

Measuring the Performance of Construction Firms, using Data Envelopment Analysis

Dr. Bassam Hassan *
Dr. Jamal Omran**
Rana Maya***

(Received 17 / 12 / 2007. Accepted 30 / 6 / 2008)

□ ABSTRACT □

Our attempt in this paper is to develop a performance benchmarking system for construction firms. This is widely known as one of the first steps in any improvement process. We use the Data Envelopment Analysis model (DEA), which is a recognized modern approach to the assessment of performance of organizations and their functional units.. It accomplishes this by identifying overall performance through benchmarking economical, technical, environmental, and social performance for construction firms. The benchmarking model is developed using field data collected from 37 Syrian construction firms. The analysis using the DEA software seems to show that 29 of the 37 firms are functionally inefficient, and provides each firm with projected values .This model can be used as an improvement tool to help guide firms in understanding how to adjust their policies and practices to improve their overall performance.

Keywords: benchmarking performance, linear programming, Data envelopment analysis.

* Professor, Department of Construction and Management Engineering, Civil Engineering Faculty, Tishreen University, Lattakia, Syria

**Associate professor, Department of Construction and Management Engineering, Civil Engineering Faculty, Tishreen University, Lattakia, Syria

***Postgraduate Student, Department of Construction and Management Engineering, Civil Engineering Faculty, Tishreen University, Lattakia, Syria

قياس أداء الشركات الإنشائية باستخدام تحليل مغلف المعلومات

الدكتور بسام حسن*
الدكتور جمال عمران**
رنا ميا***

(تاريخ الإيداع 17 / 12 / 2007. قُبل للنشر في 30/6/2008)

□ الملخص □

حاولنا في هذه الورقة تطوير نظام لقياس الأداء في الشركات الإنشائية؛ إذ عرف بشكل واسع أن القياس واحدة من الخطوات الأولى في أي عملية تحسين .
قمنا باستخدام موديل التحليل المعتمد على مغلف البيانات *Data envelopment analysis (DEA)* الذي يعد منحنى حديث لتقييم أداء المنظمات ووحداتها الوظيفية، يتميز الموديل بتجاوز قصور الموديلات السابقة بقدرته على تحديد قيمة الأداء الكلي من خلال التقييم الاقتصادي الفني البيئي والاجتماعي للمؤسسات الإنشائية.
لقد طور النموذج باستخدام معطيات حقلية جمعت من 37 شركة إنشائية في سوريا وأظهرت نتيجة التحليل باستخدام برنامج *DEA* أن 29 من هذه الشركات تعمل بعدم فاعلية، وأظهر البرنامج القيم المخططة التي يجب أن تعمل على تحقيقها هذه الشركات حتى تصبح فعالة.
يتميز الموديل باستخدامه كأداة للتحسين؛ إذ يدل الشركات على كيفية تعديل سياساتها وتقنياتها لتحسين أدائها الكلي.

الكلمات المفتاحية : القياس المقارن للأداء ، البرمجة الخطية ، تحليل مغلف البيانات

* أستاذ - قسم هندسة وإدارة التشييد - كلية الهندسة المدنية - جامعة تشرين - اللاذقية - سورية.
** أستاذ مساعد - قسم هندسة وإدارة التشييد - كلية الهندسة المدنية - جامعة تشرين - اللاذقية - سورية.
*** طالبة دراسات عليا (دكتوراه) - قسم هندسة وإدارة التشييد - كلية الهندسة المدنية - جامعة تشرين - اللاذقية - سورية.

Introduction:

It's widely recognized that, in the long term, the success of both individual construction firms and the industry will depend on improving performance by continually acquiring and applying new knowledge. This will require a more comprehensive understanding of how existing practices can get better. Construction firms therefore recognize the need for benchmarking tools that provide perspectives on both their current practices and existing shortcomings versus industry leaders.

Benchmarking aims at comparing the performance of firms relative to each other. It also aids in the identification of the industry leaders that exhibit superior performance, due to their best industry practices. (Camp 1989,1998) view benchmarking as a positive, proactive process to change operations in a structured fashion .Camp (1989) divides benchmarking into two parts as shown in Figure -1-: practices and metrics. Practices are defined as the methods that are used; metrics are the quantified effect of installing the practices. Camp (1989) indicates that management, commitment, organization, communication and employee participation are essential to the benchmarking process, and that the sum of these actions is what leads to superior performance. The Construction Industry Institute (CII) adopts the following definition of benchmarking (Hudson, 1997): a systematic process of measuring one's performance against results from recognized leaders for the purpose of determining the best practices that lead to superior performance when adapted and implemented. In spite of the increased interest in performance improvement in Syria in recent years, there have been no serious attempts to create and apply benchmarking systems or models as a tool to improve performance. This has led us to research existing benchmarking models in an attempt to develop a new performance benchmarking model, a model that is both convenient and can be used as an improvement tool for managers with their current practices, and to help improve future performance and be capable of guiding the Syrian construction industry towards more efficient and effective performance.

Importance and Aims of this Research:

The interest in benchmarking performance started in 1979. The Xerox corporation initiated a process called competitive benchmarking to examine its unit manufacturing costs. Metrics in areas such as production costs, cycle time, overhead costs, retail selling prices, and product features were identified, and the performance of Xerox was ranked in relation to that of its competitors for those metrics. Xerox continued to develop the concept of competitive benchmarking through the 1980s by establishing formal training on the subject and introducing the concept to others. Other companies such as GTE, began to use the term as early as 1983, but it was not until the late 1980s that benchmarking really came into the public domain. (Spendolini, 1992) concludes that Xerox made it clear to the world that benchmarking is one of the keys to success. During the 1990s there had been considerable interest in benchmarking in manufacturing and other service industries. The successful implementation of benchmarking is reflected in the large number of publications which address the concept, application and limitations of benchmarking (Camp 1989), (Spendolini 1992), (McNair1992), (Macneil, J., Testi, J. 1994). As manufacturing has been a reference point and source of innovations in construction over the years, it is no wonder that construction researchers looked to benchmarking for guidance to measure construction performance.

The ever-rising consumer requirements and expectations have increased demands for continually introducing improvements in the cost, timing, and quality of the construction output. As world competition intensifies, leading construction organizations throughout the world continue to be more active in enhancing their competitive position by improving their performance. Thus, setting new operating targets and standards for national markets is a must. This dynamic mechanism and well-known fierce national competition have raised the awareness of performance measurement (benchmarking) among the majority of construction organizations.

An exhaustive search of the published literature related to benchmarking was conducted by (Dorsch & Yasin 1998). The time frame for this study of published material spans from the appearance of the earliest benchmarking articles, in 1986, through the end of 1995; they found that:

(1) the quantity of practitioner-type articles greatly exceeds the quantity of academic articles related to benchmarking; and

(2) that the overall number of articles related to benchmarking has increased dramatically in recent years.

