COMPARISON OF THE ECONOMICS OF ON-SITE AND OFF-SITE FABRICATION OF REBAR IN TURKEY

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ABSTRACT

Most Turkish contractors prefer on-site fabrication of rebar due to several factors most of which are peculiar to developing countries. Therefore, the economics of on-site and off-site fabrication of rebar need to be compared in the project environment, which is subject to most of those factors, and it should be answered whether the strong preference for on-site fabrication is more economical than off-site fabrication in developing countries, namely in the Turkish construction industry. This study presents an economical comparison of the on-site and off-site fabrication practices of rebar by means of a simulation model that makes use of actual data obtained from a trade center project in Istanbul, Turkey. The study suggests that had the off-site fabrication practice been used in the project in Istanbul, the total cost of rebar would have been 1.2% higher than the total cost of rebar in the on-site fabrication practice. This finding also reveals the need for 'infrastructural' changes in the Turkish construction industry before its participants can enjoy the benefits of lean construction; a change that may be necessary in some degree for other developing countries as well.

KEY WORDS

Cut & bent rebar, On-site fabrication, Off-site fabrication, Simulation model.

INTRODUCTION

Materials constitute a large proportion of the total cost of construction. Proper management of the material flow may play a significant role in enhancing the profitability of a contractor. The generally acknowledged rules of materials management are small orders (lot sizes), frequent deliveries and reduced inventory in both raw material and work-in-progress (Sobotka 2000, Shmanske 2003). The main objective of these efforts is to lower the amount of capital tied up in inventory (Shmanske 2003) while making sure that production never stops due to shortages of materials. One of the concepts in the manufacturing industry that addresses these issues is Just-in-time (JIT) that flourished in Japan in the early 1950s (Ohno 1987). JIT is a production and delivery program with the primary goals of continuously reducing and ultimately eliminating all forms of waste, and adding value to raw materials as they proceed through various processing steps to end up as a finished product (Tommelein 1998).

One means for eliminating waste in construction is prefabrication of precast beams and columns and off-site fabrication of reinforcing steel (rebar) (Pheng and Hui 1999). Although the benefits that can be obtained by means of off-site fabrication of construction materials are documented in former studies (i.e., Pheng and Hui 1999, Pheng and Chuan 2001), on-site fabrication of rebar is most commonly preferred rather than off-site fabrication in the Turkish construction industry (Polat and Ballard 2003). Polat and Ballard (2005) reported that although off-site fabrication of rebar may provide contractors with numerous advantages, there are several factors most of which are peculiar to developing countries that compel Turkish contractors to fabricate rebar on-site. Therefore, the economics of on-site and off-site

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fabrication of rebar need to be compared in the project environment, which is subject to most of the factors discussed by Polat and Ballard (2005), in order to see whether the strong preference for on-site fabrication of rebar in the Turkish construction industry is reasonable or not.

This study presents an economic comparison of the on-site and off-site rebar fabrication practices by means of a simulation model that makes use of actual data obtained from a trade center project in Istanbul, Turkey. The trade center project was investigated since both off-site and on-site fabrication practices of rebar were found in this project. Cut & bent rebar is used in this study because 1) if rebar is not supplied to site on time, the many succeeding activities are delayed and serious budget overruns may occur, 2) rebar can be fabricated either on-site or off-site, 3) approximately 16-26% (by weight) of the total purchased amount of rebar is wasted during the construction process (Formoso et al. 2002), and 4) rebar constitutes a significant portion of the cost of reinforced concrete structures and is subject to wildly variable prices in Turkey (Polat and Arditi 2004).

