.36	308770.32
Three	9162.89	9162.89	66810.60	66810.60
Four	542.16	542.16	6209.68	6209.68
Five	32.08	32.08	232.63	232.63
Six	1.90	1.90	3.40	3.40

It is also difficult to define the meaning of "defects" from a practical point of view. For example, a company currently is working on N_0 projects, out of these projects, M_0 projects have been satisfactorily completed to customer standard, which means $N_0 - M_0$ projects are resubmitted to the company for further work. It is important to note that, the projects which are considered as unsuccessful only with respect to certain client perception, meaning that other clients may consider these projects as "satisfactory". As a result, different PIRs and DPMOs may be obtained from two different companies working on a similar number of projects in the same discipline. By saying that, it is necessary to closely examine detailed data for each company as client perception standards are always different. To further study the effectiveness of the Hyperbolic and Gaussian distributions for quality improvement, more case studies are required which can be used as typical comparison benchmarks for performance and quality prediction, which in a long run can generate more profit for organisations.

It should be clear by now that the numerical PIRs and DPMOs using the Hyperbolic and Gaussian distributions of the total prevention cost and total failure cost are very similar. This shows that for this particular hydro-seeding company, the Hyperbolic and Gaussian distributions can be effectively used to estimate its PIRs and DPMOs. From that, it is possible for managers to predict the company performance and to reduce unnecessary cost. Further improvement can be also identified by studying the PIRs and DPMOs. This validates the Hyperbolic distribution as a suitable distribution for construction quality management.

5 Conclusion

The contributions of this paper are: *i)* to introduce a new Hyperbolic distribution with fine detailed features for design of quality management, *ii)* to show that the Hyperbolic distribution is more effective than the well-known Gaussian distribution with much lower defects per million opportunities and much higher yield percentage, *iii)* to show that there exist suitable distributions which can be employed using the Six-σ principle, and *iv)* to show that the Hyperbolic and Gaussian distributions are effective tools for quality management analyses of cost data in a hydro-seeding company. Possible extension of this work to other types of activities, such as environmental and safety improvement, general staff training and productivity improvement, is also possible.

6 References

Choi, H.I. and Williams, W.J. (1989) "Improved time-frequency representation of a multi-components signals using exponential kernels." IEEE Transactions on Signal Proceeding 37(6), 862-871.

Cohen, L. (1989) "Time-frequency distribution--A review." IEEE Proceedings 77(7), 941-81.

Construction Industry Review Committee (2001) Construct for excellence: report of the construction industry review committee. Hong Kong government.

Harris, F. and McCaffer, R. (2004) Modern construction management. BlackWell Publishing.

Lathi, B.P. (1998) Modern Digital and Analog Communication Systems. Oxford University Press.

Le, K.N., Dabke, K.P. and Egan, G.K. (2003) "Hyperbolic kernel for time-frequency power spectrum." Optical Engineering 42(8), 2400-15.

Le, K.N., Dabke, K.P. and Egan, G.K. (2003) "Hyperbolic wavelet power spectra of non-stationary signals." Optical Engineering 42(10), 3017-37.

Prasad, B. (1998) "A method for measuring total value towards designing goods and services." The TQM Magazine 10(4), 258-275.

Schwalbe, K. (2006) Information Technoloy Project Management. Thomson Course Technology.