

# ASSESSING PROJECT STAFFING REQUIREMENTS USING UNSUPERVISED CLUSTERING TECHNIQUES

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## ABSTRACT

Standardization, prefabrication and mechanization have been adopted, with similar concepts of lean construction, by the Hong Kong SAR government to solve housing problems since 1980. Project managers usually believe that the number of supervisory staff is directly proportional to the scale of a project. However, it is observed that there are significant variations in the allocation of supervisory staff. The objective of this pilot study attempts to explore the relationship between the scale of building projects, in terms of project clusters, and staffing strategies. In order to derive objective classification for building projects, objective project data has been used for forming project clusters using the Self-organizing Map (SOM) algorithm, which is a well-known unsupervised clustering technique. The project clusters formed represent the natural grouping in terms of similarity. The relationships between supervisory staffing patterns and project clusters have been reviewed. The findings identifies that there is a significant difference between staffing strategies for standardized public housing project and supervisory staff has been reduced proportionally to the project scale. The results shed some light on the understanding of staffing practice adopted by contractors in Hong Kong and provide some insight for future research.

## KEY WORDS

project cluster, project scale, staffing cost, unsupervised clustering technique, site organization

## INTRODUCTION

The housing problem has been a severe issue in Hong Kong after the Chinese Civil War in 1949. Refugees surged into the territory inducing a population burden to the government. The problem was triggered by the fire sweeping through a squatter causing

about 50,000 people homeless in 1953. The disaster has initiated the public housing programmes in Hong Kong. Standardization has been the general principle in public housing development. Cross wall construction where flat slabs supported by load bearing party walls running in parallel across the building is the main form of structure for public residential housing blocks. The cross wall construction

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facilitates fast track construction. Large steel panel form and steel table form were introduced to boost productivity to cope with the rapid increase in population, which has standardized the public housing construction. Subsequently, relatively standardized typical floor designs and construction cycles have been developed that follow similar work sequence and time schedules.

Project managers usually believe that the number of supervisory staff is directly proportional to the scale of a project. However, it is observed that there are significant variations in the allocation of supervisory staff. The impacts on supervisory staff could not be easily identified when there are differences in the amount of work or the scale of project. It needs to review project staffing as which forms the major cost centre determining project overheads and the key to ensure the successful implementation of project plans or project management approaches. Appropriate allocation of supervisory staff for a project could ensure the success administration of the management functions, such as planning, organizing, leading and controlling throughout the construction stage, and thus could reduce unnecessary waste for resources and assure high productivity. This study attempts to explore the relationship between the scale of building projects and staffing strategies. Project information and data, such as construction drawings, site organization charts and project cost information, were gathered through interviews with contractors. This approach can help minimize subjective opinions induced by traditional questionnaire surveys. In order to derive objective classification for

project scale, the Self-organizing Map (SOM) algorithm which is a well-known unsupervised clustering technique is used. The staffing patterns of the project clusters are reviewed and compared to identify the correlation between staffing and project scale. The relationships between supervisory staffing patterns and project scale are reported in this paper.

### STANDARDIZATION AND PREFABRICATION

Although the term “Lean Construction” is not commonly addressed by practitioners in the construction industry of Hong Kong, the prevailing use of standardization and prefabrication in Hong Kong is comparable to the concepts of lean construction aiming at continuous development of design production systems to optimize the product outputs by minimizing resources inputs (Howell, 1999, Koskela et al. 2002). Load bearing cross wall construction has been adopted as the principal form of structure for public housing blocks in Hong Kong over the last 50 years. The simplicity in design with standardized flat slabs and wall structures lend themselves to the application of system formwork. Further, precast construction was introduced in late 80s'. Off-site fabrication of precast façades and semi-precast slabs has generally been applied to alleviate the demand for site space for facilitating production flows in confined building sites in Hong Kong. The use of large steel panel form and table form reduces the formwork costs and the demand on skilful labour. Standardization is the driven force in public housing projects

both in the design and construction processes.

