THE CRITERIA FOR IMPLEMENTING THE LEARNING CURVE THEORY ON CONSTRUCTION PROJECTS

ERNS HATTINGH
University of Pretoria, Department of Engineering and Technology Management, Graduate School of Technology Management, South Africa
erns.hattingh@gmail.com

CORNELIS C. VAN WAVEREN
University of Pretoria, Department of Engineering and Technology Management, Graduate School of Technology Management, South Africa
corro@up.ac.za

KAI-YING CHAN
University of Pretoria, Department of Engineering and Technology Management, Graduate School of Technology Management, South Africa
alice.chan@up.ac.za (Corresponding)

ABSTRACT

The desire to improve, gain knowledge and to better the quality and timing of construction projects delivered to clients has become an increased focus point in the field of construction management. Far too many construction projects run late, over budget, or are delivered to the client with an unacceptable low quality. Even though the client usually sees himself as the victim, the result might very well be due to unrealistic expectations set by the client, and possibly forcing those expectations down onto the contractor. The learning curve assumption is one such example of clients being the reason for the poor construction project deliverable they receive at the end. Clients often force the contractors into a shorter project schedule by using the learning curve reasoning as their basis of negotiations. This investigation set out to determine what criteria needs to be met in order for the learning curve to hold some form of validity in the world of construction projects. It asks if it is at all possible to use the learning curve theory, which is actually derived from the manufacturing industry, on construction projects. Based on the findings of this investigation, practical recommendations are made highlighting the concepts identified as critical for the successful application of the learning curve theory on construction projects. These identified concepts can be used as the basis of argument during negotiations between the client and the contractor on the length of the project schedule.

Key words: Learning curve; construction projects; South Africa; Delphi study

INTRODUCTION

Construction projects in Africa are at an all-time high. During the last 10 years, Africa in particular has opened its doors to foreign investment, and large multi-national companies are taking full advantage of the possibilities Africa holds. Construction projects are taking the lead in terms of investments, with mines, process plants, shopping centres, housing and infrastructure playing a big part in this economic upheaval. Companies are getting more involved in tendering for these large construction projects, and the market is very competitive in terms of price and schedule.

Although different construction projects are unique in their own way, there are still a large amount of repetitive work and similarities between a current project, and a past project undertaken by that same construction company. It is safe to say that construction projects are to a large degree, repetitive work. Too many project managers are forced to manage a project that has a reduced schedule and a limited budget, due to management and clients forcing a reduction of time and budget, based on the preconceived idea that the project must automatically finish earlier (or cheaper) due to the fact that a similar project has been successfully completed by the same company in the past. Many people are blinded by the fact that the learning curve exists and therefore assume each project with some sort of similarity with a past project will positively gain from the past learning. This assumption can have devastating effects on the outcome and successful completion of the project. The reason for this study is to determine to what degree the learning curve theory can be applied to construction projects even though no two projects are exactly the same. Projects might have some degree of similarity between them, but the ultimate deliverable will differ in some way or another.

Should it be possible to prove that the learning gained between two projects of similar nature, but not exactly matching the criteria learned through the research, are not enough to allow for a reduction in schedule or budget, companies will be in a better position to negotiate with clients during the tendering process. Clients usually choose companies with previous experience in that field to tender on their projects. For example, companies with a successful history in the construction of Electrowinning plants for copper extraction, are usually approached to tender on new projects that involve Electrowinning plants. The problem is that the client then negotiates a reduced schedule, based on the company's last successful construction of a similar plant. If it took the company 16 months to build a similar sized plant, the client will argue that due to the learning (see learning curve theory) the company has gained during that project, the current project schedule should be reduced to less than 16 months. That assumption is not entirely correct, and during this study, it will be determined which concepts within the project can be directly linked to the learning curve theory. Thus, what similarities are needed in order for the learning to be passed on from one project to the next? Can the learning curve theory be used to motivate reduced schedules and possibly budget on such projects?

Preliminary investigation suggests that various construction projects are based on some degree of repetitive work. The learning curve theory states that proficiency increases with experience. Yet, an increasing number of projects are over budget, over schedule or both. It is not clear to what extent the learning curve theory holds true for construction projects, in particularly the construction of any building, plant or structure where some form of repetition, previous learning and knowledge transfer took place. Can the learning curve theory be applied to construction projects in Africa, which in general are not exact repetition work, but still hold some degree of repetition from previous projects?

The objective of this research is to determine if the learning curve can in fact be directly applied to construction projects in Africa. The research will investigate the application of the learning curve theory on construction projects. The research will focus on the specific set of criteria that needs to match past projects, in order for a contractor to accept that the learning gained from a past project, can be applied to the new project, with the successful results.

In order to address this problem, the following research questions will need to be answered:

i. Are the role players in the construction industry aware of the learning curve theory in that industry?
ii. On construction projects, what set of criteria needs to correlate between current and past projects within the same company, in order for the learning curve theory to hold true?

In order to answer the above questions, it would need to be determined what items needs to be identical between two similar construction projects that will ensure that the “learning” that was gained on one project is passed over to the next project? (examples of possible similarities between projects that might lead to successful learning being passed over from project to project: Exact same project team, exact same geographical location of the project, exact same client, exact same scope of work, exact same deliverables, exact same risks, etc.)

