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Effective Material Logistics in Urban Construction Sites: A Structural Equation Model

Abstract

Purpose: The purpose of this paper is to identify best practice relating to the effective management of materials in an urban, confined construction site, using structural equation modelling.

Design/methodology/approach: A literature review, case study analysis and questionnaire survey are employed, with the results scrutinised using confirmatory factor analysis in the form of structural equation modelling.

Findings: The following are the leading strategies in the management of materials in a confined urban site environment; (1) Consult and review the project programme, (2) Effective communication and delivery, (3) Implement site safety management plans, and (4) Proactive spatial monitoring and control.

Research limitations/implication: With the relentless expansion of urban centres and the increasing high cost of materials, any potential savings made on-site would translate into significant monetary concessions on completion of a project.

Originality/Value: As on-site project management professionals successfully identify and implement the various strategies in the management of plant and materials on a confined urban site, successful resource management in this restrictive environment is attainable.

Keywords: Construction Management, Confined Site Construction, Management, Planning and Management, SEM, Structural Equation Modelling.

Paper Type: Research Paper

Introduction

Our cities are in a state of transition, where urban centres are quickly becoming congested, due to a significant population influx (United Nations, 2010). Significant changes have been documented in the progression from rural expansion to urban regeneration and development (Roberts and Sykes, 2000; Gordon, *et al.*, 2009). The vast majority of urban centres are being redeveloped at an alarming rate (Jones and Evans, 2008) to accommodate the significant population growth (United Nations, 2008a, 2008b, 2010). This requirement is further substantiated by Hui *et al.* (2007), who argue that our urban centres are suffering from significant and rapid urban decay, while Hao *et al.* (2010) highlight the difficulties in developing nations. However, the development of these centres is not without difficulties, with numerous development issues to contend with (Ye, 2011). With the development of these urban areas, contra to belief, they are not expanding outwards, but are being redeveloped within (Bibby, 2009); thus further illustrating the presence and importance of urban development in the construction industry. Also, it has been documented that urban development is increasing dramatically; therefore further emphasising the continued progression of urban expansion in the construction industry (Bibby, 2009).

However, with the development of these urban centres comes increased difficulty in the construction process (Rahman, *et al.*, 2008; Lambeck and Eschemuller, 2008), particularly in effective management of materials (Huang and Hsu, 2003; Lu, *et al.*, 2007). This is due to the congested nature of the urban environment (Singer, 2002), where many city centre developments are spatially restricted. This results in the need for increased management, particularly with material logistics (Lambeck and Eschemuller, 2008).

With materials accounting for forty five to sixty percent of the on-site cost of a typical construction project (Kini, 1999; Song, *et al.*, 2005; Koskela, 1999; Akintoye, 1995) and between fifteen and thirty percent of urban waste (Formoso, *et al.*, 2002), effective management

of this vital resource is essential, particularly in this spatially challenging environment (Shapira, *et al.*, 2007; Zhou, *et al.*, 2009). Due to the significant cost of materials to a projects total budget, this provides an important and attractive resource to focus on, with the aim of reducing costs (Navon and Berkovich, 2005), in order to achieve increased profits.

Where effective logistics management is implemented, significant monetary and schedule savings are attainable (Jang, *et al.*, 2003; Akintoye, *et al.*, 2000), material waste is reduced (Poon, *et al.*, 2004a, 2004b), increased productivity (Enshassi, *et al.*, 2007; Thomas and Horman, 2006; Thomas, *et al.*, 1989), increased safety (Sawacha, *et al.*, 1999; Spillane, *et al.*, 2009; Spillane, *et al.*, 2011b, 2011b; Spillane and Oyedele, 2013), and overall increased project performance is achievable (Agapiou, *et al.*, 1998). Hence, effective and efficient management of this resource in an unfavourable urban environment is essential and an ongoing concern for many on-site project management professionals.

When reviewing the wealth of literature written on the subject of logistics and effective material management, the vast majority of authors review the management process on the basis of construction sites, where space is plentiful (Bertelsen and Nielsen, 1997; Agapiou *et al.*, 1998; Jang, *et al.*, 2003; Harris, *et al.*, 2006) with Lambeck and Eschemuller (2008) providing only fleeting references to effective management of materials on a confined site basis. Furthermore, Winch and North (2006) have outlined that effective spatial management is often conducted in an ad-hoc, intuitive nature, not based on a predetermined set of criteria or guidance procedure.