The growth in the benchmarking body of knowledge proved that benchmarking has the potential when utilized systematically to enhance organizational efficiency and effectiveness for organizations in both the public and private sectors

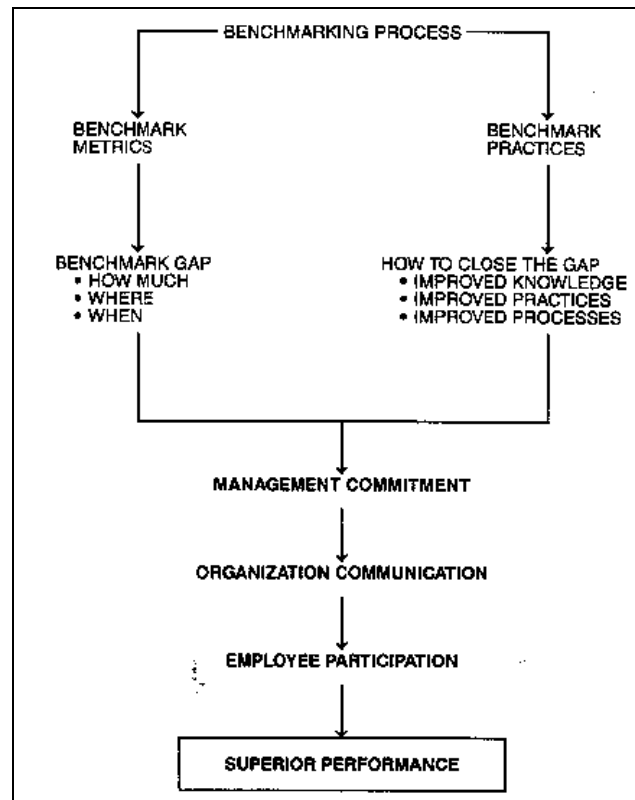


Figure - 1- Camp's generic benchmarking process. Source: Camp (1989)

Due to (Camp, 1989 ; Spendolini, 1992) There are five important benefits of benchmarking:

- More adequately meeting customer requirements.

- Establishing effective goals and objectives.
- Determining true measure of productivity.
- Attaining a competitive position.
- Becoming aware of and searching for industry best practices.

Constructing Excellence in the Built Environment is the organization leading the transformation of the UK construction industry by improving quality, cost, delivery and safety in the built environment. Through a range of tools focused on business improvement, performance measurement and knowledge dissemination, it recognized that the use of KPIs (key performance indicators) as an effective performance measurement system. This measurement system is well established in other industries but it is only in the last few years that the construction sector has looked to employ them. At that time, construction related organizations have benefited from using KPIs designed by Constructing Excellence and have realized what a powerful tool they are. (Dorsch, Yasin,1998) summarized the experience of many organizations. They showed that benchmarking, especially when used in association with total quality management and continuous quality improvement, is thought to have its place in today's business organization. Benchmarking is a multi-faceted technique that can be utilized to identify operational and strategic gaps, and to search for the best practices that would eliminate such gaps. (Halachmi, 2002a) offered an expanded list of reasons in support of introducing performance measurement as a promising way to improve performance, some of them include:

- if you cannot measure it you do not understand it;
- if you cannot understand it you cannot control it;
- if you cannot control it you cannot improve it;
- if they know you intend to measure it, they will get it done;
- if you do not measure results, you cannot tell success from failure;
- if you cannot see success, you cannot reward it;
- if you cannot reward success, you are probably rewarding failure;
- if you will not recognize success you may not be able to sustain it;
- if you cannot see success/failure, you cannot learn from it;
- if you cannot recognize failure, you will repeat old mistakes and keep wasting resources;

(Lee,Thomas,Richard,2005) recommended that measurement is one of the first steps in any improvement process. As a result, performance measurement is not just an optional choice to he improvement process that can be included if funds permit, performance measurement is the essential first step to any improvement process that is capable of enhancing the whole-life quality during the project lifecycle. This makes the development of a performance benchmarking model very important. Its goals should be to:

-Enable construction companies to benchmark their performance by providing overall performance that covers all required aspects of performance that are needed in a highly current competitive environment

-Allow for identification of practices that lead to a firms superior overall performance

Research Methods and Tools:

To achieve the aims of the research, we have followed the steps below:

- literature reviews about performance benchmarking and models

- the development of a performance benchmarking model by adapting one of the existing models to include Syrian construction companies needs and adding new current performance requirements
- applying the developed model to a random sample based on actual field data collected from 37 Syrian construction firms
- analyzing the data with DEA software

Benchmarking Models in Construction:

Adding to the complexity of the benchmarking task is the current industry structure and fact that a number of organizations get involved in the design and construction of a single project. Benchmarking only works if consistent methods of measuring the performance of operations can be developed and introduced. Due to the above stated facts, information on the performance of the construction industry as a whole is relatively scarce. There have been some initiatives concerned with the establishment of performance measurement systems for benchmarking in different countries, these are Fisher (1995), Hudson (1997) & CII (2000), CBBP(1998), SISIND (2000). They have proved that the benchmarking concept can be related and adapted to the unique working environment of the construction industry and they aimed to offer some guidance for performance measurement, provide some benchmarks that could be used by individual companies to establish their business goals and objectives, and to identify the best practices in the industry. Some of these models are listed below:

1. Fisher et al. (1995) Benchmarking Model

Fisher (1995) benchmarking model is probably the first notable benchmarking effort in the construction industry. They chose actual versus authorized cost, actual versus target schedule, actual versus estimated construction labor, and change orders versus original authorized cost (scope changes).

2. Hudson (1997) and Construction Industry Institute Benchmarking Model (2000)

Hudson (1997) performed his benchmarking study under the guidance of the Benchmarking and Metrics Committee (BM&M) of CII.. Hudson states the objective of his research as to mainly Establish a base set of metrics for systematic evaluation of project performance, Hudson's metrics were safety-health environment, schedule, cost, changes, rework.

3. Construction Best Practice Program Benchmarking Model (1998)

The Construction Best Practice Program (CBPP) benchmarking model is called the Key Performance Indicators (KPIs). The KPI framework consists of seven more groups: Time, cost, quality, client satisfaction, client changes, business performance, health and safety. For more information about indicators, you can see (KPI report,2000)

4. Performance Measurement System for Brazilian Construction Industry (SISIND)

The SISIND project was established in 1993 in Brazil. It is a performance measurement system (system of quality and productivity indicators for the construction industry). The SISIND project initially devised a set of 35 performance indicators for the residential and commercial building segment of the industry. Ten indicators have been

chosen by research team and industry representatives. They are : Cost deviation – time deviation – (non-conformity) index for critical processes- percentage of plane completed – supplier performance- degree of user satisfaction –sales time – ratio between the number of accidents and man total man-hour input – construction site best practice index – degree of internal client (workers) satisfaction. (Lantelme and Fromoso,2000)

Analysis of the Existing Construction Benchmarking Models:

The existing construction benchmarking models Fisher (1995), Hudson(1997)& CII(2000),CBBP(1998), SISIND(2000) that were discussed in the previous section fall short in two main respects:

- the existing benchmarking models report project-level industry norms of some performance metrics (i.e., cost, schedule, ..etc.). This not allows detecting overall performance of the firm. We have no means to answer the following question: Where does a certain firm stand compared to the other firms when considering overall performance (i.e., all metrics simultaneously)? (Towill 2001) stresses that it is important to emphasize that improvement in one business performance metric (say cost) must not be sought at the expense of another say quality or safety. For example, if quality performance has improved but our schedule performance has declined. How can one determine whether this trade-off is favorable or not favorable? That is, whether the overall performance is better or worse. It is important to show the relationship between the different measures from a holistic viewpoint to know if we have improved or not. This limitation also makes it difficult to identify practices that lead to superior firm overall performance, because with existing models we only have individual metrics. In order to know the overall performance we need to assign weights which may be arbitrary and subjective. Thus we will not get accurate values.

