IMPACTS OF COMPANYWIDE IMPROVEMENTS ON THE ECONOMICS OF ON-SITE FABRICATION PRACTICE OF REBAR IN TURKEY

Gul Polat[1] and Glenn Ballard[2]

ABSTRACT

Rebar supply chains need to be well managed in order to achieve project goals. The special conditions of a project's environment, which include uncertainty in the procurement and fabrication processes, great fluctuations in the unit price of rebar, and high shipping costs, directly influence the economics of rebar supply chains. While great fluctuations in the unit price of rebar and high shipping costs are beyond the control of a contractor, uncertainty in the procurement process and fabrication processes may likely be overcome through implementing companywide improvements such as establishing long-term relationships with suppliers, establishing proper ordering procedures, conducting training programs, and appointing qualified workers rather than unqualified workers. This study aims to provide contractors a decision support tool, namely a discrete event simulation model, with which to determine the probable outcomes of implementing different combinations of improvements. The simulation model was run by using actual data obtained from a 13-story trade centre project in Istanbul, Turkey. The simulation results revealed that establishing proper ordering procedures by means of employing trained personnel in charge of the procurement process and appointing qualified workers provide the contractor with an advantage of 11,113 YTL, which corresponds to an increase of 5.6% in the profit margin of the contractor. This study is limited, because it analyzes the impacts of the controllable factors on the economics of on-site fabrication practice of rebar. There is a need for further study, which analyzes the impact of implementing both companywide and nationwide and industry wide improvements on the economics of both on-site and off-site rebar fabrication.

KEY WORDS

rebar, on-site fabrication, simulation model, companywide improvements, decision making.

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INTRODUCTION

In Turkey, reinforced concrete structures are most commonly preferred rather than steel structures. While constructing reinforced concrete structures requires thousands of components, rebar is very critical in this process. The basic sequence of constructing a reinforced concrete structure is: prepare formwork, install rebar, pour concrete, wait for curing, and perform activities related to the structural framework. Obviously, if any inefficiency is experienced in the rebar supply chain, the succeeding activities are delayed, and the risk of exceeding budgets and schedules is increased. Therefore, rebar supply chains need to be well managed in order to achieve project goals.

Polat and Arditi (2005) have shown in their empirical study that the special conditions of a project's environment directly influence the economics of rebar supply chains. The factors that constitute the special conditions of a project's environment include; 1) uncertainty in the procurement process, 2) variations and uncertainty in the fabrication process, 3) great fluctuations in unit price of rebar, and 4) high shipping costs.

Great fluctuations in the unit price of rebar and high shipping costs are mostly related to the overall state of the economy of the country and beyond the control of a contractor. On the other hand, uncertainty in the procurement process and variations and uncertainty in the fabrication process are controllable factors and may likely be overcome through implementing companywide improvements such as establishing long-term relationships with suppliers, establishing proper ordering procedures, conducting training programs, and appointing qualified workers rather than unqualified workers. Undoubtedly, there is a cost to a contractor of making such improvements. Does investing in such improvements pay off? That is the question contractors should be asking.

This study aims to provide contractors a decision support tool, namely a discrete event simulation model, with which to determine the probable outcomes of implementing different combinations of improvements. For this purpose, 11 different combinations of 3 main scenarios for the improvement suggestions that need to be implemented are proposed and the impacts of implementing such improvements on the economics of on-site rebar fabrication are analyzed in order to help contractors decide if to invest in such improvements or not. Simulation is the most appropriate tool for conducting such an experiment since complex flow patterns, complex process and business rules, delays, queues, and many process variables are common in rebar management systems.

Rebar can be fabricated either on-site or off-site. A study by Polat and Ballard (2003) revealed that on-site fabrication of rebar is most commonly preferred in the Turkish construction industry. So, this initial study focuses on only the on-site fabrication practice of rebar. Actual data obtained from a trade center project in Istanbul, Turkey is used as input into the model.

RESEARCH METHODOLOGY

One way of conducting such research is to develop a simulation model, which accurately represents actual processes of a real system and demonstrates the possible outcomes of changes in model inputs. Dynamic, stochastic, and discrete event simulation modeling was found to be appropriate for this research, because the dependent variables of the model discretely change at specified points in time due to the stochastic nature of the rebar management system (Law and Kelton 2000). The simulation package Extend+BPR® was used because of its flexibility, capacity, animation capability, and sophisticated graphical user interface.

Polat and Ballard (2005) developed a simulation model that mimics the existing rebar management system actually performed by the contractor, and ran the system by plugging in data obtained from a trade center project in Istanbul, Turkey. The main framework of the simulation model is presented in Figure 1.