With years of practice, standardized typical floor construction cycles have been derived by contractors with similar work sequence and time schedules resulting in comparable productivity rates. Site production planning with respect to scheduling and production facilities layout planning appears to be indifferent between housing projects. Tender prices are therefore competitive and it is noted that the differences in estimates have been confined to costs in relation to the preliminaries items (CIOB 1997) such as temporary facilities, plant and machinery, temporary work and staffing costs. Why should there are differences in the overhead costs if the work contents and production methods are standardized? Management would advise that the differences could explain the effectiveness and efficiency and the pricing strategy of an organization. The efficiency of the management would therefore affect the overall cost and time performance of a project. This study attempts to kick-off an initial investigation on the staffing costs and staffing patterns for standardized public housing projects.

#### **PROJECT SCALE AND CLASSIFICATION**

Generally, building projects are classified by contract sums and/or the work contents in terms of number of buildings and total floor areas although construction managers allege that the form of structures, site conditions and external environment could induce differences between building projects and thus affecting the classification of projects. However, contract sum has often been used to classify building

projects. On the other hand, continuous efforts have been devoted by researchers to distinguish building projects from different perspectives such as contractor's performance, project success and disputes resolution (Chan 2004, Cheung 1998, Tam 1992). In previous studies, project scale, in terms of contract sum, is one of the variables for measuring the perceived attributes. The grouping of projects merely by the contract sum produces a simple solution, which however could be misleading. Also, for project staffing, the project scale has been regarded as the most important factor in the allocation process. It is not uncommon that staffing cost is assigned directly proportional to the contract sum. Alternative, it is alleged that staffing requirements are highly correlated with the complexity of projects. The determination, however, is usually a subjective judgment based on variables such as forms of structure, usage of building, external site conditions, etc. However, there is no consensus in defining the meaning of project complexity. Classification can largely be divided into two types: supervised and unsupervised. Supervised classification usually measures differences or similarity between objects in predetermined quantitative intervals, for examples, projects with contract sum larger than HK\$200 millions and below HK\$10 millions are classified as large scale and small scale respectively. Although the scale of project sum can be established through questionnaire surveys, it is subjective and unavoidably biased. Kohonen Self-organizing Map (SOM), a well-known unsupervised clustering technique, is proposed to generate unbiased project groups for verifying the staffing

strategy of contractors (Kohonen 1982, 2001). When applying unsupervised clustering techniques, it is not necessary to know the clusters for the objects. Instead, the SOM can be used to generate and organize data into different cluster groups as required which represent the natural grouping of projects in terms of similarity. Researchers can review and adopt the best cluster model for solving the problems being studied.

**UNSUPERVISED CLUSTERING TECHNIQUE- KOHONEN SOM**

The Kohonen SOM unsupervised clustering technique proposed has commonly been applied in neural network architecture as shown in Figure 1 (SOMLib Digital Library Homepage 2008). In the clustering process, the samples form the input

layer are represented by real vector  $x(t)$ , where  $t$  is the stage of learning. An output layer is represented by a map containing grids and each node, the neuron, contains a model vector,  $x_m(t)$ , where  $m$  is weight. In the learning process, an input vector is matched with all the model vectors, the model vector which is best fit, the most similar, with the input vector is the winner. The winner's weight is updated closer to the input vector, ie  $x_m(t+1)$  and an cluster is formed. The cluster mean is also updated for the next iteration. As the learning continues the member for the clusters increases and the movement of the vectors decreases. The learning process ceases when the clusters are stabilized or the prescribed iteration is met.