-With previous models, the relationship between expenses and the performance is absent. As two firms that arrive at the same performance are considered to be similarly efficient. And from economical point of view we have to consider the firm that commits fewer resources to arrive at a certain performance as a better performer than the firm that is spending more resources to arrive at the same performance. Construction firms need a model that provides perspective on its direction and rate of improvement. Existing models have serious limitations to guide the industry into both benchmarking and identifying practices of superior performance. As we can consider the performance superior when it is measured as certain overall value, here we guarantee that the improvement on one metric is not on expense of other one.Thus, a new benchmarking model was proposed by (EL-MASHALEH,2007). The proposed model is robust enough to address the limitations of the previous benchmarking models. The model provides an overall firm level performance measure and supports trade-off analysis among the several metrics of performance. Additionally, the proposed model relates the effort expended on the metrics of performance to the level of performance of those metrics and aids in the identification of management practices that lead to superior performance. The proposed benchmarking model is deployed using a technique called Data Envelopment Analysis (DEA), that evaluates efficiency which refers to the relationship between scarce factor inputs (project management expenses) and outputs (schedule, cost, costumer satisfaction, safety and profit). He used this relationship to evaluate efficiency in terms of physical output and cost. If we plan to identify and determine the best possible (optimal) combination of inputs to produce a given level of output, then we are talking about technological or technical

efficiency. On the other hand, if we want to determine the optimal combination of inputs that will minimize the cost of producing a given level of output, then we are talking about economic efficiency or cost efficiency. This kind of efficiency requires the availability of input prices.

EL-MASHALEH developed Technical Economic Benchmarking model that provides the firms overall performance. This model has been proven to be inefficient due to a several recent studies. New directions have to be considered in performance measurement, such as environmental and social efficiency. (Hendrickson and Horvath 2000) stated that construction projects pose enormous challenges to not only finish within an owner's schedule and budget, but to also eliminate and minimize harmful impacts to the environment. Although the topic of environmental management systems is fairly new to the construction industry, recent literature supports the need for construction firms to consider developing and implementing such systems. An increasing number of construction firms are becoming certified to international standards worldwide, especially the International Organization for Standardization (ISO) 14001 series, which provide guidelines for implementing an EMS. There are over 36,000 organizations in 112 countries that have received ISO 14001 certification (ISO 2001). Japan is leading the world with over 8,000 certifications. Construction firms are realizing that environmental management is a primary key to their success. They understand that it is imperative to eliminate or minimize harmful environmental impacts from construction. This will lead us to consider the environmental impact when benchmarking performance and the social benefit for construction sector in the Syrian government. The government stated at it's tenth fifth plan it's future vision for the construction sector. That within the next two decades the construction sector has to follow the national policy to achieve sustainable development and achieve its long term targets.

The quantitative targets as mentioned at tenth fifth plan for the Syrian government are :

- To achieve average yearly growth by 12%
- To contribute at creating working opportunities at high skills nearly (150000 working opportunity)
- To contribute at GDP (gross domestic production) to 2.6%

As such, a developed benchmarking model is proposed in the following that will cover all the required aspects of performance that are needed in the highly current competitive environment. The model will be aimed at benchmarking economical, technical, environmental, and social performance for construction firms.

Introducing Data Envelopment Analysis (DEA) Model:

DEA was initiated by, (Charnes 1978 and Rhodes 1981), based on the work of Farrell. Farrell (1957) proposed the notion of the structural efficiency of an industry. Structural efficiency is essentially a measure of the extent to which an industry tracks the performance of its own most efficient firms. It enables firms to assess their relative efficiencies compared to other firms in the industry. DEA is concerned with evaluation of performance and it is especially concerned with evaluating the activities of organizations such as business firms, hospitals, government agencies, etc.

In this section, the CCR model (Charnes - Cooper - Rhodes) of DEA is presented to demonstrate the technical details involved. DEA was accorded this name because of way it envelops observations in order to identify a frontier that is used to evaluate observations

representing the performance of all the entities that are to be evaluated. The term "Decision Making Units "(DMU) was therefore introduced to cover any such entity to be evaluated as part of a collection that utilizes similar inputs (i.e., resources, personnel, money, etc.) to produce similar outputs (i.e., sales, profits, customer satisfaction, metrics of performance, etc.) and this evaluations results in a performance score that ranges between zero and unity and represents the "degree of efficiency " obtained by the evaluated entity. DEA also identifies the sources and amounts of inefficiency in each input and output for every DMU. DEA utilizes mathematical linear programming to determine which of the DMU's under study form an envelopment surface. DEA owes its popularity to three inherent powerful features:

- It has the ability to incorporate multiple inputs and multiple outputs particularly when it is used in conjunction with linear programming. Linear programming can handle large numbers of variables and relations (constraints).
- DEA has no priority assumptions. There is no need to assign weights to the different inputs and outputs. The weights are derived directly from the data, freeing the user from arbitrary, subjective weightings.
- The measurement units of the different inputs and outputs need not be congruent. Some may involve the number of persons, areas of floor space, money expended, etc. The various scaling adjustments required for graphical purposes do not affect the relationships among the variables themselves in any way.

Example

This example illustrates the basic idea behind DEA as explained by (El-MASHALEH,2001) . Table -1- lists performance of 9 firms each with two inputs and one output. Input x1 is the number of employees (unit:10), Input x2 is the operating expenses (unit: \$100,000). Output y represents revenues (unit: \$1,000,000).

Table -1- DEA example

Firms	A	B	C	D	E	F	G	H	I
Number of employees (x1)	4	7	8	4	2	5	6	5.5	6
Operating expenses (x2)	3	3	1	2	4	2	4	2.5	2.5
Revenues (y)	1	1	1	1	1	1	1	1	1

Figure -2- plots the firms Input x1/Output y and Input x2/Output y as axes. From the efficiency point of view, it is natural to judge firms that use fewer inputs to get one unit of output as more efficient. We therefore identify the line connecting C, D, and E as the "efficient frontier." This frontier should touch at least one point and all points are therefore on or above (in this case) this line. Note that we can "envelop" all the data points within the region enclosed by the frontier line, the horizontal line passing through C and the vertical line through E, suggesting the name Data Envelopment Analysis.

The relative efficiency of firms not on the frontier can be measured by referring to the frontier point as follows. For example, firm "A" is inefficient. To measure its inefficiency, let OA, the line from zero to A, cross the frontier line at P. Then, the efficiency of A is to be evaluated by: $OP/OA = 0.8571$. This means that the inefficiency of A is to be evaluated by a combination of D and E because the point P is on the line connecting these two points. D and E are called the "reference set" for A.