LEARNING IN PROJECTS

The learning curve (LC) theory was first described in 1885 by Hermann Ebbinghaus, primarily in the field of psychology. But it was not until World War II that Theodore Paul Wright, described the effect of the learning curve on the aircraft manufacturing industry (Yelle, 1979). It was noted that the labour units required for the manufacturing of fighter aircraft decreased, as the number of unit of planes built, increased. This led to the realization that a certain amount of “learning” takes place with each aircraft manufactured. The people involved in the actual assembly learned how to assemble the aircraft in a quicker and more efficient manner. In addition, the support services implemented feedback received from the assembly line, making changes to designs, updating and correcting drawings and specifications, and in turn ensured that the assembly happens faster, without direct input. Up to now, the learning curve theory is used mostly on exact repetitive work, such as production lines and assembly lines in factories. The learning curve theory can also be described the relationship between experience and productivity.

The learning curve theory is the sum of three interrelated assumptions:

i. Each time a specific task is undertaken, the unit time that is required to do the task, decreases.
ii. The unit time is takes to complete the task, will decrease at a decreasing rate.
iii. This decreasing rate (or reduction in time), will follow a pattern that is largely predictably. (It can be graphed, and thus future predictions can be made from this graph).

Construction projects have a large degree of uncertainty involved, this due to the ever-changing political landscape, the undefined rules and regulations, unclear working conditions, poorly defined parameters and a unique business culture. Nevertheless, construction projects also have a certain degree of repetitiveness involved. In the mining and minerals processing industry, the areas within a plant are largely copies of previous plants built. The conveyors for instance, are in most cases identical in operation, apart from the lengths, height and belt width that might differ. Electrowinning plants used in Copper extraction are identical for certain amounts of ore deposits, and productions rate. The same is true for housing developments, even though the house plans and layout might differ, the foundation design and construction for single story houses are largely the same. Wall heights on single story houses are fairly standard and even an elementary item such as the fitting of a bathtub, remain a repetitive task. In each construction project, there is a certain amount of “learning” that takes place, even though the details are not exactly identical as in assembly or manufacturing plants. In the fast-tracked world of projects and project management, the client usually uses the learning curve theory to negotiate a lower price or decreased schedule with the contractor. The argument is that the project is largely based on some form of repetition from a past project, and therefore the contractor should "know how to do it by now". The contractors' price is renegotiated, and possible contingency is removed. The schedule is shortened; due to the client reasoning that, the contractor has already learned from their past mistakes, and should therefore complete the project with minimal contingency for mistakes. How much cheaper and faster the project needs to be done, remains unclear and usually ends up being indicated by the client. The learning curve formula of Wright can therefore not be used to determine or estimate the decrease time required to construct a project that is merely similar to a previous project.

Other terms for the learning curve includes "experience curve", "efficiency curve", "improvement curve", and "progress curve". These terms are used interchangeably although the term "experience curve" is generally also used to describe value added cost per unit, rather than hours or time per unit.

Learning curve theory

The view of Stump (2004), is that the learning curve theory can be applied to determine costs on construction projects when structures are repeated. This statement does not specify what is meant by repeated. What degree of duplication is needed to make the statement true? When looking at a further statement from Stump such as: "Learning curves are not applicable where there is no opportunity for increased efficiency", it can be assumed that construction projects are definitely under the direct influence of the learning curve. All projects have room for increased efficiency. Chase and Aquilano (1995:458), describes that the learning curve is based on some assumptions: That the time needed to complete a task will reduce each time the task is performed. The reductions in time can be predicted seeing that it will follow some sort of predictable pattern. These assumptions mentioned above are very valid. It does however not conclude what the criteria are for these assumptions to hold true in each individual circumstance.

Henderson (1984:3) believes that the use of learning curves has a significant risk of error, unless the true limitations and characteristics are understood. He goes further to state that even though the learning curve holds immense value, it has been applied and misapplied in the past. This view holds a lot of value, but does not go on to explain exactly how the learning curve should be applied to ensure relatively low risk of error. The misapplication and misconception of the learning curve has caused a loss of confidence in the whole concept, and thereby creating doubt into its usefulness. Henderson makes a valuable statement. It now has to be determined if this statement is also true on construction projects. This research focusses on misapplication of the learning curve theory and therefor will set out to discover the various means in which management misapplies the learning curve theory to lower project costs.

According to Hodder and Ilan (1986:229), production costs decline as experience increases. Clients that negotiate lower prices in so-called repetitive construction projects use this exact thought. This statement is however very broad, and does not look at the details of each project. Lilien (1982:51) also further states that: "the cost of doing a repetitive task decreases by a fixed percentage each time the quantity of the units produced, doubles". This fixed percentage is however not defined, and differs from product to product or project to project. The statement also assumes that the units produced are identical. What stands out is the general perception is that cost decreases every time the action is repeated. Apart from a reduction in cost, another considerable factor is that the time required to complete the specified task, action or project is also reduced (Stump, 2004). The reason for this can be that cost is directly related to the time it takes to complete the activity.

Factors influencing the learning curve

The learning curve theory has successfully been applied over the last 70 years to various industries including aeronautics, automobile, electronics, shipbuilding, petroleum, power generation and steel industries (Cunningham, 1980). Only the last 40 years has seen a gradual introduction of the learning curve into the construction industry. Until now, the learning curve has largely focussed on determining the contract pricing within a construction project. The learning curve has also been applied in situations where exact repetitive work is performed. An example of such repetitive work is the RDP housing scheme in South Africa. There, hundreds of small low-cost houses are built, all built to exactly the same building plan, with the same materials, the same crews and in the same location.

Thomas et al, 1986, made one of the most imported findings regarding the learning curve theory. It was found that the learning curve can only be applied to identical, repetitive and continues work. By just looking at this statement in isolation it can be argued that the learning curve cannot be applied to the majority of construction projects seeing that they are largely not 100% identical or repetitive work. Most projects are also not continuous, seeing that there is some sort of time lapse between the end of one project and the start of the next project. Just by looking at the continuation aspect, certainly some learning gets “lost” due to the time lapse that takes place. Projects are unique ventures that make use of standard repetitive processes. The more these processes are repeated, the more experience is gained and we expect the cost and required resources to decrease (Caruso, 2002:1).