It should be kept in mind that the economic analysis presented in this study is based on a number of assumptions regarding managerial capabilities, ethical practices, and special conditions prevailing in the Turkish construction industry, which result in huge amount of waste in time and material (Polat and Ballard 2004) and compel Turkish contractors to fabricate rebar on-site rather than off-site (Polat and Ballard 2005). Those assumptions may likely be encountered throughout any construction project carried out in the current state of the Turkish construction industry. This study compares the economics of on-site and off-site rebar fabrication practices in the actual environment of the studied trade center project, which may be more or less representative of the Turkish construction industry as a whole ("as-is" project conditions) rather than considering the economical impacts of the possible performance improvement suggestions ("what if" scenarios). If the 'infrastructural' changes for removing the obstacles to the lean transformation of the Turkish construction industry were accomplished, then the Turkish construction industry's participants could enjoy the benefits of lean construction and the findings of this study would be entirely different.

RESEARCH METHODOLOGY

One way of comparing the economics of on-site fabrication vs. off-site fabrication of rebar is to develop a simulation model that mimics the existing materials management system of rebar actually performed by the contractor, and to run the system by plugging in data obtained from actual projects, in this case the trade center project.

The research was carried out in the following phases:

1) *Static simulation:* Static simulation intends to identify the activities, processes, relationships, and decisions that exist in a real system. The flow diagram is the most well known tool that allows an analyst to represent the real system. The information used to design the flow diagram was obtained from both the actual data derived from the case study and two studies (Polat and Ballard 2003) conducted previously on materials management systems of rebar in the Turkish construction industry. The flow diagrams of the rebar management system used in the case study are presented in Figures 1 and 2.

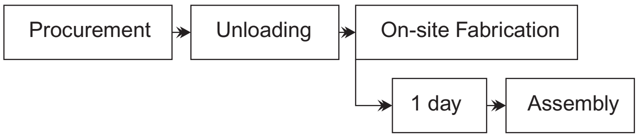

Figure 1: Flow diagram of the rebar management system used in the case study in the case of on-site fabrication

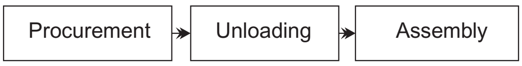

Figure 2: Flow diagram of the rebar management system used in the case study in the case of off-site fabrication

Since the same resources including crews, workstations, and technical personnel are utilized in the same activities performed repeatedly in each floor, an activity in any floor cannot start unless the same activity is finished in the lower floor.

"Procurement" involves filing purchase requisitions, sending out requests for quotations, selecting the appropriate supplier or fabricator, sending purchase orders to the supplier or fabricator, and receiving the requested goods to the site. "Unloading" involves the process in which the required rebar is unloaded from trucks and stored on site. "On-site fabrication" involves the process in which the rebar is cut to measure and bent in accordance with specifications. "Assembly" involves the process in which the straight and cut & bent rebar are tied together and are installed in formwork. It is customary to start the assembly process one day after the on-site fabrication process starts on that floor.

2) *Identifying the independent (inputs) and dependent (outputs) variables of the model:* The dependent variable is the outcome of the interaction of the independent variables. Independent variables are the inputs of the system that

influence the dependent variable as long as they are changed in a controlled manner in an experiment. The inputs and outputs of the model will be discussed in the next section.

3) *Dynamic simulation*: Dynamic simulation refers to computer simulation that accurately represents causal events and the resulting actions in a system. Discrete event simulation modeling was found to be appropriate for this research because a materials management system cannot be highly generalized (Sobotka 2000). The simulation package Extend+BPR® was used in this study because of its powerful features including high flexibility, great capacity, animation capability, and sophisticated graphical user interface.
4) *Model verification and validation:* The aim of model verification is to guarantee that every portion in a model functions as intended without internal errors. Model validation, on the other hand, intends to ensure that the developed model accurately represents the real system. It proved to be very difficult to verify and validate the model that is presented in this paper because it is impossible to obtain real data about some of the factors in order to compare these values with the values generated by the model. For instance, most contractors do not have an accounting record of the financing cost. Therefore, the model is verified and validated by simplifying some elements of the model to a form that made it possible to carry out basic common sense tests, and by using the experience and intuition of specialist practitioners as proposed by Sobotka (2000).
5) *Experimentation*: Experimentation aims to determine the effects of variations in the controllable inputs on the output of the model. In this study, the economics of on-site and off-site fabrication of rebar were observed on the total cost of rebar used to build a reinforced concrete structure.