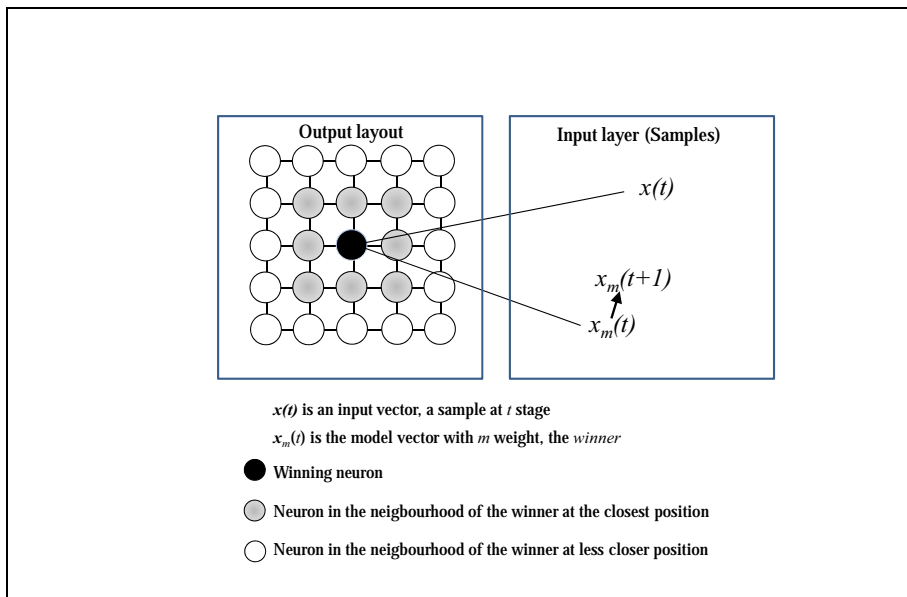


Figure 1: Kohonen Self-organizing Map Neural Network Architecture (modified from the SOMLib Digital Library - Self-Organizing Maps)

## **CLASSIFICATION OF HOUSING PROJECT USING SOM**

In classifying the collected public building project samples, 25 attributes in six groups are assigned as the input neurons. They are:

- General project information: project duration, contract sum, total floor area and number of buildings;
- General layout of the buildings: building height, typical floor level and area, non-typical floor level and area, ground floor area, area of a typical floor, and total number of floor;
- Structural Design: form of structure, special form of structure and precast component;
- Site location: urban area, sub-urban and rural area;
- Site space: site area, working space, sloping area and site access; and
- Surrounding condition: site entrance, road and traffic.

In this pilot study, data from 18 public housing projects has been collected and studied. The selection of the public housing project samples can reduce variances in procurement and quality standard since they were awarded under the standardized contract and specification governed by the Hong Kong Housing Authority. Project information and data, such as construction drawings, site organization charts and project cost information, were gathered through interviews with contractors. A 5-cluster model which groups the

projects into meaningful clusters was generated for subsequent analysis. The unsupervised clustering techniques adopt the concepts of natural clustering and clusters formed are objective. The project clusters formed provide different view in classification of building project and are capable to differentiate the project samples with respect to multi-dimensions. The cluster means for the major project attributes for the 5-cluster model are shown Table 1 and the characteristics of project clusters are shown in Table 2.

In this study, the project duration, contract sum, total floor area and the space factors show significant influence on the formation of the clusters. The space factors which have impacts on site production are seldom used to define the project nature or to classify building projects. The inclusion of the factors in this analysis enables construction managers to review the impacts of site space on the overall planning for a project. With reference to Table 2, both Cluster 3 and 4 consist of large scale projects of similar nature with differences in the site space. On the other hand, Cluster 2 and 5 consist of medium scale projects whereas projects in Cluster 5 have limitations on site planning as there are sloping areas within the site boundaries. Cluster 1 consists of small scale projects with a single building and is significant different from the other groups. With reference to the project clusters formed, the staffing costs for Cluster 3 and 4 should be higher than those of the other projects. The subsequent analysis examines the general allegation that staffing costs increase if the project scale increases.

**STAFFING COST AND STAFFING PATTERN**

Solomon (1993) and Chan (2006) reported the staffing cost for site supervision is the highest cost amongst the overhead cost and can account up to 35.9%. The findings explain that staffing has significant impacts on tender pricing. However, site organization or project organization

has received little attention in the research of construction project management when compared with studies on technical aspects such as building design, production flows and scheduling. It thus needs to review project staffing policies which are the major cost centre for project overheads and the key to ensure the successful implementation of project plans.