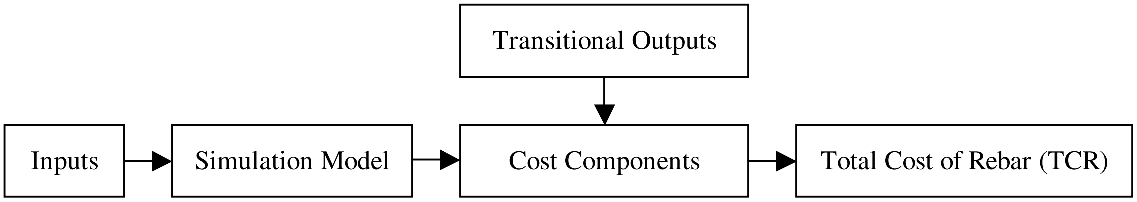

Figure 1: Main framework of the simulation model

In this study, the same trade center project was studied and the simulation model developed by Polat and Ballard (2005) was used. However, some of the input variables of that model, namely the input variables related to the controllable factors, were changed in order to observe the impacts of those infrastructural changes on the total cost of rebar (TCR).. The flow diagram of the rebar management system used in the case study is presented in Figure 2.

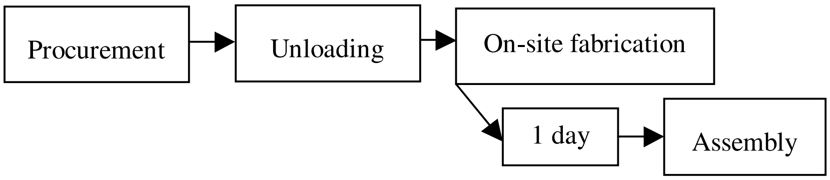

Figure 2: Flow diagram of the on-site fabrication practice

CASE STUDY

The simulation model was run by using data obtained from a 13-story trade centre project in Istanbul, Turkey, whose total contract value was $4 million. 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 the site superintendent. The field study was conducted by means of on-site interviews with these two individuals, examination of project records, and on-location observations.

INPUTS OF THE SIMULATION MODEL

The duration of procurement process (t_p) is the sum of the duration of filing purchase requisition (t_{pr}), the duration of the supplier selection process (t_{ss}), the duration of preparing request for quotation (t_{rq}), and the promised lead time for straight rebar (t_{lt}). However, probable delays in the duration of filing purchase requisitions (D_{pr}), sending purchase orders to the selected suppliers (D_{ss}), the duration of preparing request for quotation (D_{rq}), and the promised lead time for rebar resulting from the contractor's defective ordering procedure (D_{lc}) and/or the supplier's defective delivery procedure (D_{ls}) may likely occur. The durations of the activities associated with the procurement process (t_{pr}, t_{rq}, t_{ss}, t_{lt}) and the delays (D_{pr}, D_{rq}, D_{ss}, D_{lt}, D_{ls}, D_{lc}) may be caused by the controllable factor, namely uncertainty in the procurement process. While (D_{pr}), (D_{rq}), (D_{ss}), and (D_{lc}) can be reduced or eliminated by means of establishing proper ordering procedures, (t_{lt}) and (D_{ls}) can be reduced or eliminated by means of establishing long-term relationships with suppliers. Establishing long-term relationships with suppliers is directly related to the coordination capability of a contractor. However, most Turkish contractors fail to manage the relationships with suppliers and coordinate the supplier's deliveries. If a contractor appoints a staff in charge of coordinating the supplier's delivery process, then the delay in promised lead time resulting from the supplier's defective delivery procedure will likely be reduced. Most Turkish contractors appoint uneducated staff for the procurement process rather than a civil engineer or an architect as the monthly wage of an uneducated staff is much lower than an educated staff. Since the staff in charge of the procurement process does not have adequate knowledge about the construction materials and process, severe problems are commonly experienced in the procurement process. Establishing a proper ordering procedure requires employing trained personnel.