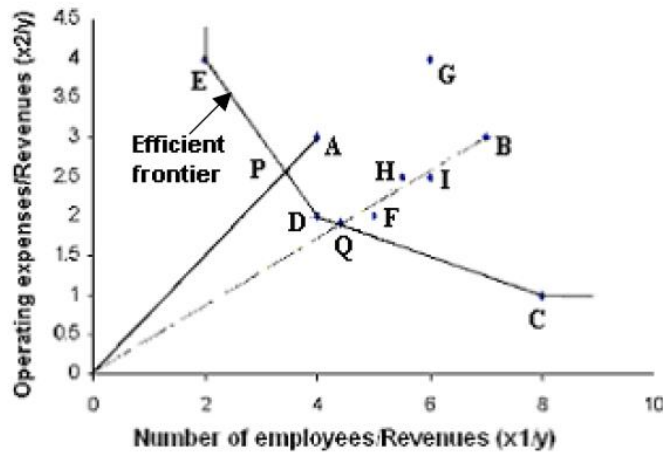


Figure –2- Firm's efficiency

The CCR¹ model will be used to benchmark the performance of construction firms. The following discussion is based on Cooper et al. (2006).

Suppose we have n DMUs with m input items and s output items. Let the input and output data for DMU j be $(x_{1j}, x_{2j}, \dots, x_{mj})$ and $(y_{1j}, y_{2j}, \dots, y_{sj})$, respectively. Therefore, the input data matrix X is an $(m \times n)$ matrix and the output data matrix is an $(s \times n)$ matrix. For each DMU, we form the virtual input and output by (yet unknown) weights (v_i) and (u_r) :

$$\text{Virtual input} = v_1 x_1 + v_2 x_2 + \dots + v_m x_m$$

$$\text{Virtual output} = u_1 y_1 + u_2 y_2 + \dots + u_s y_s$$

Since we measure the efficiency of each DMU once, we need n optimizations: one for each DMU j to be evaluated. Following the DEA literature, let us designate the DMU j to be evaluated on any trial as DMU $^\circ$ where $^\circ$ ranges over 1, 2, ..., n . We solve the following fractional programming problem to obtain values for the input “weights” (v_i) ($i = 1, \dots, m$) and the output “weights” (u_r) ($r = 1, \dots, s$) as variables.

(FP $^\circ$)

$$\max \quad \theta = (u_1 y_{1^\circ} + u_2 y_{2^\circ} + \dots + u_s y_{s^\circ}) / (v_1 x_{1^\circ} + v_2 x_{2^\circ} + \dots + v_m x_{m^\circ})$$

$$\text{subject to} \quad (u_1 y_{1j} + \dots + u_s y_{sj}) / (v_1 x_{1j} + \dots + v_m x_{mj}) \leq 1 \quad (j = 1, \dots, n)$$

$$v_1, v_2, \dots, v_m \geq 0$$

$$u_1, u_2, \dots, u_s \geq 0$$

The FP attempts to maximize the objective function θ , which is the ratio of “virtual output” to “virtual input.” The constraints of the FP mean that this ratio should not exceed 1 for every DMU. The resulted weights (v_i) and (u_r) from FP maximize the output to input ratio of DMU $^\circ$, the DMU being evaluated. From the constraints, the optimal objective value $\theta = \theta^*$ is at most 1.

The above fractional program (FP $^\circ$) is nonlinear. As such, linear programming can not be used to solve it. We therefore replace the (FP $^\circ$) with the following linear program (LP $^\circ$), which is called the Charnes-Cooper-Rhodes (CCR) model:

(LP $^\circ$)

$$\max \quad \theta = (u_1 y_{1^\circ} + u_2 y_{2^\circ} + \dots + u_s y_{s^\circ})$$

$$\text{subject to} \quad (v_1 x_{1^\circ} + v_2 x_{2^\circ} + \dots + v_m x_{m^\circ}) = 1$$

¹ For more information about DEA models you can see(COOPER, 2006)

$$\begin{aligned} (u_1 y_{1j} + \dots + u_s y_{sj}) &\leq (v_1 x_{1j} + \dots + v_m x_{mj}) \quad (j = 1, \dots, n) \\ v_1, v_2, \dots, v_m &\geq 0 \\ u_1, u_2, \dots, u_s &\geq 0 \end{aligned}$$

The objective function of the LP is to maximize θ , which reflects the output of DMU^o. The input of DMU^o was set as a constraint that is equal to 1. The other constraint indicates that the outputs of the rest of the DMUs do not exceed their inputs. Clearly, the optimal value of $\theta = \theta^* \leq 1$.

Let us suppose we have an optimal solution of (LP^o) which we represent by (θ^*, v^*, u^*) . We can then identify whether (DMU^o) is CCR-efficient or not as follows:

- (DMU^o) is CCR-efficient if $\theta^* = 1$ and there exists at least one optimal (v^*, u^*) with $v^* > 0$ and $u^* > 0$. This simply means that DMU^o is on the efficient frontier.

Compared to the rest of the DMUs, DMU^o effectively converts its inputs into outputs.

- Otherwise, DMU^o is CCR-inefficient.

In linear programming terminology, every LP has a counterpart that is called the dual. When taking the dual of a given LP, we refer to the given LP as the primal. If the primal is a maximization problem, the dual will be a minimization problem, and vice versa. The importance of the dual lies in its ability to provide additional economic insights. In our case, the dual enables us to determine all input excesses and output shortfalls. Based on the preceding discussion, the CCR-efficiency model was formulated as an LP problem with row vector v for inputs and row vector u for outputs. Both u and v are treated as variables in the following primal LP problem, which is presented in vector matrix notation:

$$\begin{aligned} \text{(LP}^\circ\text{)} \quad & \max \mathbf{u} \mathbf{y}^\circ \\ \text{subject to} \quad & \mathbf{v} \mathbf{x}^\circ = 1 \\ & -\mathbf{v} \mathbf{X} + \mathbf{u} \mathbf{Y} \leq 0 \\ & \mathbf{v} \geq 0, \mathbf{u} \geq 0 \end{aligned}$$

The dual problem of (LP^o) is expressed with a real variable θ and a nonnegative vector

$\lambda = (\lambda_1, \lambda_2, \dots, \lambda_n)^T$ of variables as follows:

$$\begin{aligned} \text{(DLP}^\circ\text{)} \quad & \min \theta \\ \text{subject to} \quad & \theta \mathbf{x}^\circ - \mathbf{X} \lambda \geq 0 \\ & \mathbf{Y} \lambda \geq \mathbf{y}^\circ \\ & \lambda \geq 0 \end{aligned}$$

Table 2 shows correspondences between the primal (LP^o) and the dual (DLP^o)

Table 2: Primal and dual correspondences. Source: Cooper et al. (2006)

Constraint (LP ^o)	Dual variable (DLP ^o)	Constraint (DLP ^o)	Primal variable (LP ^o)
$\mathbf{v} \mathbf{x}^\circ = 1$	θ	$\theta \mathbf{x}^\circ - \mathbf{X} \lambda \geq 0$	$\mathbf{v} \geq 0$
$-\mathbf{v} \mathbf{X} + \mathbf{u} \mathbf{Y} \leq 0$	$\lambda \geq 0$	$\mathbf{Y} \lambda \geq \mathbf{y}^\circ$	$\mathbf{u} \geq 0$

(DLP^o) has a feasible solution $\theta = 1, \lambda^o = 1, \lambda_j = 0 (j \neq o)$. Hence the optimal θ denoted by θ^* , is not greater than 1. To convert the above inequalities into equalities, we introduce the input excesses s^- and the output shortfalls s^+ and define them as “slack” vectors.

