CONSTRUCTION SUPPLY CHAINS: TURKISH SUPPLY CHAIN CONFIGURATIONS FOR CUT AND BENT REBAR

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ABSTRACT

This paper presents current supply chain configurations for concrete reinforcement steel (rebar) in the Turkish construction industry. The supply chains were assessed by the value stream mapping method and were investigated through visits to firms involved in the supply chain and interviews with practitioners. Five different types of rebar supply chain configurations were identified in the case studies. A significant number of problems were also identified resulting from inaccurate data transfers among participants, and also from delays and interruptions in information flow. This paper details the root causes of problems throughout the supply chain comprising engineering, detailing, reckoning, fabrication and procurement processes. It is proposed that the problems are caused by fragmentation in the construction industry, and by lack of awareness of the supply chain management concept and its benefits. Finally, a set of recommendations for performance improvement are proposed.

KEY WORDS

Concrete reinforcing steel, rebar, supply chain management, supply chain management in construction, construction supply chains, process mapping, supply chain analysis, value stream mapping.

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INTRODUCTION

The Turkish construction industry has been stagnant since the earthquake disasters occurred in 1999. The contractors managing their business in Turkey have been especially affected by this economic crisis (ZIMDER, 2002).

Since constructing steel structures requires specialized laborers and expensive technology, reinforced concrete structures are commonly preferred in Turkey (Ersoy, 1995). While reinforced concrete structures comprise thousands of components, a structural framework is constructed in three basic sequential activities: preparing formwork, installing rebar and pouring concrete. Supply chains for the components need to be well managed in order to achieve project goals. The inefficiencies in the supply chains lead to exceeding budget and schedule goals of a construction project. Therefore, the inefficiencies in the supply chains should first be identified and then removed.

From interviews with practitioners, it was inferred that late deliveries and/or arrivals of inaccurate cut & bent rebar[3] to construction were common. This paper presents the actual supply chain configurations for cut & bent rebar in the Turkish construction industry. The supply chain configurations represent designing, detailing, reckoning, milling and fabricating activities of the rebar. Supply chain participants perform different roles in this chain related to needs of the project, and, the characteristics and the capacities of the participants. Mainly two different types of supply chains prevail in Turkey, and these are analyzed and evaluated in respect of lead time. The root causes of the inefficiencies are determined. Finally, a set of recommendations for supply chain performance improvement are presented and future research is proposed.

DESCRIPTION OF SUPPLY CHAIN PRACTICES FOR CUT & BENT REBAR

Pursuing a lean construction approach[4], several firms were visited and many practitioners were interviewed in order to discover prevalent supply chain practices of cut & bent rebar in the Turkish construction industry. The analysis of data obtained reveals that various kinds of supply chain practices exist. The most common practices are presented in this study. Practices are presented using the value stream mapping method, which shows the flow of material and information from customer order through delivery to the customer, and facilitates identification of waste and its root causes (Arbulu and Tommelein, 2002). Value stream analysis involves mapping the actual state and a future state in which the waste is eliminated, defining the differences between them, and developing a road map revealing the actions required to realize the future state map (Rother and Shook, 1998). In this study, the most commonly used current state process maps for rebar supply are presented, representing the flows of information and material throughout the design, detailing, reckoning, milling and fabrication phases.

Main participants in the supply chain for cut & bent rebar in Turkey are: 1) Engineering firms, 2) Rolling mills, 3) Rebar fabricators, 4) Contractors. Designers (architect, electrical

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3 Mentions of "rebar" typically imply "cut and bent rebar".