Therefore, the purpose of this paper is to catalogue the numerous approaches on-site management can adopt, in the successful administration of materials required, in the successful completion of a confined, inner city development, with a view to providing a core set of strategies for adoption. This is achieved through a number of steps. Firstly, the literature is reviewed to highlight the various factors already identified. Various sources are considered, but to ensure rigor, preference is placed on citing peer reviewed journal papers and conference

proceedings, where possible. Secondly, three case studies are employed, to ensure that an exhaustive list of strategies highlighted from experienced professionals are also considered. The resulting factors are amalgamated in the design of a questionnaire survey for circulation to industry practitioners. Once this survey is piloted, it is distributed and the results assessed using confirmatory factor analysis technique; structural equation modelling (SEM).

Logistics of Materials on Confined Sites

When reviewing the literature on the subject of materials management, the majority focus on sites where space is plentiful (Mahdjoubi and Yang, 2001; Pertulla, *et al.*, 2003; Ala-Risku and Markkainen, 2006; Qu, *et al.*, 2016). In the case of a confined urban site environment, space is a finite, important resource, requiring continuous management interface. The difficulty of effective management of materials on complex, spatially restricted sites, are not considered for review (Mahdjoubi and Yang, 2001; Said and Lucko, 2016). The inclusion of such an environment is necessary, due to the difficulty in managing materials in such an adverse environment. Furthermore Ala-Risku and Markkainen, (2006) review the problems associated with the movement of materials on-site, but fail to acknowledge spatial restrictions as a possible issue – one which is of concern in the management of materials in an urban construction site environment. Beyond the spectrum of the built environment, consideration is given to other sectors, such as the aerospace industry (Chiang and Torng), container transportation (Tsadiras and Zitopoulos, 2016), among others.

Effective material management is not a new concept in the industry, with significant research on the subject in recent years. Only fleeting references are made to the management of materials on spatially restricted projects (Harris and McCaffer, 2006; Chudley and Greeno, 2006a, 2006b), but little information is given on the effective management of this important resource, particularly where space is a finite and essential component requiring control (Faniran and Caban, 1993; Enshassi, 1996; Formoso, *et al.*, 2002).

The importance of effective material management is well documented (Thomas, *et al.*, 2005; Enshassi, 1996) with savings of six to ten percent on productivity directly attributable to effective material management (Bell and Stukhart, 1987). Materials have been identified as one of the more prominent areas where significant improvements and savings can be made (Vorster and Lucko, 2002); thus further illustrating the importance of the topic and the need to fulfil the gap in knowledge.

There have been a number of publications on the implication and utilisation of various strategies in the management of material delivery to site. The topic of just-in-time delivery (Akintoye, 1995; Opfer, 1998; Bertelesen and Nielsen, 1997), pre-fabrication (Yeung, *et al.*, 2005), pre-assembly and standardisation (Gibb, 2001), in conjunction with the push/pull concept (Ballard and Howell, 2008), have all been analysed in the context of material management. On review, the vast majority of the research fail to acknowledge and highlight the benefits of such management techniques in the development of urban, spatially restricted, construction sites.

The management of material on-site is also documented by a number of authors (Kini, 1999; Song, *et al.*, 2005, Song, *et al.*, 2006). A wide variety of tools and techniques have been identified, with material routing acknowledged as a fundamental requirement (Koskela, 1999; Yang and Mahdjoubi, 1999; Yang, *et al.*, 2003). Due to the dynamic nature of the industry and of construction sites in particular, effective routing of materials is essential to aid in productivity (Tommelein, *et al.*, 1991; Enshassi, *et al.*, 2007). but also to reduce waste (Alarcon, 1993). It has been noted that effective routing of materials is largely based on intuition and is developed over time, through experience and knowledge acquired in the industry (Clausen, 1995; Mahdjoubi and Yang, 2001).

The design site layout has also been considered, illustrating the effect on material management in the industry. Winch (2010) highlight that this topic has been reviewed in detail by a number of researchers, but on reviewing the literature, authors fail to acknowledge the increased

managerial burden on spatially restricted environments (Mawdesley, *et al.*, 2004; Osman and Georgy, 2005). The design site layout has been highlighted as fundamental to the effective coordination and movement of materials, both onto (Spillane, *et al.*, 2013) and around site (Sadeghpour, *et al.*, 2002; Tam, *et al.*, 2002; Elbeltagi and Hegazy, 2003; Elbeltagi, *et al.*, 2004); thus sufficient consideration must be given to this aspect of material management.

To summarise, on reviewing the abundance of literature on the management of materials in the construction industry, a number of authors fail to acknowledge and detail further, the numerous strategies that on-site management should adopt, in the successful management of materials in a spatially restricted environment, as is the case in an urban, city centre development.