$$\begin{aligned} \text{(DLP}^\circ\text{)} \quad & \min \theta \\ \text{subject to} \quad & \theta \mathbf{x}^\circ - \mathbf{X} \lambda - \mathbf{s}^- = 0 \\ & \mathbf{Y} \lambda - \mathbf{s}^+ = \mathbf{y}^\circ \end{aligned}$$

$$\lambda \geq 0, s^- \geq 0, s^+ \geq 0$$

To discover the possible input excesses and output shortfalls, we solve the following two-phase LP problem:

$$\begin{aligned} & \text{(DLP}^\circ\text{)} \\ \text{Phase 1} & \quad \min \theta \\ \text{Phase 2} & \quad \min -s^- - s^+ \\ \text{subject to} & \quad \theta \mathbf{x}^\circ - \mathbf{X} \lambda - s^- = 0 \\ & \quad \mathbf{Y} \lambda - s^+ = \mathbf{y}^\circ \\ & \quad \theta \geq 0 \lambda \geq 0, s^- \geq 0, s^+ \geq 0 \end{aligned}$$

The objective of phase 2 is to find a solution that maximizes the sum of input excesses and output shortfalls while keeping $\theta = \theta^*$. An optimal solution $(\theta^*, s^{-*}, s^{+*})$ of phase 2 is called the max-slack solution. If the max-slack solution satisfies $s^{-*} = 0$ and $s^{+*} = 0$, then it is called zero-slack. If an optimal solution $(\theta^*, \lambda^*, s^{-*}, s^{+*})$ of the two LPs above satisfies $\theta^* = 1$, and is zero-slack ($s^{-*} = 0, s^{+*} = 0$), then the DMU^o is called CCR-efficient. Otherwise, the DMU^o is called CCR-inefficient.

DEA Applications for Performance Benchmarking:

Data Envelopment Analysis (DEA) is a recognized modern approach for the assessment of performance of organizations and their functional units. DEA spans the boundaries of several academic areas including management science, operational research, economics and mathematics. The theoretical development of DEA has been driven by numerous applications in various areas, including industry, agriculture and the public sector. A testament to the continuing success of DEA, is this volume comprising some of the papers presented at the 4th International Symposium of DEA, held at the University of Aston in Birmingham, UK, The 4th Symposium continued the successful series of previous DEA events: Wernigerode (Germany, 1998), Brisbane (Australia, 2000) and Moscow (Russia, 2002). The DEA can be used in different sectors with different end results, such as:

- Identification of the better managed and more innovative DMU (best practices)
- Creation of a competitive environment between the DMU in their sector, or even outside it, although they act in the form of natural monopoly
 - Establishing the key element in economic regulation
 - Analysis of the sector market structure, concerning the companies size, ownership (e. g. private versus public) and organization (e. g. verticalization and horizontalization).

There are a large number of papers that utilize DEA in performance benchmarking (Cooper, 2006) .

here are some of them displayed in construction field:

- Mohammad El-mashaleh & Willam j. o'brien & Kerry London(2001): They describe a conceptual approach to measure and compare productivity of resource utilization

- Rouse et al. (1997): This paper describes the application of Data Envelopment Analysis (DEA) to a highway maintenance setting, using measures of inputs, outputs and outcomes reported by New Zealand local authorities. A general framework of performance measurement is developed and illustrated .

- Rui Cunha Marques & António Jorge Monteiro (2004) : The aim is to apply one of the benchmarking techniques available, which is the data envelopment analysis for assessing the water and sewerage services organizations comparative efficiencies.

- Hjalmarsson and Odeck (1996): to measure efficiency of trucks in road construction and maintenance. The outputs were transportation work in kilometers per year, volume transported in cubic per year, effective hours in production per year

- Mohammad S. El- Mashaleh & R. Edward Minchin, Jr. & William J. O'Brien (2007)

The paper proposed benchmarking models using DEA. The proposed models allow construction firms to be evaluated on a company-wide basis and identify specific areas of improvement for individual firms.

Development of Performance Benchmarking Model:

The Data Envelopment Analysis model proved to be an appropriate tool to benchmark performance, so we chose it to utilize our research and to benchmark the performance of Syrian construction firms. To choose the metrics of the benchmarking model we reviewed the existing literature and included the relevant metrics. We found that the design of the performance metrics has been the subject of research for some time. Camp (1989) states that benchmarking is the mechanism to insure that customer needs are satisfied by industry practices, so they have to be determined from the basic mission of the organization or business unit. Camp argues that identifying what is to be benchmarked is often one of the most difficult steps in the process. Also, (Alarcón ; Serpell, 1996) interviewed people who were consulted on the objectives, benefits, and desirable characteristics of a performance measurement system, and on their own experience in the implementation of performance measurements. They expressed that a performance measurement system should have the following characteristics:

- Measurement parameters should be simple and limited in number.
- Definition of the system objectives should be clear and transparent.

Spendolini (1992) supports linking what is to be benchmarked to the Critical Success Factors (CSF) of a business, are the factors that have the greatest impact on the performance of the organization. The alignment of measures to the company strategies has been pointed out in the literature as a key point in the development, implementation and use of performance measurement systems. The findings of Neely (1999) indicate that the selection of measures aligned to the company strategies is an effective way to ensure that the chosen measures are the most appropriate. The extensive literature review enabled us to determine the performance metrics that give the best values and those that will form the basic elements of our performance model.

Performance Metrics:

From existing research we found that construction literature primarily concentrates performance measurement on basic indicators as: schedule, cost, quality, safety, profit and usually they are considered to develop the metrics of the firms overall performance. Since there are new international requirements of performance standards, and since we have some special circumstances in Syria as we previously referred to, we will add additional indicators to measure performance. Also, from our study and analysis during our visits to many projects we consider it very necessary and crucial to include the following metrics in our measurements: ratio of changes, environmental performance and social benefit, in order that we obtain a benchmarking model to measure economical, technical,

environmental and social performance. We have previously explained the importance of environmental performance as it has become an essential requirement during recent construction and also the importance of social benefit for public companies in Syria. We have found according to our previous research (2003), that there is usually a big ratio of changes occurring through the construction process and that these changes usually lead to many problems and delays. Most of changes are due to insufficient surveys and planning. It's necessary to give surveys and planning a top priority in regards to measurement. We must be able to measure it so that we can try and put policies together to try and eliminate the delays. We noticed from our literature review that there is not a big concern about changes and delays, as most countries have developed a standardized system for dealing with these changes and usually have no noticeable problems with changes. Below we display the metrics which we have selected for performance measurement and their calculations.. We measured benchmark performance of construction firms for the last two years.