The estimated durations of activities associated with the procurement process and probable delays in those activities ultimately influence the day of the project on which the unloading process needs to start (T_u). The duration of unloading process (t_u) depends on the productivity of workers in charge of unloading (P_u). Any fluctuation in (P_u) changes the day of the project on which the fabrication process [needs to start] (T_f). The duration of fabrication process (t_f) is dependent on the productivity of workers in charge of on-site fabrication (P_f), the percent of waste in on-site fabrication (R_w), and the probable maximum waste in on-site fabrication (R_{wmax}). Any fluctuation in (P_f) and (R_w and R_{wmax}) changes the day of the project on which the assembly process starts (T_a). The duration of assembly process (t_a) is governed by the productivity of workers in charge of assembly (P_a). Any fluctuation in (P_a) influences the day of the project on which the procurement process starts (T_p). Any fluctuation in the values of (P_u), (P_f), (P_h), (P_a), (R_w) and (R_{wmax}) directly change the values of (t_u), (t_f), (t_a) and the date on which the superstructure is completed (T_{ef}), and they can be reduced by means of improving worker productivity. Workers' productivity can be improved by conducting training programs or appointing more qualified workers. In Turkey, it is very easy to become a construction worker, because there is no need for any certificate that proves your level of education or experience. Moreover the competence of the workers is assessed only with respect to their years of experience. Most Turkish contractors appoint unqualified and inexperienced workers as the daily wage for them is very low. When a worker gets more qualified, his daily wage increases but also his productivity improves, which reduces mistakes and rework. This increase in productivity and wage rates impacts on-site fabrication and handling costs.

All of the duration and productivity values mentioned above ultimately have an impact on the total cost of rebar (TCR). The input variables obtained from a trade center project in

Istanbul, Turkey and their definitions are presented in Table 1. The input variables in bold are directly related to the controllable factors and may likely be improved by means of implementation of the improvements. The costs of the improvements including establishing proper ordering procedures, establishing long-term relationships with suppliers, conducting training programs, and appointing qualified workers rather than unqualified workers, and the probable positive changes in the values of the input variables are presented in the last column of Table 1. The values of the inputs presented in the last column of Table 1 are based on interviews with the practitioners from 7 contractors, 2 rebar fabricators, and 4 consulting firms.

Table 1: Input variables, definitions and values obtained from the trade centre project

Symbol	Description	Actual values in the trade centre project	Estimated values after companywide improvements
C_b	Bonus for early finish	75 YTL/day	75 YTL/day
C_{eqt}	Cost of cutting and bending workstations to the project	1,500 YTL	1,500 YTL
C_d	Cost of daily delay	250 YTL/day	250 YTL/day
C_f	**Daily wage of workers in charge of on-site fabrication**	**30 YTL/day**	**45 YTL/day**
C_h	**Daily wage of workers in charge of handling**	**20 YTL/day**	**25 YTL/day**
C_r	Current unit cost of straight rebar at the time it was purchased	See Figure 3	See Figure 3
$C_{r\ ave}$	Average unit price of straight rebar	505 YTL/ton	505 YTL/ton
$C_{storage}$	Monthly rental cost of storage	-	-
C_{truck}	Unit cost of delivery per truckload	200 YTL/truckload	200 YTL/truckload
C_w	Daily cost of idle crews	-	-
D_{lc}	**Delay in promised lead time resulting from the contractor's defective ordering procedure**	**0.5-1 day (triang. dist.)**	**0-0.5 day (triang. dist.)**
D_{ls}	**Delay in promised lead time resulting from the supplier's defective delivery procedure**	**0.5-1 day (triang. dist.)**	**0-0.5 day (triang. dist.)**
D_{pr}	**Delay in preparing purchase requisition**	**0-1 day (triang. dist.)**	**0-0.5 day (triang. dist.)**
D_{rq}	**Delay in preparing request for quotation**	**0-1 day (triang. dist.)**	**0-0.5 day (triang. dist.)**
D_{ss}	**Delay in sending purchase orders to selected suppliers**	**0-2 days (triang. dist.)**	**0-1 days (triang. dist.)**
N_a	Number of workers in charge of assembly	10	10
N_f	Number of workers in charge of fabrication	4	4
N_h	Number of workers in charge of handling	2	2
N_u	Number of workers in charge of unloading	2-4 (random variable)	2-4 (random variable)
P_a	**Daily productivity of workers in charge of assembly**	**0.40-0.48 tons/day/worker for the first floor; 0.25-0.3 tons/day/worker for the other floors (triang. dist.)**	**0.75-0.9 tons/day/worker for the first floor; 0.4-0.5 tons/day/worker for the other floors (triang. dist.)**
P_f	**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 (triang. dist.)**	**2-3 tons/day/worker for the first floor; 1.5-2 tons/day/worker for the other floors (triang. dist.)**
P_h	**Daily productivity of workers in charge of handling**	**16-20 tons/day/worker (triang. dist.)**	**25-35 tons/day/worker (triang. dist.)**
P_u	**Daily productivity of workers in charge of unloading**	**21-29 tons/day/worker (triang. dist.)**	**30-50 tons/day/worker (triang. dist.)**
Q_r	Quantity of rebar required specified by project manager	See Table 2	See Table 2