Research Methodology

To address the purpose of this research, a sequential mixed methodology is applied using both qualitative and quantitative approaches. This includes a detailed review of the literature, three case studies and a questionnaire survey, with twenty observed variables analysed using structural equation modelling, resulting in four overarching strategic management themes; (1) Consult and review the project programme, (2) Effective communication and delivery, (3) Implement site safety management plans, and (4) Proactive spatial monitoring and control.

Prior to doing so, it is necessary to consider the ontological and epistemological reasoning; thus providing a justification as to the overall approach applied. Grix (2002) highlights that three fundamental paradigms must be acknowledged and utilised; ontology, epistemology and methodology. Firstly, the ontological standpoint must be considered. Numerous approaches are available; however, an application approach is adopted, where Malone and Parkinson (2010) outline that the study should be evaluated against numerous cases and research questions, which identify both the scope and requirements of the research in focus. Klien *et al.* (2006) further the justification of applying an application ontology, where the interviewees “share a common

understanding of certain concepts”, which are then applied in context. From this, it is then possible to identify the overall ontological positioning as one of a constructivist (Johnson and Duberley, 2000), where human perception and social experience is considered, using the perspective of case studies.

Subsequently, the epistemological reasoning must also be considered. As Grix (2002) outlines, this premise provides clarity by illustrating that epistemology is a branch of philosophy concerning the assumptions about knowledge, with respect to its methods and validation. Subsequently, critical realism may be applied, where according to Wikgren (2004), critical realists maintain that one should move from providing a prediction to an explanation through investigation.

As a result, a sequential mixed method approach is applied, with equal priority, and subsequent value, emanating from both methods (Jogulu and Pansiri 2011), culminating in a detailed discussion founded on a confirmatory structural equation model. Holt and Goulding (2014) outline two types of mixed methods research. Explicit; whose design makes clear, the intention to achieve a qualitative/quantitative paradigmatic mix; or ambiguous; whose design does not make such clear distinctions, but which does so in its application. In this instance, an explicit mixed-method is applied, where there is a clear intention to develop and achieve a qualitative/quantitative paradigmatic mix. This is achieved in the use of interviews (qualitative) and a subsequent questionnaire survey (quantitative), which then forms the basis for the development of the structural equation model.

In order to arrive at a coherent and structurally valid model, a number of steps were taken. Firstly, a detailed and thorough review of the literature was undertaken, to identify potential factors relative to the management of materials on a confined construction site. All of the factors were compiled, with repetitious elements removed and ambiguous factors rephrased to affirm their inclusion in the subsequent questionnaire survey.

Secondly, to compliment the literature and to assist in compiling a comprehensive database of factors, a detailed case study of confined sites constructed was undertaken. To assist in triangulation and to remove bias (Hartley, 2004), should it occur, at least three personnel from each case study were interviewed. The justification for three case studies is based on the principles of triangulation, while also aiding in confirming the validation and reliability of results. To arrive at three case studies for consideration, the authors identified an array of potential case studies, based on criterion sampling method. The criteria include; the confined nature of the project, the level of completion at the time of the study, the amiability of those on-site to participate in the research, and the overall approval of the owner/main contractor to contribute to the study. Initially, a total of twelve potential case studies met the criteria. These potential case studies varied in location from the United Kingdom (4), Ireland (3), United States of America [USA] (2), Canada (1), United Arab Emirates (1) and Asia (1).

From the shortlist of twelve potential case studies, a dual sequential sampling method was employed, where firstly, random sampling, followed by convenience sampling was used. Each of the three case studies selected are contacted to confirm their ability and to ensure that they can still accommodate the authors. Subsequently, the three case studies selected are catalogued in Table 1, where the geographical location, classification and type of development are all identified.

Insert Table 1: Case Study Characteristics here

The first case study is located in Limerick, on the west coast of Ireland. It consists of apartments constructed over commercial units on the ground floor, with a central courtyard from the 1st floor. The structure consists of steel and concrete surround by a brick façade, with the exception of the final floor, which is clad in aluminium. The main contractor on-site has in excess of 21 years' experience; many of which was spent constructing similar structures within urban centres. In total, three participants contributed to the data collection in separate semi-structured

interviews. The individuals are the Site Manager, the Projects Director and the Operations Director. On average, the three participants have in excess of fifteen years industry experience. The average duration of each of the three interviews is forty minutes, with each recorded verbatim using shorthand notetaking.

The second case study was an underground storm water pumping station, located in Northern Ireland. It is a cast in-situ concrete structure rising to a pumping station located at ground level, in addition to a car park area. In this instance, the Site Engineer, Site Manager and Project Manager for the project are interviewed on-site. Each interview takes, on average, thirty minutes to complete and is conducted both within the site offices but also during a tour of the project in question. The main contractor has experience on a global scale, with those involved in the project working on numerous similar projects throughout the United Kingdom (UK) and Ireland.