4 "Mapping … supply chains is a central research task. Once chains are understood, they may be reconfigured, and both costs and lead times reduced." (Ballard, 2000).

engineer, mechanical engineer etc.) and steel mills (manufacturing steel billets) may play a role in this supply chain; however, they are not central to the action, so they are not considered in this study. The five configurations consist of approximately the same activities performed by different participants. Contents of these activities can be briefly described as follows:

1) Designing:
   - Analyzing necessary documents (architectural, mechanical, electrical and other services designs, loads etc.)
   - Determining structural type of the building
   - Preparing pre-designs
   - Performing structural analysis (static and dynamics)
   - Preparing structural designs (reinforced concrete designs)
   - Preparing detailed cut and bent rebar drawings.
2) Detailing:
   - Preparing quantity surveys
   - Determining the bending positions of the cut and bent rebar.
3) Reckoning:
   - Determining the dimensions of the steel bars that are used in the fabrication phase considering the extension capacity and property of the steel.
4) Milling:
   - Annealing the steel billets at the proper temperature
   - Giving a required shape to the annealed steel billets at the rolling mill workbenches
   - Performing thermal operation upon deformed steel bars
   - Shearing the steel bars in accordance with the sizes of the cooling platform
   - Cooling the products on the cooling platform
   - Taking samples and performing required quality control tests
   - Cutting the cooled products in the sizes needed by the customer
   - Taking samples and performing required quality control tests
   - Packaging the cut steel bars.
5) Fabricating:

- Producing straight rebar or wire rod cut according to the requirements of a specific construction project.
    - Straightening the wire rod by a machine (if wire rod is used)
    - Cutting the straightened wire rod or bar to the required length
    - Grouping the cut rods or bars in respect of length and size
    - Labeling the cut rods or bars according to the bar mark
    - Packaging the cut rods or steel bars.
- Producing stirrups:
    - If wire rod is used:
        - Cutting the straightened wire rod to the required length
        - Preparing the stirrups by a machine
        - Labeling and packaging the stirrups
    - If steel bars are used:
        - Cutting the bars to the required length
        - Forming the bars into stirrups
        - Labeling and packaging the stirrups

6) Delivery of goods (straight steel bars or cut & bent rebar) to the client.

7) Installation of cut & bent rebar.

Delivery to site and installation are mentioned but have not been detailed in this study.

Different configurations of the supply chain for cut & bent rebar are shown in the following process maps:

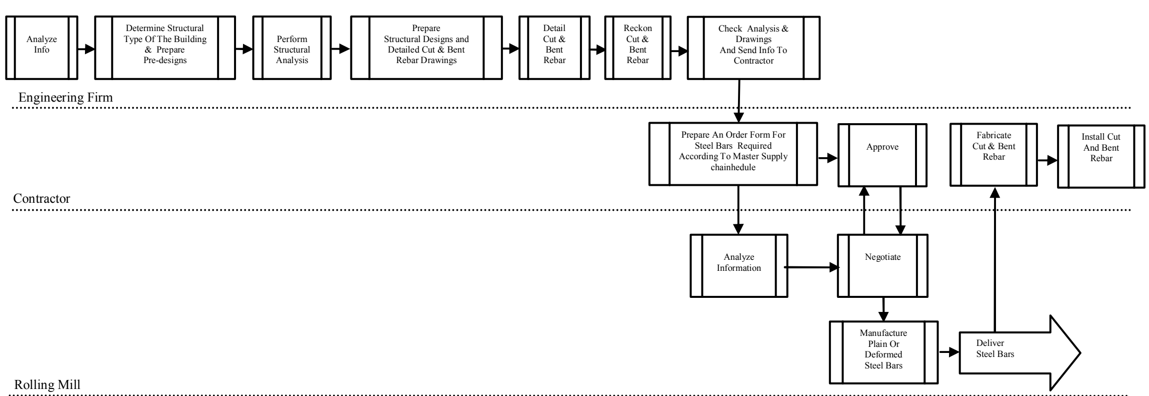


Figure 1: Configuration 1

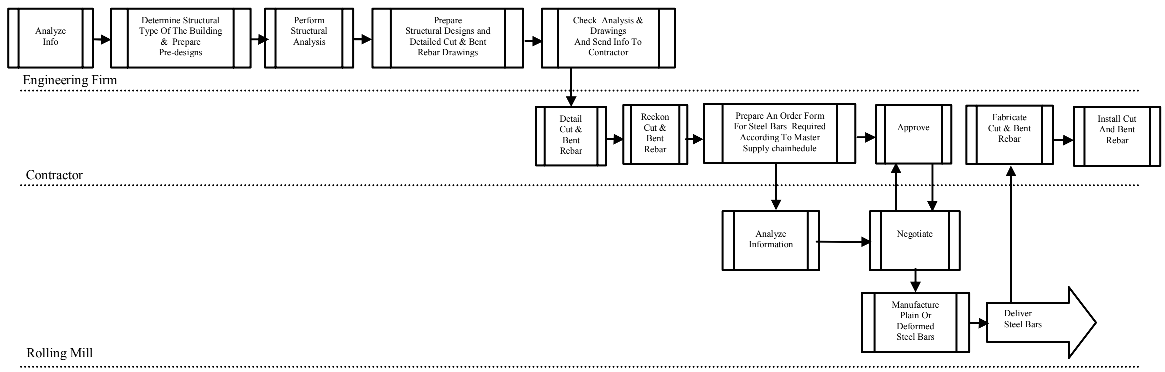


Figure 2: Configuration 2

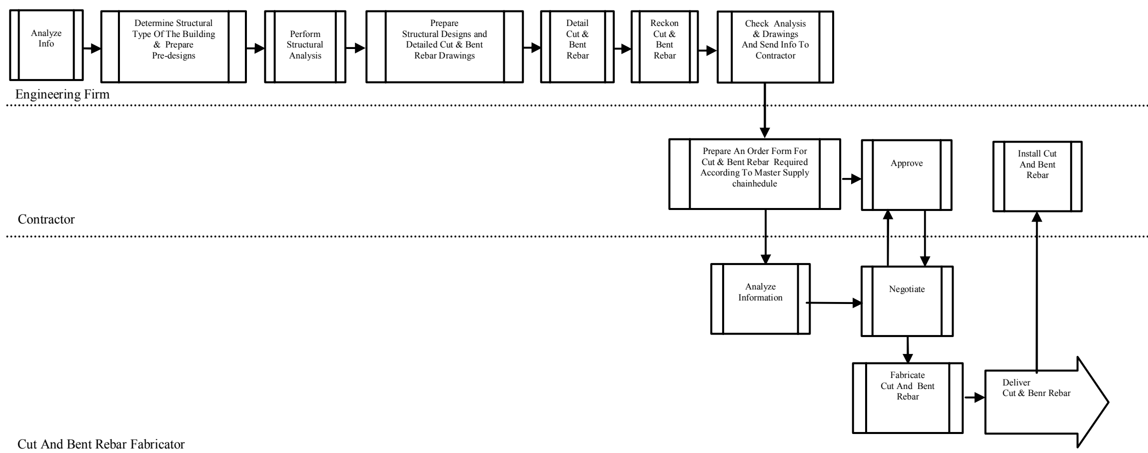


Figure 3: Configuration 3

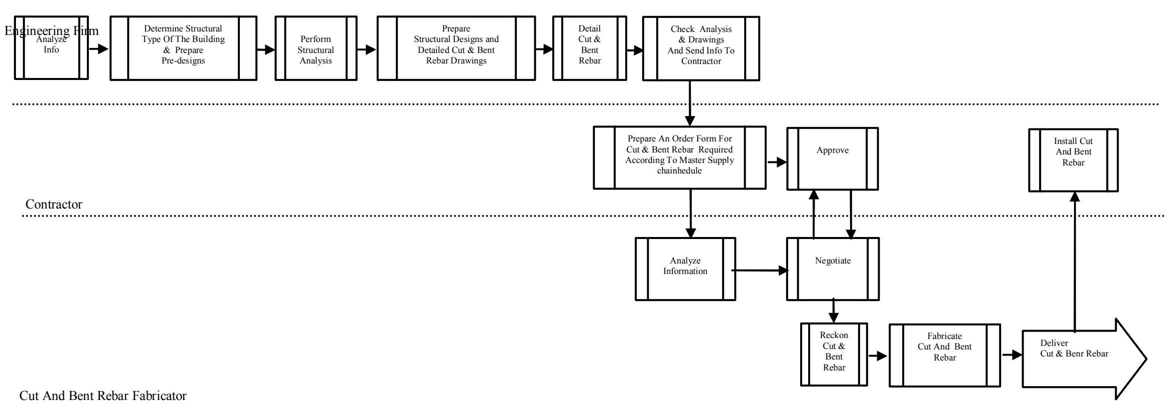


Figure 4: Configuration 4

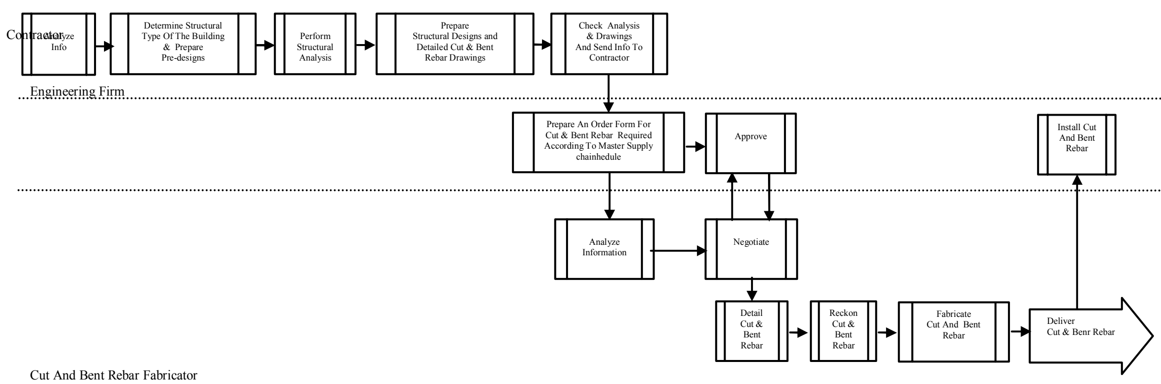


Figure 5: Configuration 5

A rolling mill always supplies the rebar, an engineer always does the design and a contractor always does the installation. However, as shown in Table 1, fabrication, detailing and reckoning are done by different players in different configurations.

Table 1: Distribution of duties in each configuration

	Detail	Reckon	Fabricate
Engineer	1,3,4	1,3	
Fabricator	5	4,5	3,4,5
Contractor	2	2	1,2

Examining the supply chain configurations, it is apparent that all have approximately the same number of handoffs between the participants. However, it should be noted that in configurations 3, 4 and 5, the fabricator procures the steel bars or wide rods from the rolling mill. Therefore, in these configurations the rolling mill is directly involved in the supply chain and directly affects the lead time of the fabricator. This situation will be considered when analyzing the performance of the supply chains.

Selection of a configuration depends on many factors such as the experience of the practitioners, capacities of the firms and requirements of the project.

In Configuration 1, the engineering firm is in charge of all activities involving designing, detailing and reckoning. The fabrication of cut & bent rebar is performed by laborers on site workbenches. Since most of the contractors in Turkey do not have in-house capacity to execute the designing, detailing and reckoning activities, this configuration is the most common. In this configuration, interdependence between the participants is less than in the other configurations. All of the data necessary for the contractor to initiate procurement and fabrication is generated by the engineering firm. A disadvantage of this configuration is that the contractor receives the documents after all of the designing, detailing and reckoning activities are accomplished. This sequential (cascading) configuration does not allow the participants to solve problems at the right time, and thus leads to rework.

In Configuration 2, the designing activity is performed by the engineering firm and the detailing and reckoning activities are performed by the contractor. When the contractor is capable of executing these activities, this type of configuration is preferred. In this configuration, the contractor can intervene with the engineering firm early in order to solve problems resulting from inaccurate data transfers, change orders and/or inadequate designs, and this avoids rework. This configuration requires smooth communication among the parties and collaboration to facilitate the transfer of information from designer to contractor, feedback from contractor to designer, and corrective action by the designer.