Contractors in the construction industry do consider the learning curve theory when doing an estimate or tender for a new project. The contractor usually draws up a baseline project rate at the end of a project, looking at the number of actual hours spent to complete the work, and then files it along with other notes regarding the project, to use in future when doing a bid for a new project (Pellegrino et al, 2012). These notes will include items such as site conditions, names of the team member working on the project, records of work, etc. When a new project comes up, these notes are retrieved. The budget and schedule are then adjusted based on the amount of similarities that exists between the past and future project. If there is an exact repeated task, the contractor will know that a noticeable improvement in efficiency can be expect. How to quantify this improvement is still a big challenge to any contractor, seeing that the improvement is based on the type of construction activity (Pellegrino et al, 2012). During some of the first studies on the learning curve in construction projects, conducted by Parker and Oglesby, 1972, is was noted that up to 10-30% improvement in productivity can be noted when repetitive construction tasks are performed. This improvement is based on the complexity of the tasks. Further studies revealed that that there is a significant positive effect on the efficiency of any construction activity, if that activity is repetitive in nature and conducted by the exact same crew (Pellegrino et al, 2012).

This research ties in with the findings of Thomas et al, (1986), which stated that the learning curve is only applicable to identical, repetitive and continues work. However, it does not answer the question of what criteria is needed in order for the contractor to assume that a certain amount of learning from a previous project can be applied to the current project. In other words, what criteria is needed to assume learning has taken place, and will be transferred, were the project was not 100% identical, and the continuation was broken. The effect of repetition in a construction project is undeniable, and not merely a theoretical idealisation, but the exact effect that repetition has on a construction project is not yet quantifiable (Gottlieb & Haugbølle, 2010). Independent concepts that improve the efficiency on project need to be investigated, and it further needs to be determined whether they are repetitive, continuous or identical factors as according to the findings of Thomas et al (1986).

Independent concepts that improve construction project efficiency

The current theory available on the learning curve deals with the mathematical or quantitative approach to the learning curve. The literature and theory does not deal with the qualitative approach to the learning curve. The learning curve clearly states the three important factors for the learning curve to succeed, being identical, repetitive and continuous tasks. And improved theory to this is needed, in which the three factors are broken down further, and from a quantitative perspective, identify what the important concepts are for a task to deemed repetitive, identical or continuous. A proposed example of this can be seen in Table 1:

Table 1: Proposed qualitative criteria describing the three learning curve factors

Identical:	*Identical project manager*
	Identical location
Repetitive:	*Same team constructing foundations of the same dimensions*
	Same team constructing the structure of the same size
Continuous:	*Time lapse of less than one week between projects*
	Time lapse of less than one month between projects

Seeing that the construction industry is a very large field, the theory will be narrowed down to construction projects of mineral processing plants within the African and South African context. In order to identify which concepts form part of the identified repetitive, identical and continuous factors, the research looked at general project management as well as real world input from the industry. Seeing that this research has direct links to project management and the way that project outcomes might be influenced, the Project Management Body of Knowledge (PMBoK) held some key inputs into possible concepts to consider for the successful application of the learning curve theory on construction projects in Africa. The PMBoK (2013) mentioned concepts throughout the document and the author identified 17 concepts that can have a direct impact on a project, should it change from one project to the next. These concepts are as follows:

i. Schedule
ii. Scope
iii. Quality
iv. Risks
v. Project specifications
vi. Location
vii. Communication protocol
viii. Stakeholders
ix. Project team
x. Project manager

xi. Client
xii. Project sponsor
xiii. Deliverables
xiv. Availability of suitable resources
xv. Contract methodology
xvi. Reporting and feedback
xvii. Organisational structure

The PMBoK construction extension (2007) also mentions several of the above concepts, but also has additional concepts identified as concepts that can have a direct impact on a project, should it change from one project to the next. These 7 concepts are as follows:

i. Time management
ii. Budget
iii. Procurement methodology
iv. Human resource management
v. Claim management
vi. Financial management
vii. Safety standards and management

Schwartzkopf (2004) commented on concepts that increased the productivity and efficiency within projects. Although not all of the concepts he mentioned will have a direct impact on the project should they change from one project to the next, the most likely concepts have been identified and are mentioned below:

i. Coordination of crew
ii. Engineering liaison
iii. Day-to-day management
iv. Material usage efficiency
v. Material delivery efficiency
vi. Construction methods
vii. Space for crews for work in
viii. Job familiarization
ix. Design

Pellegrino et al (2012) made a similar statement in terms of project efficiency, and the most likely concepts that will have a direct impact on the project should they change from one project to the next are listed below:

i. Size of construction crew
ii. Site management
iii. Storage area setup
iv. Weather

It is the opinion of the author that the following concepts are also very important and should they change from one project to the next, the outcome of the project can be impacted. These concepts were identified after discussion with various personnel actively working in the construction environment. These concepts are listed below:

i. Construction materials
ii. Construction sequence
iii. Construction tools available
iv. Repetition of work
v. Construction crew experience

A summary of these 42 concepts can be seen in Table 2. These concepts are listed in no specific order.