The third and final case study incorporates a high rise condominium constructed in downtown Chicago, USA. The main structure comprises of cast in-situ concrete, rising to thirty-five floors, with a neighbouring six story construction. Both structures are interlinked by means of a four story mezzanine/common area, which is again characterised by cast in-situ concrete with a glazed façade. During the data collection exercise, the project was 90% complete. The participants in this case are the Operations Director, Projects Director and the Site Manager. The main contractor on this occasion has approximately forty-three years' experience constructing similar structures in confined site environments in North America and Europe. The main contractor is UK derived, with the majority of their work being undertaken throughout Europe, but primarily within the UK and Ireland.

Although the three case studies are not similar in size nor structure, this provides an opportunity to explore the many potential factors that can arise in a variety of environments (below grade, low rise and high rise projects). The authors strived to acquire a diverse range of case studies,

to get a broad perspective of the potential difficulties that project managers are faced with; thus providing an broad scope on which to identify as many potential factors as possible.

The factors identified from each case study interview were then catalogued and recorded, in conjunction with those identified in the literature, and incorporated in the design of a questionnaire survey. In total, twenty factors are included. The questionnaire was piloted prior to circulation, to ensure that the questionnaire examines the objective reality in which it is designed. The questionnaire was constructed of two sections; the first, to obtain the particulars of the respondent, and the second, the level of importance of each factor or observed variable. To assess the level of importance of the factors, a dual measurement approach was adopted, where both the 'Frequency' and 'Importance' are recorded for each factor. A five point Likert scale was used, where 1; not important, 2; slightly important, 3; important, 4; very important, and 5; most important. By using dual scales, it was then possible to identify and quantify the importance of each of the factors. The questionnaire was distributed electronically, due to the ease of circulation, completion and return, particularly considering the large number of potential respondents geographically dispersed.

Qualitative Analysis

To aid in differentiating the numerous strategies in the management of materials in a confined site environment, qualitative analysis was implemented in the form cognitive mind mapping and a summarising causal loop diagram.

From the nine interviews (three interviews from each of the three case studies), cognitive mapping of each interview is conducted, to aid in deciphering and extracting the various factors for the questionnaire survey. Also, each of the case studies was mapped collectively from the individual cognitive mind maps created, to further illicit and clarify any further underlying factors. Subsequently, the overall cognitive mind map was converted into a causal loop

diagram, as outlined in Figure 1. This process illustrates the inter-relationship among the variables and to graphically illustrate, the internal feedback loops and time delays present in the various factors and their associated structures. The subsequent factors identified, in conjunction with those highlighted in the literature review, are then included and circulated in a questionnaire survey; the results of which are quantitatively analysed.

Insert Figure 1: Causal Loop Diagram here

To assist in the development and realisation of the findings from the case studies presented, while also obtaining a wider industry viewpoint from a broader perspective, it was advisable to consider a large demography within the study. To achieve this, a quantitative approach using a self-reporting process of data collection, in the form of a questionnaire survey was employed. This provided an opportunity to develop the points obtained from the qualitative methods employed, while also considering the viewpoints of a wider audience. Thus, an online questionnaire survey was developed, where, through a process of adopting a two stage selection process, potential respondents to the survey were targeted. The first stage encompassed the identification of potential candidates from various professional bodies, such as the Chartered Institute of Building (CIOB), Royal Institution of Chartered Surveyors (RICS) and the Association for Project Management (APM). Secondly, those who expressed an interest in construction site/project management were then selected and included in the study.

Quantitative Analysis

The results of the returned survey were scrutinised and reviewed, to provide the necessary information for discussion. Factor analysis was implemented to determine the nature of the dataset, with the objective of identifying possible patterns within (Tucker and MacCallum, 1997) or more simply, the method by which to “explain a larger set of measured variables with a smaller set of latent constructs” (Henson and Roberts, 2006).

However, it must be noted that one of the most common pitfalls is overindulging in a wide variety of methods and not focusing on and justifying the inclusion of a distinct few (Henson and Roberts, 2006). There is a plethora of possible quantitative methodologies and underlying methods to choose from when assessing quantitative data, but it is the responsibility of the researcher(s) in question, to subjectively and informatively identify and utilise the most appropriate methods available. With this, there were a number of possible methods considered in the analysis and comprehension of the data accumulated, as a result of the completed questionnaires returned.

But prior to this, a word of caution must also be highlighted with the use of a questionnaire as one of the principle forms of data collection, owing to the process involving a self-reporting methodology. There are two distinct types of measurement error; random and systematic error (Cote and Buckley, 1987). The prevalence of measurement error is widely acknowledged as being unavoidable and omnipresent within research (Campbell, 1969). However, the level at which this influential factor distorts the dataset must be highlighted and avoided in order to ensure validity and reliability of the resulting findings.