Configuration 3 is similar to Configuration 1. However, there are differences. While in Configuration 1, fabrication is performed by the contractor, in Configuration 3, it is performed by the rebar fabricator. If the contractor does not have sufficient in-house capacity to fabricate the cut & bent rebar, the fabricator is charged with fabrication. Reciprocal dependence between the rebar fabricator and the contractor in this configuration is as high as in Configurations 4 and 5. If the contractor does not provide accurate and timely information to the fabricator, the delivery of cut & bent rebar to the site is delayed, and installation begins late.

Configurations 4 and 5 have more-or-less similar characteristics. While the fabricator performs the reckoning in Configuration 4, the fabricator does both detailing and reckoning activities in Configuration 5. These configurations are preferred when the fabricator is capable of performing one or both of these activities and a large amount of materials are requested. The interdependency between the engineering firm and the fabricator is high. However, the fabricator does not communicate and collaborate directly with the engineering firm. The handoff between the parties is done by the contractor as a middleman. This causes interruption and delays in information flow. The reciprocal dependence between the fabricator and the contractor in these configurations are as high as in Configuration 3.

In respect of the aforementioned descriptions and explanations, the basic features of the SC configurations are summarized in Table 2.

SUPPLY CHAIN ANALYSIS

The main purpose of the rebar supply chain is to maximize the operational efficiency, profitability and competitive advantage of the participating firms by meeting the customer's requirements in a better way. Therefore, the performance of the supply chain can be measured in part by using metrics such as time, cost and quality. However, all of these metrics are aimed at attaining value effectively and efficiently. The term 'value' refers to fulfilling the customer's specific needs (Womack and Jones, 1996). In this study, only the time metric is analyzed.

In order to measure rebar supply chain performance in terms of time, several durations are appropriate, including the time to produce and to approve the detailed cut & bent rebar drawings, the time required for detailing and reckoning rebar, the time to deliver rebar to the site, the time to fabricate , and the time to install the cut & bent rebar. In this paper, the total time in process (lead time) of a rebar order is compared with the time when work was actually being performed on the order, value-adding time[5]. This metric identifies waste or non-value-adding time, the elimination of which reduces lead time.

[5] Strictly speaking, value-adding activities are those necessary for the delivery of value to the customer, and so some portions of processing time may be value-adding and some not. In this study, we did not make that

Table 2: Basic features of the SC configurations

Conf.	Characteristics	Advantages	Disadvantages	Comments
1	Engineer designs, details & reckons, then hands off to contractor, rolling mill supplies steel bars	Least interdependence of the players	High rework from separation of designers and constructors	Most commonly used configuration
2	Engineer designs then hands off to contractor, contractor details & reckons, and supplies steel bar from rolling mill	Low rework from early intervention of the contractor with engineer	Smooth communication among the players is required	Preferred if the contractor is capable of executing detailing & reckoning activities
3	Engineer designs, details & reckons, then hands off to contractor, fabricator supplies cut & bent rebar	Low interdependence of the players, Low cycle and lead time of cut & bent rebar compared with on-site fabrication	High rework from separation of designers and constructors, High reciprocal dependence between contractor and fabricator	Preferred if the contractor doesn't have sufficient in-house capacity for fabrication
4	Engineer designs, details, then hands off to contractor, fabricator reckons and supplies cut & bent rebar	Low cycle and lead time of cut & bent rebar compared with on-site fabrication	High interdependency between engineer and fabricator, High reciprocal dependence between contractor and fabricator	Preferred if the fabricator is capable of executing reckoning activity, and a large amount of materials are requested
5	Engineer designs then hands off to contractor, fabricator details, reckons and supplies cut & bent rebar	Low rework from early intervention of the contractor with engineer, Low cycle and lead time of cut & bent rebar compared with on-site fabrication	Smooth communication among the players is required, Highest interdependency between engineer and fabricator, High reciprocal dependence between contractor and fabricator	Preferred if the fabricator is capable of executing both detailing & reckoning activities, and a large amount of materials are requested

Given the fact that most contractors are not capable of detailing and reckoning, two types of supply chain configurations are most common. In the first, the contractor procures steel bars from the rolling mill and takes responsibility for fabricating and installing them (Configurations 1,2), and in the second, the contractor acquires rebar from the fabricator and does the installation (Configurations 3,4,5). Consequently, in this study the performance of the supply chain is analyzed for Configuration 1 representing the first type of supply chain (Figure 1) and Configuration 3 representing the second type of supply chain (Figure 3).