Table 2: Identified qualitative concepts having a direct impact on project learning curve outcome

Schedule	*Human resource management*
Scope	*Claim management*
Quality	*Financial management*
Risks	*Safety standards and management*
Project specifications	*Coordination of crew*
Location	*Engineering liaison*
Communication protocol	*Day-to-day management*
Stakeholders	*Material usage efficiency*
Project team	*Material delivery efficiency*
Project manager	*Construction methods*
Client	*Space for crews for work in*
Project sponsor	*Job familiarization*
Deliverables	*Design*
Availability of suitable resources	*Size of construction crew*
Contract methodology	*Site management*
Reporting and feedback	*Storage area setup*
Organisational structures	*Weather*
Time management	*Construction materials*
Budget	*Construction sequence*
Procurement methodology	*Construction crew experience*
Repetition of work	*Construction tools available*

In total, 42 concepts have been identified that can definitely have an impact on the possible successful application of the learning curve theory on construction projects in Africa. The possibility exists that several other concepts might be missed, and therefore the expert group taking part in this research will have the opportunity to add any concepts they feel are important. It is also not yet clear under which factor each of these concepts can be categorized, namely repetitive, identical or continuous factors and it is the purpose of this research to not only to categorize these concepts under the three factors, but most importantly to rank these concepts in order to determine which concepts are the most important for the successful application of the learning curve theory on construction projects in Africa.

CONCEPTUAL FRAMEWORK

From the literature review, it is clear that there is a large gap in the theory, with little to no focus on the qualitative approach to the three factors that is critical for the learning curve to be applied to the construction industry. The factors being that the tasks need to be identical, the tasks need to be repetitive and the tasks need to be continuous. With this in mind, the focus of this study is theory building. Using the existing theory to gather data and based on the results, introduce an updated or improved theory, method or model. The process follow is retroductive reasoning. No hypotheses are generated for this study, with the new theory or model being the primary outcome of the research.

Theories and models to be used for this study

The independent variables as indicated in Figure 1, is seen as the factors that were selected from previous research conducted, that the research will now manipulate in order to determine its effect on the problem being investigated. These independent variables are the three factors as identified by Thomas et al (1986), and include the *identical factors, repetitive factors* and *continuous factors* on the application of the learning curve theory. These factors are further broken down into concepts. These concepts are in fact the practical, qualitative criteria describing each factor, and the basis of the successful application of the learning curve theory on construction projects. The research will focus on how these three factors and their associated concepts typically apply to construction projects in general. By changing or manipulating the independent variables, the impact on the successful application of the learning curve theory on construction projects is noted. The three independent variables, with typical examples of each, can be seen below:

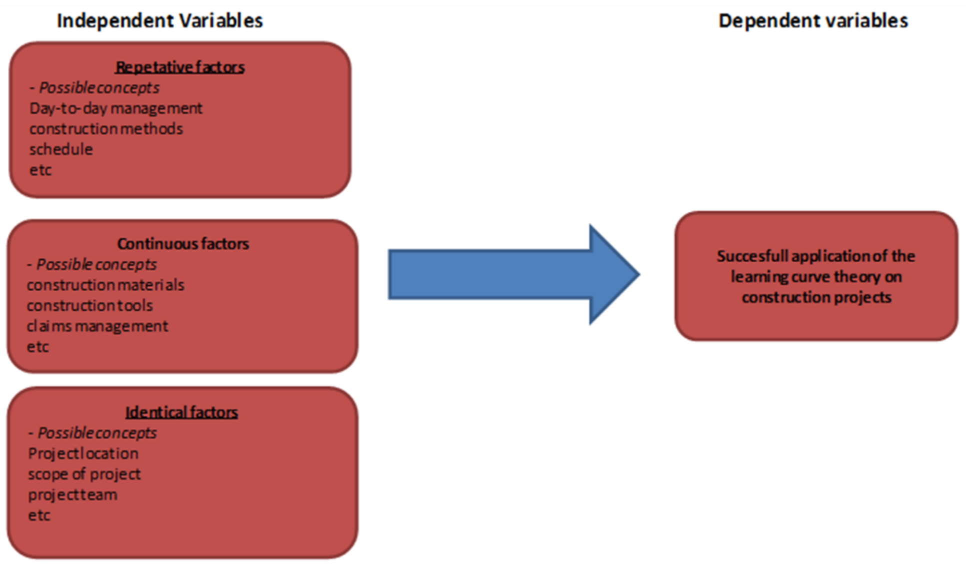

Figure 1: Conceptualized relationship between variables

The conceptual model followed during the research mainly focusses on the three independent variables (or factors) and their concepts, and its impact on construction projects. All within the realm of the identified problem statement, namely the successful application of the learning curve theory on construction projects in Africa. An objective approach is used to determine which important concepts form part of each individual factor. Once the important concepts are determined, the concepts are discussed, evaluated and categorized per factor, through means of a Delphi study. The purpose is to determine which concepts within each independent variable or factor are non-negotiable for project success, with the end result to successfully apply the learning curve theory to construction projects.

The three independent variables and their associated concepts are analysed and discussed from a qualitative reasoning point of view. During the specific investigation into the possibility of applying the learning curve theory to construction projects, each independent variable and its associated concepts has the possibility to verify or disqualify the application of this theory on project. From Figure 2, it is suggested that the successful application of the learning curve theory on construction projects will increase the possibility of overall project success. The exact effect is not explored during this research, but it is serves as a good basis for future research However, the process does not stop there. Knowledge transfer will need to take place, which in effect has an indirect link back to the independent variables. Without knowledge transfer, repetitive, identical and continuous momentum is lost. This leads to a breakdown of the theory in itself. Even though knowledge transfer is not specifically mentioned in the literature review, this forms an important cornerstone for the successful application of the learning curve theory on construction projects. It is assumed for the purpose of this research that organizational learning and knowledge transfer between project members, stakeholders and specifically within the said company, successfully takes place.