As a questionnaire is a self-reporting process of data collection, it is possible that the respondents are influenced by common method bias. To ensure that this is not the case, the resulting dataset is reviewed using Harman's single factor test. On reviewing the dataset, the results indicate that the single factor accounts for just 26% of the total variance, a figure widely accepted in numerous social sciences as being within satisfactory tolerances of 15% to 30% (Cote and Buckley, 1987). Therefore it can be concluded that common method bias within the dataset is not present and therefore not an issue, and the quantitative analysis can proceed to reviewing the data within.

In total, 105 questionnaires were returned with usable data from 216 distributed, giving a return rate of usable data of 48.6%. Respondents ranged from Project Managers (36), Site Managers

(15), Contracts Managers (14), Quantity Surveyors (11), Project Architects (4), Site Engineers (4), Structural Engineers (2), Health & Safety Officers (2) and Project Engineers (2), with the remaining 15 being other professions within the built environment. Experience of the respondents ranged from 1 to 5 years (32), 6 to 10 years (17), 11 to 15 years (19), 16 to 20 years (10) and 21 + years (27). Respondents were located in Ireland (25), United Kingdom (61), Canada (11), USA (3) and Australia (5).

It was noted that a number of responses to the questionnaire had missing data, where on quantification, there were 57 and 27 missing values on the 'Frequency' and 'Importance' scales respectively. On assessing if the data is missing at random and thus; not influencing the dataset, Roger J. Little's Missing Completely at Random test is introduced (Little, 1988). On assessing the 'Frequency' and 'Importance' scales, the results indicate that at a significance level of 0.996 and 0.782 respectively, the data is completely missing at random and therefore not introducing bias to either dataset (SPSS, 2007, 2011). Table 2 catalogues the twenty factors, their respective source (literature only, case study only, literature and case study), the associated 'Importance', 'Frequency' and subsequent 'Severity' of each, as prescribed by the respondents.

Insert Table 2 Effective Material Logistics - Factors and Associated Severity Rank here

In order to test the reliability and validity of the dataset and to unearth underlying trends with a view to classifying the observed variables, confirmatory factor analysis is undertaken. Using the twenty observed variables and their corresponding results, both first and second order factor analysis is used to measure the unobserved variables. This structural equation modelling process is divided into both measurement and structural model assessment, as follows.

Measurement Model Assessment

The measurement model is used as a basis on which to affirm the reliability and validity of the various factors and the resultant model proposed. Tabachnick and Fidell (2007) highlight that

factor loadings (β) above 0.71 are excellent, 0.63 representing very good, 0.55 good, 0.45 fair, and any factor loadings below, 0.32 as poor. In order to improve the model, a number of iterations are required to develop model fit, where factor loadings (β) range from 0.29 to 0.86. Through an iterative process, standardised residual covariances within the model are interrogated to improve the factor loadings, and therefore, the model fit. In conjunction, the possibility of mitigating error terms is also considered, through a process of co-varying observed variables. Finally, all factor loadings are individually examined based on the recommendations of Tabachnick and Fidell (2007) as outlined above. Through this process, just two of the twenty factors are omitted (PMS6: Use space outside the site boundary for storage of plant and materials; PMS14: Improved communication with personnel to facilitate plant and materials), due to significant standard error and negative variance. Subsequently, the respective factor loadings for each variable is improved, resulting in the enhancement of the overall model fit. Figure 2 portrays the structural equation model, where eighteen observed variables are classified under four unobserved variables, which are then scrutinised, using confirmatory factors analysis.

Insert Figure II: Structural Equation Model – Effective Material Logistics in Confined Construction Sites here

The exact limitation on which factor loadings (β) should be discredited varies, with Hair *et al.*, (2010) insisting that loadings should be ≤ 0.50 , but Matsunaga (2010) argues that this should be increased to ≤ 0.60 , with values in excess of 0.70 demonstrating significant loading. From the subsequent iterative process, the revised model is developed with factor loadings (β) 0.51 to 0.84.

Furthermore, Joreskog rho (ρ) internal Composite Reliability (CR) (Joreskog 1971) is introduced to test the reliability of the latent variables under scrutiny. This approach critiques

each of the variables, to assess if they measure more of the group that they are allocated, than any other group present. Results are obtained from the squared multiple correlation coefficient, with a range from 0 to 1, with values ≥ 0.7 preferred.