$R_{repo\ ave}$	Interest rate (average overnight reverse rate)	0.09%	0.09%
R_w	**Percent of waste in on-site fabrication**	**7%-11% (triang. dist.)**	**3%-7% (triang. dist.)**
$R_{w\ max}$	**Probable maximum waste in on-site fabrication**	**11%**	**7%**
S_{truck}	Capacity of the trucks	26 tons	26 tons
T_a	Day of the project on which the assembly process needs to start	See Table 5	See Table 5
T_{ef}	**Date on which the superstructure is expected to be completed**	**See Table 6**	**See Table 6**
T_f	Day of the project on which the on-site fabrication process needs to start	See Table 5	See Table 5
T_p	Day of the project on which the purchasing process needs to start	See Table 5	See Table 5
T_u	Day of the project on which the unloading process needs to start	See Table 5	See Table 5
t_f	Duration of the on-site fabrication process	See Table 4	See Table 4
t_{lt}	**Promised lead time for straight rebar**	**2-3 days (triang. dist.)**	**1-2 days (triang. dist.)**
t_p	Duration of the procurement process	See Table 4	See Table 4
t_{pr}	**Duration of filing purchase requisition**	**1.5-2 days (triang. dist.)**	**0.5-1 days (triang. dist.)**
t_{rq}	**Duration of preparing request for quotation**	**1.5-2 days (triang. dist.)**	**0.5-1 days (triang. dist.)**
t_s	Duration storage area is kept in service	-	-
t_{ss}	**Duration of the supplier selection process**	**1-2 days (triang. dist.)**	**0.5-1 days (triang. dist.)**
t_u	Duration of the unloading process	See Table 4	See Table 4

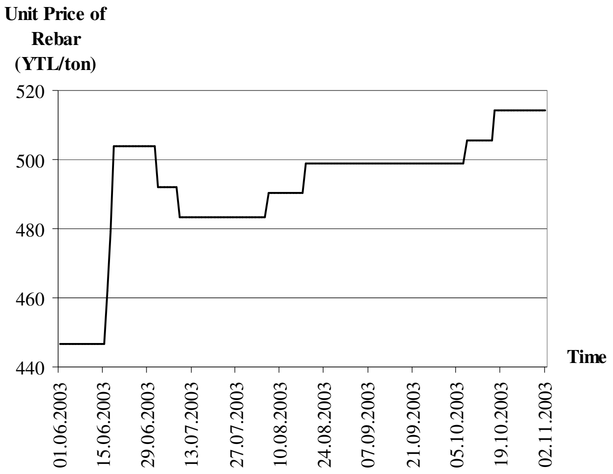

Figure 3: Unit Price of rebar in the period of June 2003 to October 2003 in Istanbul, Turkey

Table 2: Quantity of rebar required by site manager at the trade centre project

Floor	Required Quantity of Rebar (tons)	Floor	Required Quantity of Rebar (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		

In order to observe the impacts of implementing the companywide improvements on the economics of on-site rebar fabrication, 11 different combinations of 3 main scenarios presented in Table 3 are considered to be implemented by the contractor.