Table 1: Cluster Means for the 5-cluster Building Model

Cluster	Number of Project	Project Duration (months)	Contract Sum (millions)	Total Floor Area (Sq m)	Number of building	Site Area (Sq m)	Working Space (Sq m)
1	5	26.80	137.94	34486	1.20	6143	3111
2	2	30.00	435.12	102366	2.50	11754	8026
3	4	29.25	689.38	165901	4.50	21654	14384
4	2	35.50	684.03	175584	5.50	37745	21342
5	5	24.60	506.01	133710	4.00	17231	12237

Table 2 Project Characteristics of the 5-cluster Building Model

Project Cluster	Project Characteristics
1	Small scale projects with one single building and adequate site space for setting up temporary facilities.
2	Medium size projects with standardized buildings and non-standardized building, and sufficient site space for setting up temporary facilities.
3	Large scale project with multi-building and sufficient site space for setting up temporary facilities.
4	Large scale project with multi- building and adequate site space for setting up temporary facilities but surrounded by considerable amount of sloping area
5	Medium scale project with three to four buildings and sufficient site space for setting up temporary facilities.

Traditionally, the number of supervisory staff assigned to a project depends on the contract sum and the project duration. In order to achieve consistency in the comparison, the total staffing costs for the project samples are standardized in terms of

contract sum and project duration. The standardized monthly staffing cost (SMSCTOT) is expressed as:

$$\text{SMSCTOT Ratio} = (\text{Total staffing cost}) / (\text{Contract sum} \times \text{Project duration})$$

To obtain an overall view about the staffing patterns of project samples,

the staffing costs are broken down into top management cost (SMSCT), middle line management cost (SMSCM) and front line management cost (SMSCF). The SMSCT covers the staff costs for supervisory staff at the top level of a site organization such as the project manager, the assistant project manager and the site agent. The SMSCM includes staff members at the middle position such as project engineers, site supervisors and quantity surveyors etc. The SMSCF includes those supervisory staff at the production line level such as foremen, assistant engineers and administrative officers. The distributions of the staffing costs for the Project Clusters are shown in Figure 2(a-d) and Table 3. The analysis gives the following observations on the staffing patterns:

- Project Cluster 1 – The projects have been assigned with the highest staffing costs with the highest proportion in SMSCT and very high SMSCM. The SMSCF are relatively low. The differences could be due to the relatively smaller scale of projects and minimal supervisory staff for the top and middle management levels is assigned irrespective of the project scale.
- Project Cluster 2 – The projects have been assigned with relatively constant staff costs for the different levels of management with a high proportion of 60.26% for SMSCF. The mean total staffing cost is similar to projects in Cluster 3, 4 and 5.
- Project Cluster 3 – The projects have been assigned with small variations in staffing costs at different levels of management. Amongst the costs, the mean SMSCF is the highest, which accounts for 65.90% of the staffing cost whereas the mean SMSCT of 7.47% is the lowest.
- Project Cluster 4 –The projects have been assigned with small variations in staffing costs at different levels of management. The mean SMSCT of 7.63% is low, which is similar to projects in Cluster 3. However, the SMSCM of 41.27% is the highest. Although both Cluster 3 and 4 are large scale projects, projects in Cluster 4 have more restricted slopping site space. This could have induced the differences in the staffing patterns.
- Project Cluster 5 – The staffing costs for medium scale projects in Cluster 5 are similar to Cluster 2 with slightly lower in SMSCT. With a closer inspection of the staffing patterns, it is observed that the staffing costs decrease when the contract sums increase especially for SMSCT and SMSCM.