The time values presented in Figure 6 and Figure 7 are actual values per 100 tons of rebar determined from an ongoing trade center project in Istanbul. Both of the configurations were found in this project. The time values were obtained from interviews with the practitioners and calculated by sight during visits to each of the firms participating in this chain. It should be noted that the values are valid for rebar with dimensions out of standard (length > 12 m, diameter >20 mm). Time values differ for rebar with standard dimensions.

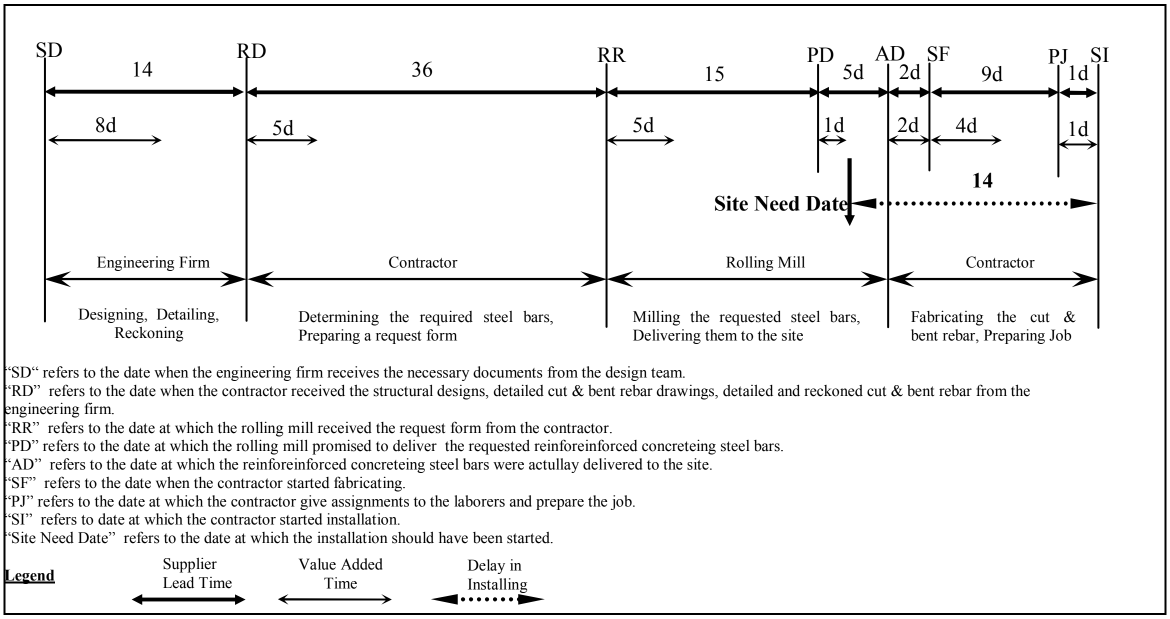
Figure 6, valid for Configuration 1 (Figure 1), illustrates the relationships between value-adding time and actual elapsed time (supplier lead times). The supply chain begins with the date at which the engineering firm receives the necessary documents from the design team and ends with the installation of the cut & bent rebar. For example, although the contractor determines the required steel bars and prepares the request form in 5 days, it takes 36 days for the contractor to send the request form to the rolling mill. From interviews with the practitioners, it was found that the request form for the required cut & bent rebar was prepared floor by floor. The construction of any floor takes approximately 8 weeks (6.5

distinction, so equate the duration of value-adding activities with processing time. More precise measurement is needed in future studies.