FRAMEWORK OF THE SIMULATION MODEL

Figure 3 depicts the framework of the simulation model.

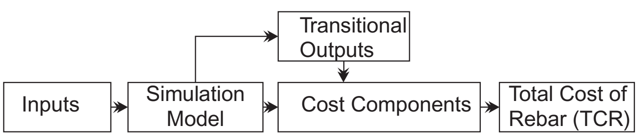

Figure 3: Framework of the simulation Model

INPUTS OF THE SIMULATION MODEL

Table 2 depicts the input variables' values and units.

TRANSITIONAL OUTPUTS OF THE SIMULATION MODEL

Transitional outputs are generated by the simulation model based on the inputs presented in the preceding section and the logical relationships between the various activities involved in rebar management systems. The transitional outputs and some of the inputs are later used by the simulation model to calculate the outputs of the model.

1) *Quantity of rebar in stock* (Q_s): This transitional output indicates the quantity of rebar in inventory at any time during the project.

$$Q_s = \sum Q_1 - \sum \left(Q_r \times (1 + R_w)\right)$$

The summation sign accounts for the different deliveries.

2) *Quantity of rebar to be purchased* (Q_p): Once a purchase requisition is sent to the Purchasing Department, the inventory is checked. In case the amount of rebar in inventory is not sufficient to meet the required amount, a purchase order is issued. The quantity of the rebar to be purchased is calculated as the difference between the required quantity of rebar including probable maximum waste and the quantity of rebar in stock.

$$Q_p = \left[Q_r \times (1 + R_{wmax})\right] - Q_s$$

Since the waste during on-site fabrication is zero in the case of off-site fabrication, Q_p is taken as the same as Q_r.

3) *Duration between the time of purchase and the time the rebar is sent to fabrication* (t_e): Early purchasing of rebar increases financing cost. Financing cost depends on the duration between the time of purchase (which equals to the actual date of delivery and the actual date on which the unloading process starts) and the actual time of the rebar is sent to fabrication.
4) *Quantity of rebar handled* (Q_h): The handling activity includes moving the delivered rebar from the trucks to the storage area and delivering the required rebar augmented by the actual quantity of wasted rebar ($1 + R_w$) from the storage area to the work area. When the purchased rebar is delivered to the site earlier than needed, it stays in storage until it is needed. If the delivery date of the rebar occurs earlier than the date on which the fabrication process should start, the delivered rebar is directly sent to storage.
5) *Total delay throughout the supply chain and fabrication processes* (D_{pr}): Total delay throughout the supply chain and fabrication process is the sum of the time gaps between the

actual and scheduled start dates of each activity associated with rebar.

6) *Total delay in the completion of the last floor* (D_{prl}): Contractors may be subject to pay a penalty in case the delivery of the superstructure is delayed. This is measured by considering the completion of the last floor compared to the scheduled finish date. Total delay in completion of the last floor (D_{prl}) is equal to the difference between the actual and scheduled finish dates of the assembly process of the last floor.
7) *Early completion of the project* (D_{pre}): Early completion of the project, which normally occurs with off-site fabrication and assembly, results in incentive payments to a contractor. Moreover, time savings reduce overhead and increase profit velocity.

OUTPUTS OF THE SIMULATION MODEL

In this study total cost of rebar (TCR) is used to compare the economics of on-site and off-site fabrication practices. The cost components of TCR are defined below:

1) Purchasing cost (PC): The purchasing cost represents the direct cost of rebar to the contractor.

$$PC = \sum \left(C_{pi} \times Q_1 \right)$$

The summation sign accounts for the different acquisitions. C_{pi} is the unit price of rebar. While C_{ps} is the unit price of straight rebar in the on-site fabrication practice, C_{pc} is the unit price of cut & bent rebar in the off-site fabrication practice. Since a waste amount of 7-11% occurs during on-site fabrication, Q_r (quantity of rebar required) is augmented by probable maximum waste (R_{wmax}) amount in the calculation of Q_p in the on-site fabrication practice. On the other hand, $Q_p = Q_r$ in the off-site fabrication practice.