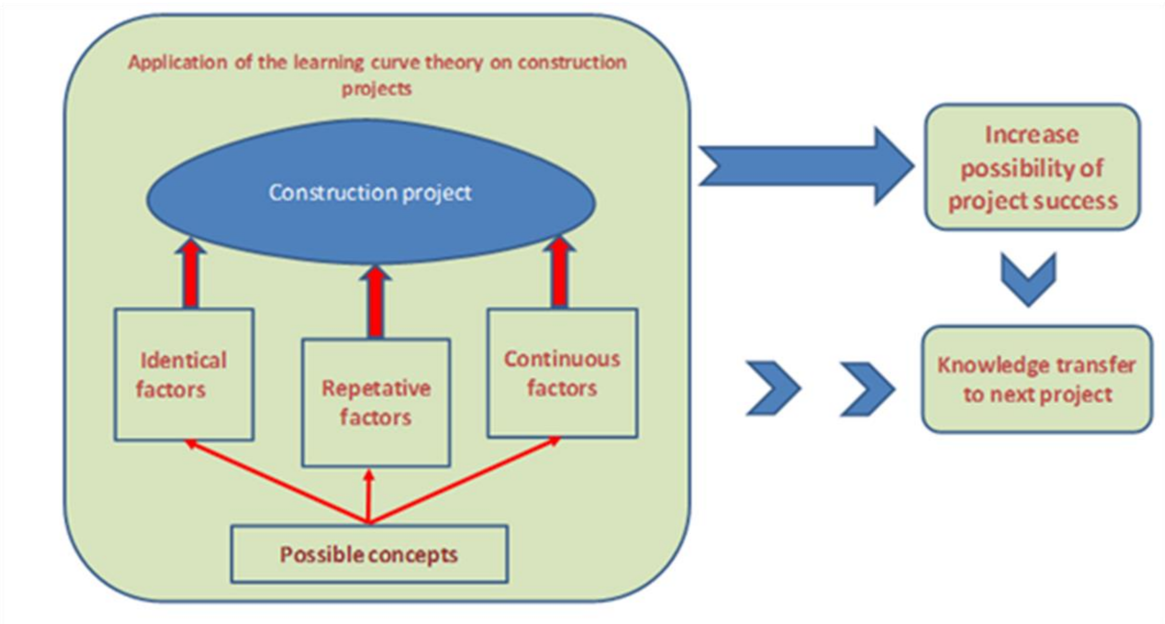

Figure 2: Conceptual method used to investigate the application of the learning curve theory on construction projects

The independent variables are studied to gain a better understanding of their impact on the construction project itself.

RESEARCH METHOD

The research was broken down into two separate stages, with the first stage being the investigation that explored, confirmed and categorized the concepts according to identical, receptive and continuous factors as noted during the literature study. Once the concepts were confirmed, the research went further into the second stage and ranked the identified concepts in order of importance. This article only highlights the results obtained during the first stage which was completed by doing a Delphi study.

Concept identification using the Delphi research technique

The purpose of using the Delphi research method for the data collection phase was to reach agreement about or test the concepts identified during the literature review phase as the main contributors to the successful application of the learning curve theory to construction projects. The secondary purpose was to categorise these concepts per critical factor (identical, continuous or repetitive), keeping in mind the objective of successfully implementing the learning curve to construction projects. The Delphi method allowed for in-depth investigative research in areas where there is a deficiency in the body of knowledge or where few other theories exist. With this method, existing theory was used to explain and understand different situations or scenarios pertaining to the specified problem. Theories from experts in the specific field of study were used and applied to situations and scenarios with a view to finding a solution to the research problem. The Delphi method is a group communication method whereby the opinions of panel members are converged (Linstone and Turoff, 2002). It is a flexible research method involving an iterative process for the collection and analysis of data. In accordance with this method, experts in the specific field within which the problem occurs are engaged with and the process is completed through a series of feedback loops to the experts. According to Adler and Ziglio (1996), the Delphi method is ideal for research where there is insufficient knowledge about the phenomenon or problem being studied. It also works well in a situation where the problem, solutions and/or opportunities need to be better understood. Linstone and Turoff (2002) regard the Delphi method as ideal for using the collective human intelligence of a number of experts to focus on and solve the problem at hand. In the Delphi method, specific questions are posed that focus on specific problems. After the questions have been sent out to panel experts and their feedback has been received, questionnaires are developed based on data collected from the previous rounds. Either the process ends when the problem has been solved or the questions have been answered or when sufficient information has been exchanged.

Linstone and Turoff (2002) gives a clear description of what the Delphi process entails. The Delphi process starts with the development of suitable research questions. These questions can stem from the researcher's own experiences in the industry or from the literature review that was conducted. The research questions then lead to the research design during which process the various research methods, including qualitative and quantitative methods, are evaluated and the advantages and disadvantages of the methods are compared. Both quantitative and qualitative methods can be used as part of the Delphi process. A researcher chooses the Delphi method specifically when the opinions, judgements and insights of experts are needed. After completing the research design, the sample to be used during the research is determined. Selecting the participants (the sample) is a critical step in the research process because their opinions are used for the output of the Delphi method. In the first round of the Delphi technique, use is made of questions that have been compiled well and thought through well. The participants need to understand the questions because incorrect understanding will be detrimental to the results of the research. The first-round questions consist of both open-ended and closed-ended questions. The purpose of these broad questions is almost to create a brainstorming session and to get the participants to think outside of the normal parameters. As soon as the results of the first round are returned to the researcher, the information is analysed. The analysis can include coding or statistically summarising the information. The results of the first-round analysis are then sent back to each participant, along with the same basic first-round questions. The second questionnaire is based on the findings or results obtained from the first round. This creates the opportunity for the researcher to better direct the focus of the research. Alternatively, the researcher is steered by the answers or opinions of the participants. The purpose of Round 1 is to create a list that can be analysed, paired down or ranked in Round 2. The questions posed in the different rounds can include open-ended, closed-ended, quantitative and qualitative questions. The Delphi process can continue to a third, fourth or possibly fifth round, depending on the complexity of the research. Each round follows the same principles as described above. Consensus and convergence of answers usually appear during the third round (Jacobs, 1996). Generally, the questions in the subsequent rounds become more focussed. After the final round's results are returned, the researcher needs to generalise and verify the documented results.