1- Schedule Performance:

Percentage of the projects are delivered on/ahead of schedule without additional period

$SP = (\text{Number of projects delivered on/ahead of schedule} / \text{Total number of projects}) * 100\%$

2- Cost Performance :

Percentage of the projects are delivered on/under budget without additional costs

$CP = (\text{Number of projects delivered on/under budget} / \text{Total number of projects}) * 100\%$

3- Customer Satisfaction :

Percentage of repeated business customers

$CSP = \text{percentage of private customers that come back for a repeat business with the firm} + \text{percentage of public customer satisfaction}$

4- Safety Pperformance

Recordable incidence rate: $SAP = \text{number of recordable accidents} / \text{number of employees}$

5- Environmental Performance :

Commitment to international standards for environmental management ISO 14000

$EP = \text{percentage of commitment to ISO 14000 standards}$

6- Change in Scope of Work :

Percentage of change : $CWP = \text{cost of change} / \text{planned cost}$

7- Profit : Net profit after tax : $pp = (\text{Net profit after tax as a} / \text{total expenditure}) * 100$

8- Social Benefit :

$Sb1P = \text{The number of permanent employees which have health and security assurance}$

$Sb2P = \text{the value of annual executed projects by S.P}$

9- PM Expenses: the project management personnel salaries and expenses

We have also suggested measuring IT and employees insurance as expenses at the questionnaire but we have not been able to get complete information about them from respondents, so we have excluded them from analysis.

Customer satisfaction is measured in terms of the percentage of repeat business customers for the private sector, but for public customers there are not repeat customers because their contracts are usually bid so we evaluated there satisfaction depending on their opinions at the end of project. Due to the fact that this type of satisfaction is an

opinion this may include some subjectivity. In order to help public projects, we recommend that Syrian firms design special forms (as those followed used by international firms) to objectively and subjectively measure client satisfaction levels for all phases of a project. Safety performance is usually measured using OSHA incident rates which are based on the Occupational Safety and Health Act (1970), which requires employers to record and report detailed accident information. As most construction firms do not have accurate safety information, we calculated it as a previous formula ($SP = \text{number of recordable accidents} / \text{number of employees}$), but it's preferable when information is available to follow the OSHA guidelines. Environmental standards are defined in many publications like (ISO 2002). The ISO 14001 standard defines an EMS as "a management tool enabling an organization of any size or type to control the impact of its activities, products or services on the environment." The ISO 14001 establishes a framework for managing through the development of formal processes, procedures and the environmental aspects of an organization. The standard contains 17 key elements grouped into five major areas: environmental policy, planning, implementation and operation, checking and corrective action, and management review. A unique aspect of the system is that it is designed to be appropriate for any company, regardless of industry, size, location, and the level of their environmental responsibilities (ISO 1996).

We have selected a metric that measure the percentage of commitment upon these requirements for construction firms in our proposed model.

As for social benefit, all of us noticed that the last fifteen years we have witnessed the growth of large interest on public investment criteria for benefit-cost analysis for projects and programs in both developed and less developed countries. The criteria has been adjusted to allow for surplus labor, savings constraint and reinvestment benefit. Companies will generally have some direct benefits and costs that result from the goods and services they produce and the resources they use up. These goods and services and resources generally will involve market transactions. A company may also have external benefits and costs. These are the good things and the bad things that result from the projects and are imposed upon society rather than resulting from market transactions. This is the social benefit of projects. If a project is profitable usually it will also be socially worthwhile and it is possible that a project may have a negative profitability and still be socially worthwhile. Usually the social benefit concerns are in regard to income distribution among different categories in society and we can explain the social sides as follows:

- The effect on the creation of new job opportunities, number of job opportunities, percentage of employees
- The effect of income distribution to the limited income categories
- If the outcome is to serve the low income category

In our case, we have to be concerned, as we previously mentioned, with the Syrian governments strategy to allow for surplus labor in construction sector. So it is necessary to take this point into consideration when evaluating the companies outputs. Companies that employ permanent employees have important social outcomes including, but not limited to: workplace health and safety, employee retention, labor rights, human rights, wages and working conditions, Naturally will perform better in the scope of social benefit. By including the social benefit metric we align the measures of performance to the strategies which has been pointed out in the literature a key point in the development, implementation and use of performance measurement systems. This new indicator adds value to our developed model from previous proposed models as it considers The changing nature of work and the Changing organizational roles. Because rates of return on

social investment are hard to calculate and they include many standards which are out of the scope of this research, therefore we considered only two of its standards. They include: the number of permanent employees which have health and security insurance and the value of annual executed projects by S.P as this indirectly benefits the largest number of people.

Analysis of Results:

To measure performance, we designed a survey questionnaire that contains questions on the selected metrics explained above to quantify the performance of construction companies. We then applied it to a simple random sample that is of the best known probability sample where each member of the population has an equal probability of being selected. The data for this research was collected through a survey questionnaire of personal interview of respondents from firms in Damascus and Lattakia during 2007. Personal interviews need lots of effort, time and cost compared to other methods. We gathered information through a versatile and flexible direct communication with respondents, and the presence of an interviewer generally increases the response rate. A few of the interviewers were confused about some questions so we clarified matters related to the questionnaire, and thereby obtained the most accurate responses. We think that the personal interviews were the more effective way to obtain correct and complete information, and a relatively good response rate. If we had distributed the questionnaire to the employees without personal interviews we believe that they would not have responded in such a candid manner about their companies. Then we collected information about the firms overall performance. Firms are asked to supply their schedule performance, cost performance, customer satisfaction, safety performance, environmental performance, change status, profit, social benefit and expenses. Below we show the firms general information, the total number of respondents from each firm. There are 37 firms that execute yearly projects for more than 12,519 milliard SP. Only 1 firm is over 50 million SP, 2 are between 25-50 million SP, 6 are between 5-25 million SP, 15 are between 1-5 million SP, 5 less than 1million SP, and 8 gain no profit which has special positions as most of them are public firms, and in accordance to Syrian government strategies, as mentioned above, they have a social responsibility in provide working opportunities and to allow for surplus labor, so all their revenues come back to surplus employees. It is also worth mentioning that most of the respondents are not convinced by these ratios of profit, due to non systematic ways implemented in Syrian contracts. Also in the way the contractor is chosen and the obligation to decrease the price of labor in order to get the bid. This means that naturally there will be a decrease in the profit, which will reflect negatively on the quality of the projects, as said by respondents.

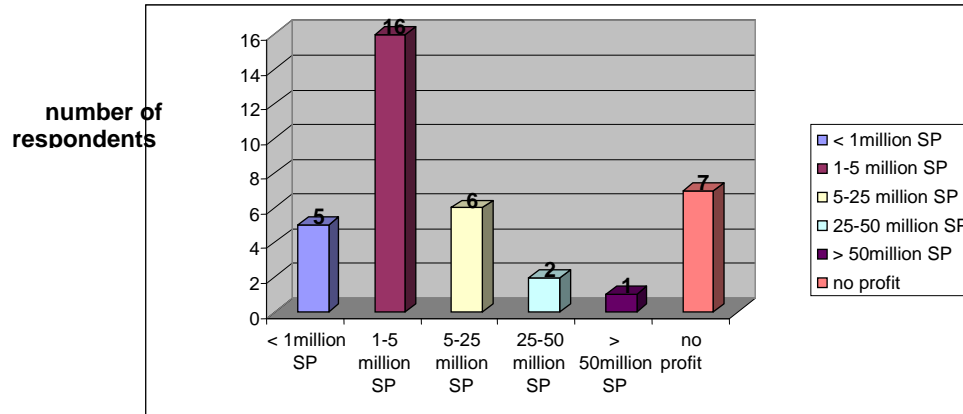


figure -3 -shows the respondents position by annual profit

We applied DEA model using DEA-Solver learning version LV3.0/ CCR(CCR-I) introduced by (Cooper; Seiford; Tone 2006) which is input oriented model as we collected data about the project management expenses as input, the learning version can solve problems with up to 50 DMUs, but for the professional version the problem size is unlimited in terms of the number of DMUs, and inputs & outputs items within the capacity of an excel worksheet and the main memory of PC. The DEA models named after the metrics of performance that each model includes, we will display the CCR model that includes all metrics of performance. The following analysis represents the data and benchmark firms. The analysis supplies inefficient firms with projected values for the metrics of performance. These projected values **can guide the inefficient firms to improve their performance to become efficient at all the measured metrics.** In the following table -3- there are the decision making units (DMUs) that are included in the CCR model with inputs and outputs, as the letter (o) refers to output and the letter (I) refers to input, **we coded them to keep confidentiality of firms.**