Table 3 Proportion of Staffing Costs

Project Cluster	SMSCT	SMSCM	SMSCF
Cluster 1	15.25%	38.46%	46.30%
Cluster 2	12.42%	27.29%	60.26%
Cluster 3	7.47%	26.62%	65.90%
Cluster 4	7.63%	41.27%	51.10%
Cluster 5	10.20%	28.01%	61.78%

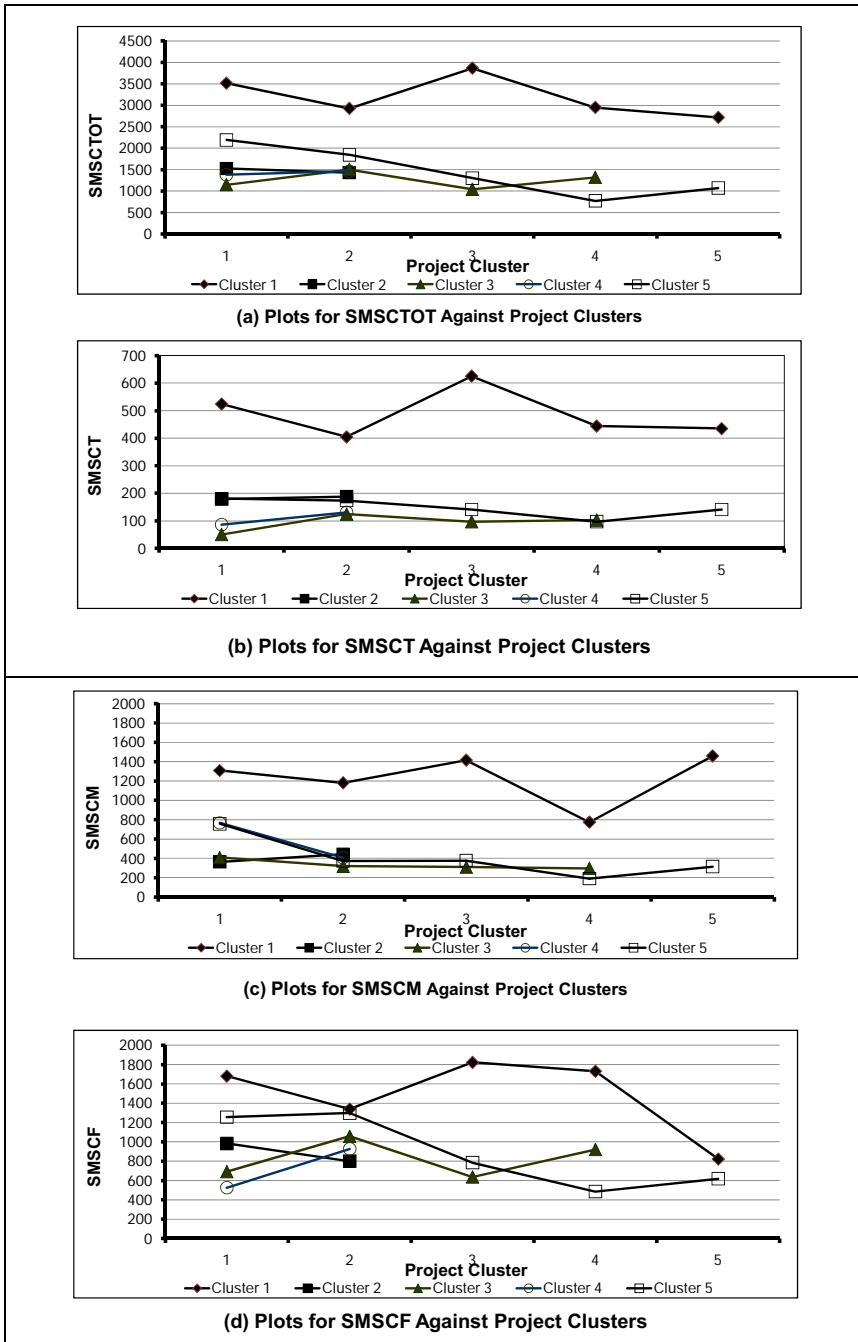


Figure 2: Plots for Staffing Costs Against Project Clusters



## STAFFING PATTERNS FOR MANAGEMENT LEVELS

The staffing patterns explained above demonstrate the differences between the project clusters. When the project scale increases the proportion of SMSCT decreases presuming that the number of senior management staff assigned is not sensitive to the project scale or project nature. There are large variations in the SMSCM. Except for Cluster 4, the SMSCM is relative low and this may explain the general complaints from engineers that they have been overloaded by the amount of co-ordination and supervisory duties imposed by modern complex projects. It has to point out that deficiency in co-ordination could be the root of poor site space utilization, material management and overrun in schedule owing to late production information. As discussed in previous section, contractors have assigned higher SMSCM for projects in Cluster 4 to enhance project co-ordination since the site space is relative confined and surrounded by slopes. Generally, the SMSCFs are relatively high and increase proportionally with the project scale. However, it is shown that there are larger variations in the staffing for the front line management as shown in Figure 2(d). The total staffing costs show a negative relationship with contract sums and this does not conform to the assumption that staffing costs increases in proportion to contract sums.

## CONCLUSIONS

Defining the complexity and the scale of building projects is usually based on subjective judgement and the allocation of supervisory staff is

determined by the project scale. The appropriation of staffing is therefore liable for arguments due to possible bias in the classification. The proposed SOM clustering technique has improved the classification by employing objective natural clustering for the public housing project samples. Five project clusters have been identified providing a new perspective in differentiating building projects using 25 variables. The staffing patterns of the project clusters have shown that there are differences in staffing costs with respect to the scale of project and the site space. A minimal of senior management staff is generally assigned irrespective of the project scale and it appears that the proportion of middle line management staff is relative low and this could be one of the causes for poor co-ordination. On the