From the above description it can be deduced that there is no typical Delphi study or method. Each and every Delphi study needs to be modified to suit the specific research and circumstances at hand. In the current study, the Delphi questionnaire was distributed electronically by means of an innovative web-based programme. This programme required the selected group of experts to access the questionnaire via a web page in order for each respondent to complete the survey anonymously. The hyperlink to the web page was distributed by the researcher to each individual respondent via e-mail. It was possible to monitor all responses electronically throughout the process. The programme allowed respondents to start and complete the survey at any time. It also recorded all of the responses in a central database. Reminders were sent to the respondents via e-mail. An overview of the study objectives was provided to the respondents at the start of the questionnaire and great emphasis was placed on the confidentiality of the information provided. All respondents were requested to answer an informed consent question at the start of the questionnaire to make sure they understood that their participation was voluntary.

Delphi survey research technique

The size of a panel or an expert group is not cast in stone. Researchers have different opinions about the size of a Delphi study group, and recommendations range from 4 to 171 experts. Delbecq et al (1975) recommend that the panel size should be kept to a minimum and that the results should rather be verified through follow-up studies and explorations. There is no agreement in the literature about the optimal number of participants. Delbecq et al (1975) are of the opinion that 10 to 15 participants are sufficient if their backgrounds are homogeneous. Although group error is reduced as the sample size increases, there is a point where data analysis becomes cumbersome and the value added by more data is marginal. At this point, the study is no longer cost-effective. For the current study, a minimum expert panel size of 10 was selected due to all respondents being project managers and thus having a homogeneous background for the purpose of this study. In order to maintain the rigour of the Delphi technique, a response rate of 70% was desired (Hasson, Keeney & McKenna, 2000). To have at least 10 respondents in the final round, at least 20 experts had to be approached to participate in the survey so that at least 10 respondents took part in each round.

Qualifications of an expert: It can be agreed that the participants should be quite competent in the field of knowledge relating to the problem being researched (Adler and Ziglio, 1996). For this reason, companies specialising in the construction of mineral processing plants in Africa or South Africa were contacted to obtain the contact details of their project managers. Based on the above criteria, experts were chosen and contacted to serve on the panel. Only project managers with more than 15 years' experience in EPCM type construction in the African or South African mineral process plant construction industry were deemed suitable to act as experts in the Delphi method data collection process.

Sampling: A purposive sample was required for the Delphi study. The participants were selected based on their knowledge and expert ability to understand and answer the research questions posed. In other words, the sample was not chosen to be representative of the general population but of a specific group of experts.

Hsu and Sandford (2007) recommend that a sample should be chosen from the following groups:

- Top management or decision-makers
- Professional staff members
- Any other person whose judgement is specifically sought after

The purposive sample of experts chosen for this study consisted of project managers (past or present) employed by active construction companies and project houses specialising in EPCM contracting methodologies in the South African and African mineral processing plant construction industry. The experts all had tertiary qualifications and were actively involved in the day-to-day project management of construction processes. All the experts were willing to participate. Gender or race did not determine selection. All the panel experts were proficient in English.

Data collection: The Delphi method is well suited to capture qualitative data and it is a structured process in which various research methods, such as quantitative, qualitative and mixed methods, can be used. Electronic communication was selected as the preferred medium. Although the use of printed questionnaires for completion by hand was an option, this method was deemed to be out of date and time-consuming. Electronic mail and communication have a much faster turnaround time, and this in turn helps to keep the motivation and participation alive. Another advantage of electronic mail and communication is that feedback and data are available immediately in electronic format, which eliminates the data transcription phase, thereby saving further time.

Data collection procedure: Questions in the form of a simple questionnaire were chosen as the primary data collection instrument for the Delphi study. The researcher distributed the web page hyperlink to each individual respondent via e-mail. The first-round data was collected and evaluated within about one week, and the same turnaround time could be maintained for the second and third rounds. An electronic survey was created using a web-based survey programme and the link to it was forwarded via e-mail to the individuals in the expert group. Clear instructions on answering the survey were given in the e-mail as well as in the introduction to the survey.

First-round questions *A Delphi study usually* starts with open-ended and closed-ended questions in the form of a simple questionnaire that solicit certain information from the respondent group (Custer, Scarcella & Stewart, 1999). Once the feedback information has been collected, the researcher converts panel experts' responses into a structured questionnaire. In the current study, the structured questionnaire was used as the survey instrument during Round 2 of the data-collection process.

Questions in subsequent rounds: During the second and subsequent rounds, the expert panel was required to confirm the items or responses from the first round. This helped to establish the priorities or ratings of the first-round feedback and identify the areas of disagreement in the collected data. After each round, the expert panel received feedback in the form of a feedback section in the next questionnaire, which included the summarised ratings from previous rounds. The expert panel had the opportunity to revise the judgements they made in the subsequent rounds. The number of Delphi iterations or rounds depended on the required degree of consensus that was expected from the research.