2) Financing cost (FC): When a material is purchased before it is needed, the inventory is carried in storage with a financing cost. This cost depends on the length of time the material is kept on inventory and the value of money. If the contractor borrows money to purchase the material, the financing rate is equal to the actual interest rate. If the contractor pays cash for the material, then the financing rate is equal to the opportunity cost of capital to the contractor.

$$FC = \sum \left[\left(C_{pavi} \times Q_s \right) \times \left(\left(1 + R_{inav} \right)^{t_e} - 1 \right) \right]$$

The summation sign accounts for the changes in the values of Q_s and t_e. While C_{pavs} is the average unit price of straight rebar in the on-site fabrication practice, C_{pavc} is the average unit price of cut & bent rebar in the off-site fabrication practice.

3) On-site fabrication cost (OC): This is the sum of the costs associated with on-site fabrication activities.

$$OC = \sum \left[\left(Q_f / \left(N_{fw} \times P_{fw} \right) \right) \times \left(N_{fw} \times C_{fw} \right) \right] + C_{cbw}$$

The summation sign accounts for the changes in the values of Q_f and P_{fw} throughout the project. OC is taken as zero in the off-site fabrication practice.

4) Handling cost (HC): This is the cost of moving the rebar from the trucks to the storage area and delivering the rebar from the storage area to the work area.

$$HC = \sum \left[\left(Q_h / \left(N_{hw} \times P_{hw} \right) \right) \times \left(N_{hw} \times C_{hw} \right) \right]$$

The summation sign accounts for the different handlings.

5) Storage cost (StC): Storage cost consists of the rental cost of the storage area, management cost, and maintenance and upkeep cost, which includes the cost of rebar movement within the storage area.

$$StC = C_s \times t_s$$

6) Delivery cost (DC): This is the cost of moving the rebar from the supplier's warehouse to the construction site.

$$DC = \sum \left[C_t \times roundup\left(Q_p / S_{ti} \right) \right]$$

The summation sign accounts for the different deliveries. While S_{ts} is the capacity of trucks used for transporting straight rebar in the on-site fabrication practice, S_{tc} is the capacity of trucks used for transporting cut & bent rebar in the off-site fabrication practice.

7) Waiting cost of idle crews (WC): This is the cost of idle workers waiting for the rebar to arrive in case rebar is not available on site when it is needed.

$$WC = C_w \times D_{pr}$$

8) Shortage cost (ShC): This is the cost of delay caused by shortage of rebar. This delay causes a delay in the pouring of concrete in the last floor, resulting in penalties to the contractor.

$$ShC = C_d \times D_{prl}$$

9) Early finish bonus (EfB): This is the revenue for time savings, which normally occurs with offsite prefabrication and assembly. Early completion of the project results in incentive payments to a contractor, reduced overhead, and increased profit velocity.

$$EfB = C_b \times D_{pre}$$

The total cost of rebar is therefore:

$$TCR = PC + FC + OC + HC + StC + DC + WC + ShC - EfB$$

CASE STUDY

The simulation model was run by using actual data obtained from the 13 story high trade center project, whose contract value was $4 million, in Istanbul, Turkey. The construction of the superstructure started in June 2003 and finished in October 2003. The research was conducted after the completion of the superstructure. The contact persons in the company were the project manager and site manager. The field study was conducted by means of on-site interviews and observations.