other hand there are higher variations in the front-line staff. This pilot study identifies that there is a significant difference between staffing strategies for standardized public housing projects and contractors tend to reduce supervisory staff proportionally to the project scale. There are needs to investigate whether standardization could result in reduction on supervision and what impacts on quality and time management in project management would be. The findings are interesting and forming a new direction in the study of project management since the actual contractors' staffing strategies are deviated from the hypothesis or the claim of project managers that supervisory staff increases proportionally to the scale of a project. Also, it is worthy of study on staffing requirements for site organization for standardized building projects.

## REFERENCES

- Chan, T.W.C, (2006). "A decision-making matrix model for estimating construction project overhead", Project Management Institute Research Conference, 2006, 16-19 July, Montreal, Canada.
- Chan A.P.C, Scott, D & Chan A.P.L. (2004). "Factors affecting the success of a construction project", *Journal of Construction Engineering and Management*, ASCE, 130(1), February, 153-155.
- Cheung SO (1998). Project dispute resolution satisfaction of construction clients in Hong Kong, Ph.D. thesis, University of Wolverhampton.
- CIOB (1997). *Code of Estimating practice*, The Chartered Institute of Building, Longman, and London, United Kingdom.
- Glenn Ballard and Greg Howell (1998). "What Kind of Production is Construction?" *Proceedings Sixth Annual Conference of the International Group for Lean Construction*, IGLC-6, Guaruja, Brazil, August 13-15.
- Gregory A. Howell (1999). "What is Lean Construction-1999." *Proceedings Seventh Annual Conference of the International Group for Lean Construction*, IGLC-7, Berkeley, CA, July 26-28, 1-10.
- Kohonen T. (1982). Self-organized formation of topologically correct feature maps, *Biological Cybernetics*, 43, 59-69.
- Kohonen T. (2001). *Self-Organizing Maps*, 3rd ed. Springer Series in Information Sciences, New York.
- Koskela, L. and Howell, G., (2002). "The Underlying Theory of Project Management is Obsolete." *Proceedings of the PMI Research Conference*, 2002, Pg. 293-302.
- Solomon G. (1993). "Cost Analysis, preliminaries, the marketplace effect", *Chartered Quantity Surveyors*, October, 1993, 9-11.
- The SOMLib Digital Library - Self-Organizing Maps. (2008) <http://www.ifs.tuwien.ac.at/~andi/somlib/som.html>
- Tam C.M. (1992). Discriminant analysis model for predicting contractor performance in Hong Kong. PhD Thesis, Loughborough University of Technology.