Validity: Watkins (2012:74) further explains that the validity of a research study is the degree to which the finding is a reflection of what is actually being studied and of what the reality of the situation is. Internal and external validity is also largely associated with the size of the expert group. Results obtained from a large group can be more convincingly verifiable. In the case of a small group, results should be verified through follow-up research (Delbecq et al, 1975). The criteria for reaching consensus between expert groups have been widely discussed. On the one hand, Broomfield and Humphris (2001) argue that a 70% agreement on a topic or item is needed between members to qualify as consensus, whereas McKenna, Hasson and Smith (2002) state that consensus has been reached when 51% of the panel members are in agreement. On the other hand, Williams and Webb (1994) argue that there should be 100% agreement about the items to qualify as consensus. For the purpose of this research, and because of the relatively small expert group, 70% agreement on an item or topic was accepted as the criterion for consensus.

The questions in the questionnaire were based on the findings in existing literature and the knowledge gained during the literature review phase. Content validity was ensured by using clear and simple language in the questions. The questionnaires were distributed simultaneously to the respondents. Each questionnaire contained clear instructions to prevent confusion or misunderstanding. As the participating experts had no knowledge about the other participants they could not discuss the questions among one another or influence another's opinions. All the experts who were approached to participate in this study agreed to do so.

RESULTS

Twenty experts were approached to participate in the Delphi survey. The numbers that participated in the different rounds were as follows:

i. Round 1
   a) Nineteen respondents took part.
   b) Seven responses were invalid.
   c) Twelve responses were valid for all the questions.

ii. Round 2
   a) Only the 12 respondents of Round 1 who had given valid answers were approached to take part in Round 2.
   b) None of the responses in Round 2 were invalid.
   c) Twelve responses were valid for all the questions in Round 2.

iii. Round 3
   a) Only the 12 respondents of Round 2 who had given valid answers were approached to take part in Round 3.
   b) Two of the Round 2 respondents did not take part in Round 3.
   c) None of the Round 3 responses were invalid.
   d) Ten responses were valid for all the questions in Round 3.

After Round 3, the convergence of answers indicated that consensus had been reached; therefore, no further rounds in the Delphi study were required.

Round 1: Criteria testing using the Delphi method

A complete analysis was performed of the results obtained in Round 1 of the Delphi study.

Questions 1 to 3 in all the three rounds covered the following aspects: The invited experts had received permission from their companies to participate in the Delphi study; their participation was voluntary; and they provided confirmation of their work experience. If they had answered no to any of the questions that required a yes answer, they could not continue taking part in the study. An additional question asking their familiarity with learning curve theory used in the fabrication industry is asked and majority of the experts on the panel were familiar with the learning curve theory.

Question 5 in the questionnaire askes: *The following concepts are identified as critical items for construction project success. Should these items change from one project to the next, the outcome of the project might be significantly influenced. Do you agree with each concept?*

At least 70% of the experts agreed that 38 of the 42 concepts mentioned were critical and could influence the outcome of a project. Broomfield and Humphris (2001) state that at least a 70% agreement on a topic or item is needed to indicate that consensus has been reached.

In order to give respondents the opportunity to add concepts that had not yet been identified in the literature but which they felt were critical for the successful application of the learning curve theory to construction projects, the following question was asked in the questionnaire as an open-ended question: *Can you name any other concept that you deem critical in order to successfully apply the learning curve theory to construction projects?*

The experts identified the following additional critical concepts:

i. Planning, monitoring and controlling
ii. Duration between projects
iii. Contractor/Client relationship
iv. Using the same supplier/fabricators
v. Managing expectations
vi. Pre-fabrication of material
vii. Team dedicated to one project only
viii. Material delivery sequence

These newly identified concepts were then included in rounds 2 and 3, giving the respondents the opportunity to rate these concepts as well.

For linking the criteria to certain factor, Question 7 in the questionnaire asks: *Based on the given definitions, please rate each identified concept as either an identical, repetitive or continuous factor. (The definitions for continuous, repetitive and identical factors as cited earlier in the text were given to the respondents to assist in answering Question 7.)*

With reference to the statement of Broomfield and Humphris (2001) that consensus has only been reached when at least 70% of the members on a panel are in agreement about a topic or an item, it is found that in Round 1 no consensus was reached on the rating of any of the 42 concepts mentioned to the factors. In conclusion it can be said that the results of the first round of the Delphi survey in terms of relating to factors were inconclusive.

Round 2: Criteria testing using the Delphi method

A complete analysis was performed of the results obtained during Round 2 of the Delphi study.

The eight additional concepts identified in Round 1 were incorporated into Round 2 so that the respondents had the opportunity to rate these concepts as well. That brought the total number of concepts to be evaluated to 50. In this round, 46 of the 50 concepts were agreed upon by at least 70% of the experts as the critical items that will change the outcome of the project should these items change from one project to another.

For associating the concepts to factors, from Round 2 it became clear that the answers started to converge. Of the 50 concepts, only 11 of the concepts were classified and agreed upon by 70% or more of the expert panel. These concepts were:

i. Project specification – Identical factor
ii. Location – Identical factor
iii. Weather – Identical factor
iv. Construction tools available – Identical factor
v. Quality – Identical factor
vi. Space for crews to work in – Identical factor
vii. Efficiency of material delivery – Identical factor
viii. Repetition of work – Repetitive factor
ix. Stakeholders – Continuous factor
x. Procurement methodology – Identical factor
xi. Safety standards and management – Identical factor

Round 3: Criteria testing using the Delphi method

The eight additional concepts identified in Round 1 were again incorporated into this round, and the respondents had the opportunity to rate these concepts as well. That brought the total number of concepts to be evaluated to 50. It was indicated in Round 3 that 50 out of the 50 concepts were agreed upon by at least 70% of the expert panel. Broomfield and Humphris (2001) state that for consensus to be reached, 70% of the members of a panel should agree on a topic or an item. It can, therefore, be noted that consensus was reached on 100% of the identified concepts. These concepts are believed to have significant influence on project should they change from one project to another.