To complement Joreskog rho (ρ), Cronbach's Alpha (α) (Cronbach 1951) is also consulted, as a measure of internal composite reliability. Both Raine-Eudy (2000) and Nunnally (1978) are at difference on the minimum prescribed values, stating ≥ 0.70 and ≥ 0.50 respectively. In this instance, this measure of internal reliability is easily achieved in the model as a whole (0.93) and each of the four constructs modelled (0.82, 0.86, 0.77 and 0.86).

To ascertain the validity of the model, there are a number of potential methods that can be employed. The first adopted in this instance is the Average Variance Extracted (AVE), where each of the groups is measured. This method of validity assess each of the groups presented, by reviewing each of the variables within. By consulting the latent variables, this process poses the question whether the variable would explain more within another group or not. The minimum prescribed results are questioned, with Hulland (1999) arguing that values ≥ 0.25 be accepted; however, results ≥ 0.05 are preferred (Fornell and Larcker, 1981).

Fornell and Larcker (1981), as reiterated by Wong (2013) also suggest that the square root of AVE, in each latent variable can be used to establish discriminant validity. Paswan (2009) provides a simplistic overview of the process, where all of the constructs AVE should be greater than the corresponding squared inter-construct correlations. To summarise, the AVE in each case should be greater than the squared correlation estimate (Sq. Correlation Est.); thus highlighting that the variables within that group measure more within the group assigned than any other group available.

Table 3 documents the unobserved variables from the model and the associated group names attributed to each, with the respective Joreskog rho (ρ), Mean, Standard Deviation and Factor

Loadings (β) for each observed variable. Additionally, the Cronbach's Alpha (α) at 95% Confidence Interval, the Average Variance Explained (AVE) and the Composite Reliability (CR) for both the groups prescribed and the model as a whole are presented. For further detail on the various methods and the subsequent parameters on which to assess structural equation models, readers are encouraged to consider seminal works by Tabachnick and Fidell (2007), Joreskog (1971), Nunnally (1978) and Nunnally (1978), among others.

Structural Model Assessment

In order to affirm the model as a whole, it is necessary to review and assess the structural model. Numerous authors such as Kline (2005), Hooper, *et al.* (2008), Crowley and Fan (1997), in addition to Kenny and McCoach (2003) all advocate the importance of, and necessity, to undertake and assess the structural model. However, Howell *et al.*, (2008) argue that one should choose and account for key measurement statistics. Konanahalli, *et al.* (2014), together with Hooper, *et al.* (2008) advocate the use of comparative fit index (CFI), normed fit index (NFI), goodness of fit (GFI) and the Root Mean Square Error of Approximation (RMSEA).

Firstly, the comparative fit index (CFI) is introduced to measure the overall model fit, as is particularly apt in this instance, as it takes account of sample size (Hooper, *et al.*, 2008). This approach compares the sample covariance matrix with the null model, where results should be ≥ 0.90 (Kline, 2005). Secondly and in conjunction with CFI, the normed fit index (NFI) is also scrutinised. McDonald and Ho (2002) outline that again, the minimum level be ≥ 0.90 , but Hooper *et al.*, (2008) indicates that values just below this may also be acceptable, where the sample size is large. Thirdly, the goodness of fit (GFI) is used as a reference point, again where values should be ≥ 0.90 as a minimum, but preferably ≥ 0.95 where possible. In the context of the model as a whole, the Root Mean Square Error of Approximation (RMSEA) is consulted, where values ≤ 0.10 indicating excellent model fit, are also adopted. Chi-squared divided by the

degrees of freedom (χ^2/df) where values are ≤ 2 , indicate excellent model fit (Eyuboosh, 2010). Finally, PClose is reviewed, where values closer to 0 indicating higher model fit (Kline 2005). Table 3 **Error! Reference source not found.** provides a detailed overview of the various structural model assessment methods employed, in conjunction with the model as a whole. Subsequently, based on the above parameters, results of 0.927 (CFI), 0.839 (NFI), 0.827 (GFI), 1.662 (CMIN/DF), 0.08 (RMSEA) and 0.009 (PClose) all confirm good model fit.