AbouRizk and Halpin (1992) found that the beta distribution is appropriate for representing construction activity durations. The beta distribution can be approximated with a triangular distribution, which requires three parameters for its definition: the lower or optimistic limit, the mode or most likely value, and the upper or pessimist limit (McCabe 2003). Therefore, the triangular distribution is used in order to represent the random factors inherent in the durations of the activities associated with rebar.

The quantity of rebar required by site manager for each floor is presented in Table 1.

The fluctuations of the unit prices of rebar throughout the trade center project located in Istanbul, Turkey are presented in Figure 4. While the average unit price of straight rebar (C_{pavs}) was calculated as 505 YTL, the average unit price of cut & bent rebar (C_{pavc}) was calculated as 569 YTL in the period of June 2003 to October 2003 in Istanbul, Turkey.

Table 1: Quantity of rebar required by site manager at the trade center project

Floor	Required Quantity of Rebar, Q_r (tons)	Floor	Required Quantity of Rebar, Q_r (tons)
1	60	8	23
2	30	9	23
3	30	10	23
4	30	11	23
5	30	12	23
6	23	13	23
7	23		

Most contractors manage their business with the monthly payments they receive from the owner (Polat 1999). They can invest their limited cash for only a short term. Therefore, in this study, the financing cost is calculated by considering repurchase transactions, which are accepted as the standard financial instrument for short-term loans of cash or securities (Morrow 1995). The overnight repo rates in Turkey varied between 0.07 to 0.10% in the period of June 2003 to October 2003 (www.tcmb.gov.tr). In this study, an average overnight repo rate of R_{inav} = 0.09% was used.

Based on the records provided by the project manager of the trade center project, C_s was zero. Since there were many free spaces on the construction site, the rebar was stocked on the construction site. Therefore, this cost is not taken into account in this study.

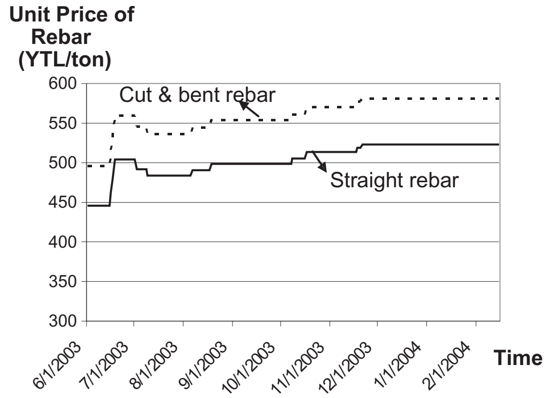

Figure 4: Unit Price of rebar in the period of June 2003 to October 2003 in Istanbul, Turkey

Based on the records provided by the project manager of the trade center project, C_t was 200 YTL per truckload. Since cut & bent rebar needs more space than straight rebar, while the trucks were able to transport 26 tons of straight rebar (S_{ts}), they were able to transport 20 tons of cut & bent rebar (S_{tc}).