Table 3: Different combinations of three main scenarios and related inputs

Scenario #	Description	Related Inputs
Scenario 0	Actual project environment	-
Scenario 1	Actions are taken against uncertainty in the procurement process.	-
Scenario 1.1	Establishing long-term relationships with suppliers by means of appointing a staff in charge of achieving coordination between the contractor and the supplier.	t_{lt}, D_{ls}
Scenario 1.2	Establishing proper ordering procedures by means of employing trained personnel in charge of the procurement process.	$t_{pr}, t_{rq}, t_{ss,}, D_{pr}, D_{rq}, D_{ss}, D_{lc}$
Scenario 1.3	Implementing S.1.1 and S.1.2	$t_{pr}, t_{rq}, t_{ss,}, D_{pr}, D_{rq}, D_{ss}, t_{lt}, D_{lc,,} D_{ls}$
Scenario 2	Actions are taken against variations and uncertainty in the fabrication process by means of either appointing qualified workers rather than unqualified workers or conducting training programs.	-
Scenario 2.1	Appointing qualified workers rather than unqualified workers.	$P_u, P_f, P_h, P_{a,} R_w, R_{wmax}$
Scenario 2.2	Conducting training programs.	$P_u, P_f, P_h, P_{a,} R_w, R_{wmax}$
Scenario 3	Actions are taken against both uncertainty in the procurement process and variations and uncertainty in the fabrication process.	-
Scenario 3.1	Implementing S.1.1 and S.2.1	$t_{lt}, D_{ls,} P_u, P_f, P_h, P_{a,} R_w, R_{wmax}$
Scenario 3.2	Implementing S.1.1 and S.2.2	$t_{lt}, D_{ls,} P_u, P_f, P_h, P_{a,} R_w, R_{wmax}$
Scenario 3.3	Implementing S.1.2 and S.2.1	$t_{pr}, t_{rq}, t_{ss,}, D_{pr}, D_{rq}, D_{ss}, D_{lc,,} P_u, P_f, P_h, P_{a,} R_w, R_{wmax}$
Scenario 3.4	Implementing S.1.2 and S.2.2	$t_{pr}, t_{rq}, t_{ss,}, D_{pr}, D_{rq}, D_{ss}, D_{lc,,} P_u, P_f, P_h, P_{a,} R_w, R_{wmax}$
Scenario 3.5	Implementing S.1.3, and S.2.1	$t_{pr}, t_{rq}, t_{ss,}, D_{pr}, D_{rq}, D_{ss}, D_{lc,} t_{lt}, D_{ls,} P_u, P_f, P_h, P_{a,} R_w, R_{wmax}$
Scenario 3.6	Implementing S.1.3, and S.2.2	$t_{pr}, t_{rq}, t_{ss,}, D_{pr}, D_{rq}, D_{ss}, D_{lc,} t_{lt}, D_{ls,} P_u, P_f, P_h, P_{a,} R_w, R_{wmax}$

A contractor may implement one of the eleven different combinations of three main scenarios presented in Table 3. Start times and durations of the main activities associated with rebar are directly related to the scenario adopted because the values of the input variables change in each scenario. Durations of the main activities associated with rebar with respect to the scenario preferred are shown in Table 4. Since the same crews, workstations, and technical personnel are utilized in the same activities performed repeatedly for each floor, an activity associated with a floor cannot start until the same activity associated with the lower floor is finished. It is customary to start the assembly process one day after the fabrication process starts on that floor. Start times of the main activities associated with rebar with respect to the scenario preferred are shown in Table 5.

Table 4: Durations of the main activities associated with rebar, generated by Primavera Project Planner®

	Procurement process				Unloading process	On-site fabrication process		Assembly process	
	Durations (t_{pi})				Durations (t_{ui})	Durations (t_{fi})		Durations (t_{ai})	
	Scenario #				Scenario #	Scenario #		Scenario #	
Floor	S.0 S.2.1 S.2.2	S.1.1 S.3.1 S.3.2	S.1.2 S.3.3 S.3.4	S.1.3 S.3.5 S.3.6	S.0, S.1.1, S.1.2, S.1.3, S.2.1, S.2.2, S.3.1, S.3.2, S.3.3, S.3.4, S.3.5, S.3.6	S.0, S.1.1, S.1.2, S.1.3	S.2.1, S.2.2, S.3.1, S.3.2, S.3.3, S.3.4, S.3.5, S.3.6	S.0, S.1.1, S.1.2, S.1.3	S.2.1, S.2.2, S.3.1, S.3.2, S.3.3, S.3.4, S.3.5, S.3.6
1	11	10	7	6	1	11	6	14	10
2	11	10	7	6	1	9	5	11	9
3	11	10	7	6	1	9	5	11	9

4	11	10	7	6	1	9	5	11	9
5	11	10	7	6	1	9	5	11	9
6	11	10	7	6	1	7	4	9	7
7	11	10	7	6	1	7	4	9	7
8	11	10	7	6	1	7	4	9	7
9	11	10	7	6	1	7	4	9	7
10	11	10	7	6	1	7	4	9	7
11	11	10	7	6	1	7	4	9	7
12	11	10	7	6	1	7	4	9	7
13	11	10	7	6	1	7	4	9	7

Table 5: Start times of the main activities associated with rebar, generated by Primavera Project Planner®