Insert Table 3: Factors, their Associated SEM Groups and Measurement Scores here

Discussion

From the resulting structural equation model, a total of eighteen factors are segregated into four constructs, which portray the consolidated strategies for effective material logistics in urban, confined construction sites. The first model construct is that of ‘Consult & Review Project Programme’ (PMSa) where the model above documents the importance of this construct. Within this construct, there are four factors varying from $\beta=0.55$ to $\beta=0.82$. The second construct for discussion is ‘Effective Communication & Delivery’ (PMSb) with $\beta=0.95$ and 90% of the variance explained. Again, this is a four factor construct with significant values of $\beta=0.84$, $\beta=0.79$, $\beta=0.72$ and $\beta=0.70$. The third most prominent construct in this model is; ‘Proactive Spatial Monitoring & Control’ (PMSd). This is a significant construct with a total of seven factors ranging from $\beta=0.51$ to $\beta=0.82$, with an average of $\beta=0.67$. In total, this construct explains 85% of the variance in the overall model ($\beta=0.92$). The final construct in this overall model is ‘Implement Site Safety Management Plans’ (PMSc) which accounts for 66% of the variance and $\beta=0.81$. This construct is the smallest for consideration with just three factors explaining $\beta=0.53$ to $\beta=0.63$ of the variance in this construct. Each of the four constructs are discussed, in turn, as follows.

Consult & Review Project Programme (PMSa)

The first strategic construct for review encompasses the project programme, where on-site management are encouraged to consult and review the programme, to ensure the effective and proactive management of plant and materials on-site. This construct encompasses four factors, each of which is highly correlated, while also contributing to the overall construct significantly. In addition, with a mean of 2.78 and standard deviation of 1.32, this further illustrates that this construct is of high importance, with a limited variation from the norm recorded by the respondents. This affirms that the project programme is inherently grounded within

management of any construction site, but this is illustrated further where on-site management have to constantly consult and review the programme, to accommodate the various resources. Where effective consultation and review procedures are not adopted and implemented, the resulting qualitative (interviews) and quantitative (correlation analysis) affirm that difficulties in the management of plant and materials will emerge.

Additionally, the time input required by management in the coordination and control of the various resources must also be noted. This concurs with the opinions of many of the interviewees, particularly those in the site management and middle management interviews, who identify the importance of consulting the project programme in relation to the delivery of materials to site. In addition, the strength of the benefit derived is also affirmed, particularly in the causal loop, but more so, the structural equation model.

Lycett, *et al.*, (2004) and Thomas, *et al.*, (1989) agree with the points identified by the qualitative and quantitative data collection and surmise that there is still a requirement for organisations to implement effective review procedures, in order to assist in project delivery. Many of the senior participants concur that this construct is of paramount importance to the successful completion of a confined construction site, due to the increased dynamic nature of the industry and environment in question. Winch and North (2006) further this argument, by highlighting that on-site management, must not only utilise, but also monitor the programme, particularly where spatial limitations emerge. Osman, *et al.*, (2002) provide additional weighting to the argument, by suggesting that dynamic programming is essential, particularly where site layout plans are in review. Therefore, based on the arguments of the participants, those in the literature and in addition to the quantitative data, this suggests that this construct is of primary importance in the strategic management of materials on a confined construction site.

Effective Communication & Delivery (PMSb)

The second construct incorporates four factors, again all of which are highly correlated (≥ 0.7) and with significant regression weighting ($\beta=0.95$), each of which represents 90% variance in this construct. Again, the aspect of the effective communication required by management is essential, this affirms that communication, although important in all aspects of construction, is eminently more significant in the delivery and allocation of material on-site. It is reasonable to assume, based on the quantitative data outlined, that where on-site management proactively engage and encourage effective communication and delivery of materials on-site, the issues that can emerge are mitigated or eliminated. Furthermore, this illustrates that through effective communication and delivery of materials, this can ultimately result in significant saving, in the time required by site management personnel.

This may be attributed to less rework, double handling, reorder and waste which can occur due to such issues (Love and Li, 2000; Formoso, *et al.*, 2002). Many of these points are also revisited by a number of the interviewees. In addition, correlation at 95% confidence interval emerges ($\rho=0.224$) compounding the fact that effective communication and delivery, ultimately results in a reduction in costs – a point noted by Blough (1983) and Ng, *et al.*, (2009), to name but a few. This illustrates that the findings are linked and affirmed by literature on the subject, further strengthening the benefit of this construct in the management of material on-site.

Interestingly, each of the interviews echo the importance of effective communication and delivery with regard to material management. This therefore provides further weighting to the importance of this construct, while also documenting its significance with regard to confined site construction. Dainty *et al.*, (2006) also provide additional argument to the point by documenting that communication is of paramount importance to both plant and material management.

Implement Site Safety Management Plans (PMSc)

The third construct for consideration incorporates three factors; ‘draft a method statement for high risk delivery of plant and materials to site’, ‘use a safe system of work plan in the management of plant and materials’ and ‘draft and employ a traffic management plan to aid in the movement of mobile plant’ with regression weights of $\beta=0.794$, $\beta=0.793$ and $\beta=0.730$ along with inter-correlation of $\rho=0.885$, $\rho=0.785$ and $\rho=0.797$ respectively. The questionnaire respondents indicate that these factors are used on a consistent basis, where the mean and standard deviation of 3.2 and 1.2 are recorded respectively. This illustrates that both the interviewees questioned, in conjunction with the questionnaire respondents, concur that this strategy is effective in the mitigation of material management issues on-site. Within this construct, all three factors allude to the importance of health and safety management – an aspect reiterated by the Health and Safety Executive.