Table 2: Input variables' values obtained from the trade center project

Symb.	Description	Values in the trade center project
C_b	Bonus for early finish	75 YTL/day
C_{cbw}	Cost of cutting and bending workstations to the project	1500 YTL
C_d	Cost of daily delay	250 YTL/day
C_{fw}	Daily wage of workers in charge of on-site fabrication	30 YTL/day
C_{hw}	Daily wage of workers in charge of handling	20 YTL/day
C_{pc}	Current unit cost of cut & bent rebar at the time it was purchased	See Figure 4
C_{ps}	Current unit cost of straight rebar at the time it was purchased	See Figure 4
C_{pavc}	Average unit price of cut & bent rebar	569 YTL/ton
C_{pavs}	Average unit price of straight rebar	505 YTL/ton
C_s	Monthly rental cost of storage	-
C_t	Unit cost of delivery per truckload	200 YTL/truckload
C_w	Daily cost of idle crews	-
D_{ltc}	Probable delay in promised lead time of cut & bent rebar	1-3 days (triangular distribution)
D_{lts}	Probable delay in promised lead time of straight rebar	1-2 days (triangular distribution)
N_{aw}	Number of workers in charge of assembly	10
N_{fw}	Number of workers in charge of fabrication	4
N_{hw}	Number of workers in charge of handling	2
N_{uw}	Number of workers in charge of unloading	2-4 (random variable)
P_{aw}	Daily productivity of workers in charge of assembly	0.40-0.48 tons/day/worker for the first floor; 0.25-0.3tons/day/worker for the other floors (triangular dist.)
P_{fw}	Daily productivity of workers in charge of on-site fabrication	1.28-1.60 tons/day/worker for the first floor; 0.8-1 tons/day/worker for the other floors (triangular dist.)
P_{hw}	Daily productivity of workers in charge of handling	16-20 tons/day/worker (triangular distribution)
P_{uw}	Daily productivity of workers in charge of unloading	21-29 tons/day/worker (triangular distribution)
Q_r	Quantity of rebar required specified by site manager	See Table 1
R_{inav}	Interest rate (average overnight reverse rate)	0.09%
R_w	Waste during on-site fabrication	7%-11% (triangular distribution)
R_{wmax}	Probable maximum waste during on-site fabrication	11%
S_{rf}	Capacity of the rebar fabricator	25 - 50 tons/day (triangular distribution)
S_{tc}	Capacity of the trucks used for cut & bent rebar	26 tons
S_{ts}	Capacity of the trucks used for straight rebar	20 tons
t_a	Duration of assembly process	See Tables 3 & 4
T_{aij}	Day of the project on which assembly process needs to start	See Tables 3 & 4
T_{efi}	Date on which the project is expected to be completed	T_{efs}: 179 T_{efc}: 163
t_f	Duration of on-site fabrication process	See Table 3
T_{fij}	Day of the project on which on-site fabrication process needs to start	See Table 3
t_{lts}	Promised lead time for straight rebar	1-3 days (triangular distribution)
t_p	Duration of procurement process	See Tables 3 and 4
T_{pij}	Day of the project on which the procurement process needs to start	See Tables 3 and 4
t_s	Duration of storage	-
t_u	Duration of unloading process	See Tables 3 & 4
T_{uij}	Day of the project on which unloading process needs to start	See Tables 3 & 4

Table 3: Start times and durations of the main activities associated with rebar in the on-site fabrication practice, generated by Primavera Project Planner®

Floor	Durationo f Proc.	Start Times of Proc.	Duration of Unload.	Start Times of Unload	Duration of On-site Fabric.	Start Times of On-site Fabric.	Duration of Asse.	Start Times of Asse.
1	11	0	1	13	11	14	14	16
2	11	13	1	26	9	27	11	32
3	11	26	1	39	9	40	11	45
4	11	39	1	52	9	53	11	58
5	11	52	1	65	9	66	11	70
6	11	65	1	77	7	79	9	83
7	11	77	1	90	7	91	9	94
8	11	90	1	103	7	104	9	105
9	11	103	1	116	7	117	9	118
10	11	116	1	129	7	130	9	131
11	11	129	1	142	7	143	9	144
12	11	142	1	154	7	156	9	157
13	11	154	1	167	7	168	9	170

Table 4: Start times and durations of the main activities associated with rebar in the off-site fabrication practice, generated by Primavera Project Planner®

Floor	Duration of Procurement	Start Times of Procurement	Duration of Unloading	Start Times of Unloading	Duration of Assembly	Start Times of Assembly
1	10	0	1	11	14	12
2	9	17	1	28	11	29
3	9	30	1	40	11	42
4	9	43	1	53	11	54
5	9	56	1	66	11	67
6	9	68	1	79	9	80
7	9	79	1	89	9	91
8	9	89	1	100	9	101
9	9	100	1	110	9	112
10	9	110	1	121	9	122
11	9	121	1	131	9	133
12	9	131	1	142	9	143
13	9	141	1	151	9	154

In the trade center project, if the rebar did not arrive on time, other tasks were assigned to the workers. The absence of strong unions in Istanbul allowed the contractor to reassign workers to different activities without problem. Obviously, multitasking leads to reduced focus and loss of productivity of workers. Any decrease in the daily productivity of workers brings about an inevitable increase in the on-site fabrication and handling costs. However, the contractor does not have any record of the economic impact of multitasking and it was very difficult for us to reckon it. For that reason, the economic impact of multitasking on the on-site fabrication and handling costs, and the waiting cost are neglected in this study.