PM – project management expenses , **cs** per: costumer satisfaction performance, **S** per: schedule performance, **SA** per: safety performance, **E** per: environmental performance, **cw** per: change performance , **p** per: profit performance

C per: cost performance, **Sb** per: social benefit performance, **Sb2** per: social benefit

Notice: as we want in the model to increase outputs we put safety as $1/SA$ and the change performance as $1/CW$.

Table- 3- decision making units (DMUs) for the sample firms

firms	(I)PM EX %	(O)S PER %	(O)C PER %	(O)CS PER %	(O)1/SA PER	(O)E% PER	(O)1/CW PER %	(O)P% PER	(O)Sb PER	(O)Sb2 PER
A	7.5	100	10	50	105.26	0	0.02	15	10	20000000
B	3	100	70	70	1000	10	0.02	5	6	25000000
C	3	70	10	50	22.72	0	0.0125	7	4	50000000
D	10.7	90	40	80	1100	0	0.025	10	1100	160000000
E	12	0	0	0	540.45	0	0.05	0	2700	100000000
F	2.5	70	50	50	29.4	0	0.04	10	15	100000000
G	4	50	50	80	17.55	0	0.05	10	10	25000000

H	10	73	0	50	285.7	10	0.04	0	9650	400000000
I	7	10	0	30	285.7	0	0.017	0	1427	60000000
J	3	100	0	80	602.4	0	0.05	0	100	50000000
K	10	50	50	100	192.3	0	0.025	0	1917	100000000
L	10	70	0	90	1000	20	0.033	30	150	20000000
M	20	50	75	85	833.33	20	0.033	0	1650	62000000
N	12	50	20	70	625	20	0.05	0	1225	425744
O	10	90	0	90	33.33	0	0.1	10	8	2500000
P	15	90	0	80	31.35	0	0.04	7	14	7500000
Q	4	60	60	80	33	0	0.2	6	20	6000000
R	3	90	50	50	20	0	0.05	6	0	2000000
S	5	60	80	70	1000	0	0.1	5	10	7000000
T	10	90	10	90	1000	0	0.033	15	5	3000000
U	20	85	50	80	129.87	20	0.066	30	30	10000000
V	6	90	70	50	21.27	10	0.2	5	35	5000000
W	10	40	10	90	14.49	0	0.066	5	4	2500000
X	25	90	50	80	1000	20	0.033	5	15	3000000
Y	15	90	80	70	55.55	20	0.2	5	5	5000000
Z	8	0	0	50	11.11	0	0.04	5	8	2500000
A1	15	98	60	50	60.24	0	0.1	10	10	5000000
B1	5	50	50	50	1000	0	0.05	20	10	1000000
C1	22	90	10	95	1000	50	0.025	30	59	10000000
D1	12	0	0	90	909	10	0.04	25	70	80000000
E1	5	90	20	50	1000	0	0.066	5	10	4000000
F1	10	100	20	95	1000	0	0.05	3	5	6000000
G1	5	90	20	60	1000	0	0.1	10	0	500000
H1	3	80	10	80	1000	0	0.1	5	5	400000
I1	10	90	70	70	38.3	0	0.1	10	3	3500000
J1	10	98	0	95	17.46	0	0.02	5	15	3000000
K1	10	90	80	70	10	0	0.033	20	10	1000000

The next table -4- shows the descriptive statistics about performance metrics

table -4- descriptive statistics about performance metrics

Statistics on Input/Output Data

	PM EX	S PER	C PER	CS PER	1/SA PER	E PER	1/CW PER	P PER	Sb PER	Sb2 PER
Max	25	100	80	100	1100	50	33	30	9650	400000000
Min	2.5	0	0	0	10	0	0.0125	0	0	425744
Avg	9.5324	71.189	31.756	69.459	460.1292	5.6756	0.9525	9.027	549.0541	314173669
SD	5.5917	29.43	28.8101	21.0464	440.6855	10.537	5.341	8.5249	1647.669	710715812

Tables -5a- 5b gives descriptive statistics about the results of model 1, the number of DMUs is 37 included 8 efficient and 29 inefficient ,the average of scores is 0.63 with standard deviation of 0.26 with maximum score is 1 and minimum score is 0.21.

Tables -5a -5b descriptive statistics about the results of model 1

No.	DMU		
	None	No. of DMUs in Data =	37
No. of DMUs	37	No. of DMUs with inappropriate Data =	0
Average	0.629767	No. of evaluated DMUs =	37
SD	0.266083	Average of scores =	0.629767
Maximum	1	No. of efficient DMUs =	8
Minimum	0.215587	No. of inefficient DMUs =	29
		No. of over iteration DMUs =	0

table-6- shows the results of the CCR model using CCR-I model of DEA (we displayed part of them). For each DMU, the results show the score, data, projection, difference between projection and data, and percentage difference between projection and data. The projected values have great importance to inefficient DMUs, as by arriving at the projected values they have an opportunity to become 100 % efficient. For example, firm C has to reduce expenses by 22.47% and it has to increase its cost performance by 386.45% and increase 1/SA performance by 999.9% and 1/cw performance by 136.39% and social benefit performance by 149.68% and social benefit 2 by 22.74%.

table- 6- the results of the model 1 using CCR-I model of DEA

No.	DMU I/O	Score Data	Projection	Difference	%
1	A	0.52048673			
	PM EX	7.5	3.9036505	-3.59635	-47.95%
	S PER	100	100.693133	0.6931335	0.69%
	C PER	10	71.9841582	61.984158	619.84%
	cs PER	50	72.7524107	22.752411	45.50%
	1/S PER	105.26	105.26	0	0.00%
	E PER	0	0.1536505	0.1536505	999.90%
	1/cw PER	0.02	5.88E-02	3.88E-02	194.03%
	P PER	15	15	0	0.00%
	Sb PER	10	169.566393	159.56639	999.90%
	Sb2 PER	200000000	200000000	0	0.00%
2	B	1			
	PM EX	3	3	0	0.00%
	S PER	100	100	0	0.00%
	C PER	70	70	0	0.00%
	cs PER	70	70	0	0.00%
	1/S PER	1000	1000	0	0.00%
	E PER	10	10	0	0.00%
	1/cw PER	0.02	0.02	0	0.00%
	P PER	5	5	0	0.00%
	Sb PER	6	6	0	0.00%