Floor	Procurement process								Unloading process							
	Start times (T_{pi})								Start times (T_{ui})							
	Scenario #								Scenario #							
	S.0	S.1.1	S.1.2	S.1.3	S.2.1 S.2.2	S.3.1 S.3.2	S.3.3 S.3.4	S.3.5 S.3.6	S.0	S.1.1	S.1.2	S.1.3	S.2.1 S.2.2	S.3.1 S.3.2	S.3.3 S.3.4	S.3.5 S.3.6
1	0	0	0	0	0	0	0	0	13	11	8	7	12	11	8	7
2	13	11	8	7	12	11	8	7	26	23	16	14	25	23	16	14
3	26	23	16	14	25	23	16	14	39	35	24	21	38	35	24	21
4	39	35	24	21	38	35	24	21	52	46	32	28	51	46	32	28
5	52	46	32	28	51	46	32	28	65	58	40	35	64	58	40	35
6	65	58	40	35	64	58	40	35	77	70	49	42	77	70	49	42
7	77	70	49	42	77	70	49	42	90	81	57	49	89	81	57	49
8	90	81	57	49	89	81	57	49	103	93	65	56	102	93	65	56
9	103	93	65	56	102	93	65	56	116	105	73	63	115	105	73	63
10	116	105	73	63	115	105	73	63	129	116	81	70	128	116	81	70
11	129	116	81	70	128	116	81	70	142	128	89	77	141	128	89	77
12	142	128	89	77	141	128	89	77	154	140	98	84	154	140	98	84
13	154	140	98	84	154	140	98	84	167	151	106	91	166	151	106	91

Floor	On-site fabrication process								Assembly process							
	Start times (T_{fi})								Start times (T_{ai})							
	Scenario #								Scenario #							
	S.0	S.1.1	S.1.2	S.1.3	S.2.1 S.2.2	S.3.1 S.3.2	S.3.3 S.3.4	S.3.5 S.3.6	S.0	S.1.1	S.1.2	S.1.3	S.2.1 S.2.2	S.3.1 S.3.2	S.3.3 S.3.4	S.3.5 S.3.6
1	14	12	9	8	14	12	9	8	16	14	10	9	15	14	10	9
2	27	25	22	21	26	24	17	15	32	30	26	25	28	25	22	21
3	40	36	32	31	39	36	25	22	45	43	39	38	40	37	32	31
4	53	47	43	42	52	47	33	29	58	56	52	51	53	49	43	42
5	66	59	53	52	65	59	42	36	70	68	65	64	66	60	53	52
6	79	71	64	63	78	71	50	43	83	81	78	77	79	72	64	63
7	91	82	72	71	91	82	58	50	94	92	88	87	92	84	72	71
8	104	94	80	79	103	94	66	57	105	102	99	98	105	95	80	79
9	117	106	88	87	116	106	74	64	118	113	109	108	117	107	88	87
10	130	117	96	95	129	117	82	71	131	123	120	119	130	119	96	95
11	143	129	105	103	142	129	91	78	144	134	130	129	143	130	105	103
12	156	141	113	112	155	141	99	85	157	144	141	140	156	142	113	112
13	168	152	121	120	168	152	107	92	170	155	151	150	169	154	121	120

Table 6: Completion of rebar assembly on last floor occurs (T_{efj})

Scenario #	T_{efj}	Scenario #	T_{efj}	Scenario #	T_{efj}	Scenario #	T_{efj}	Scenario #	T_{efj}	Scenario #	T_{efj}
S.0	179	S.1.2	161	S.2.1	176	S.3.1	161	S.3.3	128	S.3.5	127
S.1.1	164	S.1.3	159	S.2.2	176	S.3.2	161	S.3.4	128	S.3.6	127

COST COMPONENTS

The cost components of the total cost of rebar are defined by Polat and Ballard (2005). The brief definitions for the cost components of the total cost of rebar are presented below:

1. Purchasing cost (PC): The purchasing cost represents the direct cost of rebar to the contractor. It is directly governed by the quantity of rebar to be purchased and the unit price of rebar when it is purchased. In turn, the quantity of rebar required is a function of the scrap rate; i.e., the percentage of material wasted. In Turkey, while inflation tends to increase over time, the unit price is driven by market demand. In a period of increasing price, buying rebar earlier would reduce the purchasing cost, but in a period of decreasing price, buying rebar earlier would increase the purchasing cost.
2. Financing cost (FC): When material is purchased before it is needed, the inventory is carried in storage with a financing cost. It depends on the length of time rebar is kept in inventory (i.e., the time between delivery and the actual start time of an activity), and the value of money.
3. On-site fabrication cost (OC): This is the sum of the costs associated with on-site fabrication activities. It is governed by the total duration of on-site fabrication process which directly depends on the daily productivity of workers and the number of workers in charge of on-site fabrication, the daily wage of workers, and the cost of cutting and bending workstations to the project. Conducting training programs and/or appointing more qualified workers add extra cost to the total cost of rebar, but they result in increases in the productivity of the workers in charge of on-site fabrication process, which brings about shorter duration of on-site fabrication process.
4. Handling cost (HC): This is the cost of moving rebar from one point on site to another. It depends on the quantity of rebar to be handled, the time when rebar is delivered to the construction site, the duration of the productivity of handling workers, and the number of workers in charge of handling. Achieving the delivery of the ordered rebar when it is needed on site by means of establishing proper ordering procedure and/or establishing long term relationships with suppliers reduces the quantity of rebar to be handled and any improvement in the productivity of handling workers shortens the duration spent on handling rebar, which apparently lowers the handling cost.
5. Storage cost (StC): Storage cost consists of the rental cost of the storage area and depends on the time the storage area is kept in service.
6. Delivery cost (DC): This is the cost of moving the rebar from the supplier's warehouse to the construction site and depends on the number of truckloads involved in each delivery as well as the unit cost of delivery per truckload.
7. Waiting cost (WC): This is the cost of idle workers waiting for rebar to arrive. Total delay throughout the project is the sum of the time gaps between the actual and scheduled start dates of the activities associated with rebar.
8. Shortage cost (ShC): This is the cost of delay caused by shortage of rebar. 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 rebar assembly process in the last floor compared to the scheduled finish date.

9. Early finish bonus (EfB): This is the revenue generated from time savings in case the delivery of the superstructure occurs ahead of schedule and the contract includes a bonus for early delivery. Early completion of the project results in incentive payments to a contractor, reduced overhead, and increased profit. Any improvement resulting in early completion of the project increases early finish bonus.
10. Cost of establishing proper ordering procedure (OpC): This is the sum of the monthly wages of an expert civil engineer, who is responsible for managing procurement activities.
11. Training costs (TC): This is the cost of conducting a training program to boost the capabilities and skills of the workers.
12. Cost of establishing long term relationships with suppliers (LrC): This is the sum of the monthly wages of a specialist, who is responsible for establishing close relationships with suppliers and achieving on time deliveries with the right quantity and quality. It should be noted that this task may likely be carried out by the expert civil engineer, who is also responsible for managing procurement activities. But, cost of establishing long term relationships with suppliers (LrC) should be considered to be the cost of hours spent on establishing close relationships with suppliers.

SIMULATION RESULTS AND DISCUSSION

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 at least 100 times until the coefficient of variance went below 0.5% each scenario. Five of the foremost factors that have a direct and significant impact on the economics of the rebar management system and their values in each combination of the scenarios are shown in Table 7.

Table 7: Important factors in different combinations of the main scenarios

Important Factors	**Scenario #**											
	S.0	**S.1.1**	**S.1.2**	**S.1.3**	**S.2.1**	**S.2.2**	**S.3.1**	**S.3.2**	**S.3.3**	**S.3.4**	**S.3.5**	**S.3.6**
Day on which the project is completed	178	164	161	159	174	174	159	159	126	126	124	125
Number of days spent on on-site fabrication	79	83	81	77	41	42	42	42	43	40	42	40
Daily wage of the worker in charge of fabrication	30	30	30	30	45	30	45	30	45	30	45	30
Daily wage of the worker in charge of handling	20	20	20	20	25	20	25	20	25	20	25	20
Number of days spent on handling	22	23	22	22	12	10	11	11	11	11	11	12

The values of each cost component and TCR in the case study and the estimated TCR for on-site fabrication after the recommended companywide improvements have been implemented are presented in Table 8.

Table 8: Cost components and total cost of rebar in different scenarios

Cost Comp.	**S.0 (YTL)**	**S.1.1 (YTL)**	**S.1.2 (YTL)**	**S.1.3 (YTL)**	**S.2.1 (YTL)**	**S.2.2 (YTL)**	**S.3.1 (YTL)**	**S.3.2 (YTL)**	**S.3.3 (YTL)**	**S.3.4 (YTL)**	**S.3.5 (YTL)**	**S.3.6 (YTL)**
PC	191,622	191,700	188,770	187,777	183,508	184,022	184,660	184,146	180,890	181,389	182,704	182,205
FC	368	375	576	844	312	291	298	301	299	307	298	304
OC	6,240	6,480	6,360	6,120	5,190	4,020	5,100	4,020	5,370	3,900	5,280	3,900
HC	890	897	845	862	584	399	551	410	548	411	529	459
StC	-	-	-	-	-	-	-	-	-	-	-	-
DC	3,200	3,200	3,200	3,200	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
WC	-	-	-	-	-	-	-	-	-	-	-	-
ShC	0	0	0	0	0	0	0	0	0	0	0	0
EfB	0	-(1,050)	-(1,275)	-(1,425)	-(300)	-(300)	-(1,425)	-(1,425)	-(3,900)	-(3,900)	-(4,050)	-(3,975)
OpC	-	-	6,000	6,000	-	-	-	-	5,000	5,000	5,000	5,000
TC	-	-	-	-	-	1,500	-	1,500	-	1,500	-	1,500
LrC	-	500	-	500	-	-	500	500	-	-	500	500
(TCR[3])	**202,320**	202,102	204,476	**208,378**	192,294	192,932	192,684	192,452	**191,207**	191,607	193,261	192,893