This point is particularly accurate, due to the proven benefits on the implementation and sustained development of a health and safety culture on-site (Health and Safety Executive, 2004) with particular benefits introduced in the reduction of accidents due to moving plant on-site (Health and Safety Executive, 2011). The benefits of implementing each of the three factors within this construct are also documented throughout the qualitative analysis and discussion, with numerous interviewees not only acknowledging the importance of, but also the necessity in, implementing each of the strategies within this construct.

Proactive Spatial Monitoring & Control (PMSd)

The final construct encompasses the largest number of individual factors at seven. Each of the factors load above the minimum of 0.5, indicating that each factor contributes to the overall construct and thus the discussion at hand. The construct as a whole accounts for 85% of the variance, while also obtaining a mean score of 2.9 and a high standard deviation of 1.32; therefore indicating consensus from the questionnaire respondents, while achieving a high

overall weighting. This illustrates that proactive management is imperative in the coordination, monitoring and control of space in the management of materials on-site. Although important, the high percentage of variance explained by this construct further aids the validity and importance of this construct, while also illustrating the implication of the relationship of this construct and the underlying factors within.

Of interest, the importance of productivity relating to spatial monitoring is also discussed; a point iterated by Winch and North (2006) and Winch (2010), along with numerous interviewees throughout the course of this research. This aspect also resonates throughout the construction process, from spatial identification of the location of various aspects of the construction (Bernold, 2002) to the site layout (Sadeghpour, *et al.*, 2006) to workflow patterns (Tan, 2005) culminating in on-site management struggling to effectively manage in adverse site conditions. This can emphasise the need to implement such strategies, not only at management level, but throughout the site organisational structure present on a confined construction project (Makulsawatudom and Emsley, 2001).

Conclusion

Our urban centres, and as a result, the construction industry, is in a point of transition. The (re)development of urban located, spatially restricted, confined construction sites is quickly becoming the norm. However, research has shown, that in the management of on-site materials, an ad-hoc, intuitive approach is often adopted. In theory, this approach is satisfactory, but there is a need to identify, document and quantify the various approaches and underlying strategies one adopts when operating and managing an array of materials, in a spatially restrictive environment. Hence, the purpose of this research is to identify the core strategic themes on which on-site project managers, co-ordinate and control the distribution of materials on a spatially restrictive construction site.

To achieve this purpose, a sequential mixed methodology is applied using both qualitative and quantitative approaches. This includes a detailed review of the literature, with the subsequent inclusion of three case studies, to measure the actuality of the findings. To get a broader perspective of the industry, a detailed questionnaire survey is also employed, with the findings analysed. Results are scrutinised using structural equation modelling, to validate the proposed themes developed from twenty potential observed variables. The results conclude that four overarching strategic management themes emerge, relating to the effective logistical management of materials on a confined construction site; (1) Consult and review the project programme, (2) Effective communication and delivery, (3) Implement site safety management plans, and (4) Proactive spatial monitoring and control. Such work on material logistics and site management, fail to acknowledge the inherent difficulties of the management of these resources, where space is limited. Subsequently, it is possible to consider the findings from this study, where one finds themselves requiring additional management intervention, due to difficulties encountered as a direct result of a lack of space on-site.

It is therefore suggested that new management professionals exposed to managing complex projects within a spatially restrictive environment, acknowledge and apply the findings herein. Due to the pre-existing ad-hoc and initiative approach adopted by today's professionals within this environment, it is essential to conform to a more formal and systematic approach, in the strategic management of materials within a spatially restrictive environment. This is essential, particularly due to the adverse environment in which many urban projects are constructed, with the emphasis now on the redevelopment and growth within urban centres. It is also suggested that the findings, can be transferrable to other sectors, where spatial limitations are present. On a local scale, it is also worth investigating performance monitoring and evaluation that these results achieve; an aspect that was beyond the scope of this study. However, on a more global context, it is suggested that further research be undertaken in other geographical regions, to

identify if the results within, can be generalised and applied. Additionally, further developments in emerging and developing countries, suggest that further investigation into these sectors be undertaken, given the significant differences in the management and coordination of projects in these locations. However, in an academic context, this research fulfils a succinct but evident gap in knowledge within modern, developed countries, as demonstrated in the void of research on spatially restricted site logistics.

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