	Sb2 PER	25000000	25000000	0	0.00%
3	C	0.77526882			
	PM EX	3	2.32580645	-0.674194	-22.47%
	S PER	70	70	0	0.00%
	C PER	10	48.6451613	38.645161	386.45%
	CS PER	50	50	0	0.00%
	1/S PER	22.72	344.775484	322.05548	999.90%
	E PER	0	3.09677419	3.0967742	999.90%
	1/CW PER	0.0125	2.95E-02	1.70E-02	136.39%
	P PER	7	7	0	0.00%
	Sb PER	4	9.98709677	5.9870968	149.68%
	Sb2 PER	50000000	61367741.9	11367742	22.74%
4	D	0.70911975			
	PM EX	10.7	7.58758137	-3.112419	-29.09%
	S PER	90	110.672823	20.672823	22.97%
	C PER	40	62.3459359	22.345936	55.86%
	CS PER	80	82.1007656	2.1007656	2.63%
	1/S PER	1100	1100	0	0.00%
	E PER	0	10.4459113	10.445911	999.90%
	1/CW PER	0.025	4.57E-02	2.07E-02	82.70%
	P PER	10	10	0	0.00%
	Sb PER	1100	3819.95536	2719.9554	247.27%
	Sb2 PER	1600000000	1600000000	0	0.00%

Conclusion & Recommendations:

The benchmarking model is developed using field data collected from 37 Syrian construction firms. The analysis using the DEA software seems to show that 29 of the 37 firms are functionally inefficient. The software also provided each firm with projected values that they must meet in order to become efficient. This developed benchmark model addresses the limitations that have been previously identified in other benchmarking models. **The ability of this benchmark model to better access economical, technical, environmental, and social performance for construction firms is what makes it superior.** The model, currently used industry-relevant metrics most frequently identified in the literature, measures the overall efficiency of a construction company by adding new performance metrics that are required in this currently highly competitive market. The newly developed model allows construction firms to be evaluated for overall performance and identify specific areas for improvement. It also allows for individual firms to become as efficient as the most efficient firms in industry. This model is distinguished by its ability to analysis large number of firms (DMU_S) and metrics (inputs and outputs). We recommend the use of the developed benchmarking model as the first step in improving the performance of Syrian construction firms, and to help in the expansion of research by allowing construction firms to apply this model to all types of industry.

REFERENCES:

1. -BANKER, R., CHARNES, A., and COOPER, W.. *Some models for estimating technical and scale inefficiencies in data envelopment analysis*. Management Science, 30, 1984, 1078-1092
2. -CAMP, R. *Benchmarking: The search for industry best practices that lead to superior performance*, ASQC Quality Press, Milwaukee, WI. 1989.
3. -CAMP, R. *Global cases in benchmarking: best practices from organizations around the world*, ASQ Quality Press, Milwaukee, WI. 1998.
4. -CBPP.. "Key performance indicators. Project delivery and company performance." Construction Best Practice Program publication, Watford, UK. 1998
5. -CII CONSTRUCTION INDUSTRY INSTITUTE. *Guidelines for implementation of CII concepts: best practices for the construction industry*. Implementation Resource 42-2, Construction Industry Institute, University of Texas at Austin. 1995
6. -COOPER, W.; SEIFORD, L.;and TONE, K. *Data envelopment analysis and its uses With DEA-solver software, and references*, Springer science + business media,LLC,US,2006,354
7. -CONSTRUCTION INDUSTRY INSTITUTE. Institutional site . < www.cii.benchmarking.org> accessed 2004
8. EI-MASHALEH ; R. EDWARD MINCHIN, JR.; WILLAM j. O'BRIEN . *Management of Construction Firm Performance Using Benchmarking* .J. Mgmt. in Eng., Volume 23, Issue 1, January 2007,10-17
9. -FISHER, D., MIETSCHIN, S., and POLLOCK, D.*Benchmarking in construction industry*." Journal of Management in Engineering, 11(1), 1995,50-57.
10. -JEFFREY J. DORSCH ; MAHMOUDM. YASIN . *A framework for benchmarking in the public sector Literature review and directions for future research* . International Journal of Public Sector Management, Vol. 11 No. 2/3, 1998, 91-115
11. -HALACHMI, A. *Performance measurement and government productivity*, Work Study, Vol. 51 No. 2, 2002a, 63-73
12. HJALMARSSON, L., and ODECK, J.. *Efficiency of trucks in road construction and maintenance: an evaluation with data envelopment analysis*. Computers and Operations Research, 23(4), 1996, 393-404.
13. -HUDSON, D.. "Benchmarking construction project execution." PhD dissertation. University of Texas, Austin, 1997
14. -INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO.). *The ISO survey of ISO 9000 and ISO 14000 certificates, eleventh cycle, 2001*." <www.iso.ch/iso/en/iso9000-14000/iso9000/iso9000index.html> (October 2002)
15. -KPI WORKING GROUP.*KPI report for the minister for construction*, department of the environment, transport and the regions, Iland house,UK,2000 .
16. -LANTELME,E.M.;FORMOZO,C.T. *improving performance through measurement : the application of lean production and organizational learning principles*,8th international conference of the international group for lean construction, university of Sussex ,Brighton,2000
17. -LUIS F. AIARCON ; ALFREDO SERPELL . *Performance measuring, benchmarking, and modeling of project performance*, 5th international conference of the international group for lean construction, the University of Birmingham, UK, August, 1996.

18. -MACNAIL, J., TESTI, J., CUPPLES, J. and RIMMER, M., *Benchmarking Australia: Linking Enterprises to World Best Practice*. Longman Business and Professional, Australia, 1994.
19. -MCGEORGE, D.; and PALMER, A.. *Construction management: new directions*, Blackwell Science Ltd, Oxford. 1997
20. -MCNAIR, C.J. and LEIBFRIEND, K.H.J., *Benchmarking: a Tool for Continuous Improvement*, Harper Business, New York, NY, 1992.
21. -MOHAMMAD EI-MASHALEH; WILLAM j. O'BRIEN; KERRY LONDON .*Envelopment methodology to measure and compare subcontractor productivity at the firm level*, The 9th IGLC conference in Singapore , 6 - 8 August 2001 , Singapore.
22. -ROUSE, P., PUTTERILL, M., and RYAN, D.. *Towards a general managerial framework for performance measurement: a comprehensive highway maintenance application*. *Journal of Productivity Analysis*, 8(2), 1997,127-149
23. -RUI CUNHA MARQUES; ANTONIO JORGE MONTIERO . *benchmarking the economic performance of Portuguese water and sewarge services*. 4th international symposium of DEA, Aston business school, Aston university UK, 5th-6th September 2004
24. -SANG-HOON LEE¹; STEPHEN R. THOMAS, M.ASCE²; and Richard L. Tucker, F.ASCE³ *Web-Based Benchmarking System for the Construction Industry*. *Journal of Construction Engineering and Management*, Vol. 131, No. 7, July 1, 2005,790-798
25. -SPENDOLINI, M. *The benchmarking book*, AMACOM, American Management Association, New York, 1992.
26. -TOWILL, R. *The idea of building business processes: the responsive house builder*. *Construction Management and Economics*, 19, 2001, 285-293