Establishing long-term relationships with suppliers adds an extra cost of 500 YTL. However, it does have a considerable impact on TCR. Establishing proper ordering procedure adds an extra cost of 1,000 YTL per month, which eventually increases TCR significantly. The main advantage of procuring rebar early is the low purchasing cost. On the other hand, it has several disadvantages including high handling cost and financing cost. Moreover, that kind of improvement does not have any positive impact on reducing the on-site fabrication cost or increasing the early finish bonus. The simulation results confirmed that taking actions against uncertainty in the procurement process alone does not help reducing TCR.

Apparently, improving workers' productivity is much more efficient on the economics of rebar management system than taking actions against uncertainty in the procurement process. The main reason behind that consequence is that improving workers' productivity results in early completion of the project, which ultimately brings about incentive payments to a contractor, reduced overhead, and increased profit. Variations and uncertainty in the fabrication process can be overcome by means of either appointing qualified workers or conducting training programs. The simulation results revealed that implementing any of those improvement suggestions results in more or less the same TCR.

Based on the simulation results, both establishing proper ordering procedure and improving workers' productivity bring about the lowest TCR. Apparently, implementing the scenario # 1.3 results in the highest TCR, and implementing scenario # 3.3 brings about the lowest TCR. Implementation of scenario # 1.3 in the trade center project adds an extra cost of 6,058 YTL. This corresponds to a decrease of 3.1% in the profit margin of the contractor. On the other hand, implementing scenario # 3.3 in the trade center project provides the contractor with an advantage of 11,113 YTL, which corresponds to an increase of 5.6% in the profit margin of the contractor.

CONCLUSIONS

Rebar is very critical in the process of constructing reinforced concrete structures. Therefore, rebar supply chains need to be well managed in order to achieve project goals. The special conditions of a project's environment directly influence the economics of rebar supply

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[3] **TCR = PC + FC + OC + HC + StC + DC + WC + ShC - EfB + OpC + TC + LrC**

chains. Great fluctuations in the unit price of rebar and high shipping costs are mostly related to the overall state of the economy of the country and beyond the control of a contractor. On the other hand, uncertainty in the procurement process and variations and uncertainty in the fabrication process are controllable factors and may likely be overcome through implementing companywide improvements such as establishing long-term relationships with suppliers, establishing proper ordering procedures, conducting training programs, and appointing qualified workers rather than unqualified workers. Undoubtedly, there is a cost to a contractor of making such improvements.

This study provides contractors a decision support tool, namely a discrete event simulation model, with which to determine the probable outcomes of implementing different combinations of improvements. For this purpose, 11 different combinations of 3 main scenarios for the improvement suggestions that need to be implemented are proposed and the impacts of implementing such improvements on the economics of on-site fabrication practice of rebar are analyzed in order to assist contractors to decide on making investments in such improvements or not. The simulation model was run by using actual data obtained from a 13-story trade centre project in Istanbul, Turkey. The simulation results revealed that establishing proper ordering procedures by means of employing trained personnel in charge of the procurement process and appointing qualified workers provide the contractor with an advantage of 11,113 YTL, which corresponds to an increase of 5.6% in the profit margin of the contractor.

This study is useful in two ways. First, it proposes a model of benefit to contractors, which familiarizes them with the impacts of implementing such improvements on the economics of on-site fabrication practice of rebar and assists them to decide on making investments in such improvements or not. Secondly, it suggests a further study. The present study is limited, because it analyzes the impacts of the controllable factors on the economics of on-site fabrication practice of rebar. However, in a different project environment in which the nationwide (i.e., stable unit price of rebar or low fluctuations in unit prices of rebar) and industry wide (i.e., low shipping cost) improvements were implemented in order to reduce the negative impacts of the uncontrollable factors, the most economical rebar management system might have been totally different. Thus, there is need for further study, which analyzes the impacts of implementing nationwide and industry wide improvements as well as the companywide improvements on the economics of on-site fabrication practice of rebar.

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