For associating the concepts to factors, it was indicated in Round 3 that the answers converged. Of the 50 concepts, 35 of the concepts were classified and agreed upon by 70% or more of the panel of experts. These concepts were:

i. Project specification – Identical factor
ii. Project team – Identical factor
iii. Project manager – Identical factor
iv. Client – Identical factor
v. Location – Identical factor
vi. Weather – Identical factor

vii. Scope – Identical factor
viii. Organisational structure – Identical factor
ix. Deliverables – Identical factor
x. Risks – Repetitive factor
xi. Schedule – Repetitive factor
xii. Budget – Identical factor
xiii. Construction sequence – Repetitive factor
xiv. Construction tools available – Identical factor
xv. Construction methods – Repetitive factor
xvi. Availability of suitable resources – Identical factor
xvii. Quality – Identical factor
xviii. Communication protocol – Repetitive factor
xix. Space for crews to work in – Identical factor
xx. Day-to-day management – Repetitive factor
xxi. Job familiarisation – Identical factor
xxii. Engineering liaison – Repetitive factor
xxiii. Efficiency of material delivery – Identical factor
xxiv. Storage area setup – Repetitive factor
xxv. Repetition of work – Repetitive factor
xxvi. Procurement methodology – Identical factor
xxvii. Human resource management – Identical factor
xxviii. Financial management – Repetitive factor
xxix. Safety standards and management – Identical factor
xxx. Duration between projects – Continuous factor
xxxi. Contractor/Client relationship – Identical factor
xxxii. Using the same suppliers/fabricators – Identical factor
xxxiii. Pre-fabrication of material – Identical factor
xxxiv. Team dedicated to one project only – Identical factor
xxxv. Sequence of material delivery – Identical factor

Taking the statement of Broomfield and Humphris (2001) into account that, for consensus to be reached, 70% of the members of a panel should agree on a topic or an item, it can be noted that consensus was reached on the 35 concepts mentioned above.

Analogies drawn from the Delphi survey data

In Round 3, there was a total number of 10 valid responses. In this round it was clear that answers were converging and that no further rounds were required. More than 70% of the expert panel agreed that it was critical for all 50 of the identified concepts to remain the same in order for the learning curve to be applied to construction projects. As far as classifying the identified concepts as either a repetitive, identical or continuous factor was concerned, consensus was reached on 35 concepts. In respect of another 14 concepts there was majority agreement among the expert panel members, and only one concept could not be agreed on at all. Due to the relatively small expert panel size, it is recommended that the results should be verified through follow-up research (Delbecq et al, 1975).

CONCLUSIONS AND RECOMMENDATIONS

Fifty concepts (see Table 3) were identified during the literature review and the Delphi study as relevant and valid concepts that had to be the same between two projects in order for the learning curve theory to be applied to construction projects.

Table 3: Fifty critical concepts for learning curve application to construction projects

Project specifications	*Job familiarisation*
Project team	*Coordination of crew*
Project manager	*Engineering liaison*
Client	*Efficiency of material usage*
Location	*Efficiency of material delivery*
Weather	*Construction crew experience*
Scope	*Storage area setup*
Design	*Repetition of work*
Project sponsor	*Site management*
Organisational structure	*Size of construction crew*
Deliverables	*Stakeholders*
Risks	*Time management*
Contract methodology	*Procurement methodology*
Schedule	*Human resource management*
Budget	*Claim management*
Construction materials	*Financial management*
Construction sequence	*Safety standards & management*
Construction tools available	*Planning, monitoring and controlling*
Construction methods	*Duration between projects*
Availability of suitable resources	*Contractor/Client relationship*
Quality	*Using the same suppliers/fabricators*
Communication protocol	*Managing expectations*
Reporting and feedback	*Pre-fabrication of material*
Space for crews to work in	*Team dedicated to one project only*
Day-to-day management	*Material delivery sequence*

The Delphi survey confirmed that the 50 identified concepts are in fact critical concepts for the successful application of the learning curve theory to construction projects. All of these concepts need to be the same or have at least a high degree of similarity between two projects in order to stand any chance of decreasing a project schedule. Furthermore, the expert panel classified the concepts as either an identical, repetitive or continuous factor. Of the expert panel, 70% or more agreed on the following concepts (see Table 4):

Table 4: Factor classification from Delphi study (at least 70% agreement)

Identical factors	***Repetitive factors***	***Continuous factors***
Project specification	*Risks*	*Duration between projects*
Project team	*Schedule*	
Project manager	*Construction sequence*	
Client	*Construction methods*	
Location	*Communication protocol*	

Weather	*Day-to-day management*	
Scope	*Engineering liaison*	
Organisational structure	*Storage area setup*	
Deliverables	*Repetition of work*	
Budget	*Financial management*	
Construction tools available		
Availability of suitable resources		
Quality		
Space for crews to work in		
Job familiarisation		
Efficiency of material delivery		
Procurement methodology		
Human resource management		
Safety standards & management		
Contractor/Client relationship		
Using the same suppliers/fabricators		
Pre-fabrication of material		
Team dedicated to one project only		
Sequence of material delivery		

The concepts identified were classified under the three factors (identical, repetitive and continuous) that Thomas et al (1986) have identified as necessary for the learning curve theory to hold true. Other aspects relating to the theory of Thomas et al (1986) about the classification of concepts have no further relevance to the current research.

It must be noted that in order for the learning curve theory to be successfully applied to construction projects, all 50 identified concepts need to be valid. In practise, the possibility of having all 50 concepts identical to a previous project are very slim. Further research will be required in order to identify the top 10 most important concepts. This can be done through the use of a mean ranking survey to determine the level of importance of each concept. Research can then also elaborate on the exact impact of each individual concept on the successful implementation of the learning curve theory on construction projects.

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