The activity duration is estimated at the beginning of the project to account for uncertainties. But the actual duration of an activity is a result of various random factors and turns out to be either shorter or longer than or equal to the estimated duration. The scheduled times of the main activities associated with rebar was generated by Primavera Project Planner® after plugging in the logical connections between the main activities associated with rebar illustrated in Figures 1 and 2, and the input values presented in Table 2. The scheduled start times generated by P3 are presented in Table 3.

It should be noted that average values for both productivity of workers and duration estimates are used in scheduling. It is assumed that JIT materials management system is implemented in the off-site fabrication practice.

SIMULATION RESULTS

For good results, Chase and Brown (1992) recommend a coefficient of variance below 5% when conducting experiments. A coefficient of variance of 0.5% was targeted in this study and the simulation model was run 100 times until the coefficient of variance went below 0.5% for both on-site fabrication and off-site fabrication practices. The values of each cost components and total cost of rebar for both of the on-site and off-site fabrication practices in the case study are presented in Table 5.

Table 5: Cost components and total cost of rebar for each of the fabrication practices in the case study

Cost Components	On-Site Fabrication Practice (YTL)	Off-Site Fabrication Practice (YTL)
Purchasing Cost	189,566	197,739
Financing Cost	360	186
On-Site Fabrication Cost	6,750	-
Handling Cost	928	817
Storage Cost	-	-
Delivery Cost	3,000	5,400
Waiting Cost	-	-
Shortage Cost	0	0
Early Finish Bonus	0	1,200
Total Cost of Rebar (TCR)	200,604	202,942

While TCR was found to be 200,604 YTL in the on-site fabrication practice, it was 202,942 YTL in the off-site fabrication practice. Obviously, implementation of the off-site fabrication practice in the trade center project adds an extra cost of 2,338 YTL. This corresponds to an increase of 1.2% in TCR.

This finding is to be expected in the special conditions prevailing in the Turkish construction industry including uncertainty and variability in the supply chain, high inflation rates, high shipping costs, high material and time waste, and low wages of workers. These conditions are likely to be encountered in developing countries.

CONCLUSIONS

Since contractors are profit-seeking organizations and profit margins are generally low, selecting the most economical way to fabricate rebar is one of the major concerns of the contractors. This model is of benefit to contractors because it familiarizes them with the probable outcomes of both on-site and off-site fabrication of cut & bent rebar practices and allows them to compare their total cost of rebar at the beginning of the project.

It was found that implementing on-site rather than off-site fabrication of cut & bent rebar in the investigated trade center project might provide the contractor with the cost advantage of 2,338 YTL. This corresponds to an increase of 1.2% in the total cost of rebar. This finding is to be expected in the special conditions prevailing in the Turkish construction industry. The economic analysis presented in this study is based on a number of assumptions regarding managerial capabilities, ethical practices, and the current conditions prevailing in Turkey, which are obstacles to the lean transformation of the Turkish construction industry. Those assumptions may approximately represent the Turkish construction industry as a whole. If the 'infrastructural' changes for removing the obstacles to the lean transformation of the Turkish construction industry suggested by Polat and Ballard (2004, 2005) were accomplished, then the Turkish construction industry's participants could enjoy the benefits of lean construction and the findings of this study would be entirely different.

Additional study of the preconditions for successful implementation of lean techniques is much needed, including confirmation that the findings of this study apply more broadly to less developed countries as a whole.

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