working days per week). When the contractor begins constructing a floor, the documents including structural designs, detailed cut & bent rebar drawings, details and reckonings of the next floor begin to be checked. (Practitioners reported that calculation mistakes, contradictions between the designs, obscure points and non-constructible details are very common. Basic causes of these problems are non standardized format of data and lack of coordination between the parties). This process takes approximately three days. In case one or more of the aforementioned problems occur, the documents are sent back to the engineer or the required data is requested. It takes 1 to 3 weeks to acquire the requisite data. The request form is prepared based on the corrected documents, which are conveyed to the foreman in charge of the reinforced concrete structure. He analyzes the documents and prepares the request form after 70 – 80 % of the construction of the floor is completed. This new request form is compared with the one previously prepared. If there is a difference between them, the reason is investigated and the actual demand is determined. This process takes approximately two days. The final request form that will be sent to the rolling mill is based on the actual requirements on site which is also proved by the scheduled demands. The revised request form is transmitted to the rolling mill. Consequently, while only 5 days are spent on determining the required steel bars and preparing a request form, the transmission of this form to the rolling mill takes 36 days.

The rolling mill's lead time is the period from receiving the request form from the contractor (RR) until actually delivering the requested steel bars to the site (AD). This process takes 20 calendar days (15d+5d). However only 6 days (5+1) during that period were spent actually upon milling and delivering the bar; i.e., 6 days value -added time. Both the interviews with the practitioners and observations revealed that when a request is received for cut & bent rebar with nonstandard dimensions, the rolling mill takes approximately 10 - 15 days to supply the rebar. The main reason for this delay is the inflexible production system of the rolling mills resulting from long setup times. Rolling mills exhibit mass production characteristics. Single purpose machines are utilized for producing goods with standard dimensions. Producing goods out of standard dimensions require re-setup of the machines, and the production process stops for a while. Since the rolling mill was working on previously received orders of goods with standard dimensions, the production process couldn't be stopped. Therefore, in this case the delay was 14 (20-6) days. The contractor's fabrication phase starts with procuring the steel bars. Late delivery of rebar caused the contractor's fabrication phase to begin late.

As another example, although only 4 days are spent on the fabrication, this process takes 9 days. There are no construction unions in Turkey. While the cost of the workers is very low, their skills are not satisfactory. In this case, the basic reason of the delay was priority changes (i.e. the truck comes to the site, the goods should immediately be unloaded, and the laborers help to unload) and reworks due to workers' mistakes.



FiFigure 6: Lead times in procuring steel bars, fabricating and installing.

In this configuration, it is observed that only 26 days are spent on the necessary activities for the supply chain while the whole chain takes 82 days. 68 % of total time is wasted. The percentages of wasted time in all activities of the supply chain are summarized in Table 3.

Table 3: Wasted time in the supply chain activities in Figure 6

Activities	Value-add	Lead Time	W. Time (%)
Designing, Detailing, Reckoning	8	14	43
Determining the required steel bars, Preparing a request form	5	36	86
Milling the requested steel bars	5	15	67
Delivering the manufactured steel bars to the site	1	5	80
Preparation for fabrication	2	2	0
Fabricating the cut & bent rebar	4	9	56
Preparing job	1	1	0
Total Values	**26**	**82**	**68**

The main reasons for this high amount of waste appear to be inaccurate data transfers among the participants, delays and interruptions in information flow, lack of coordination among the parties, non standardized format of data, inflexible production systems, etc.

Figure 7 represents Configuration 3 (Figure 3). In Figure 7, the rebar fabricator actually delivers the requested cut & bent rebar to the site in 19 days (17d+2d) while fabrication and delivery takes 3 days (2d+1d). In this case the delay is 16 days; 12 days due to delay in the supply of rebar, 1 day due to priority changes, 2 days due to misunderstandings and rework resulting from slipshod ordering procedure, 1 day due to setup. The contractor's installation phase starts with procuring the cut & bent rebar. When the fabricator's lead time extends, the contractor's installation phase is delayed.

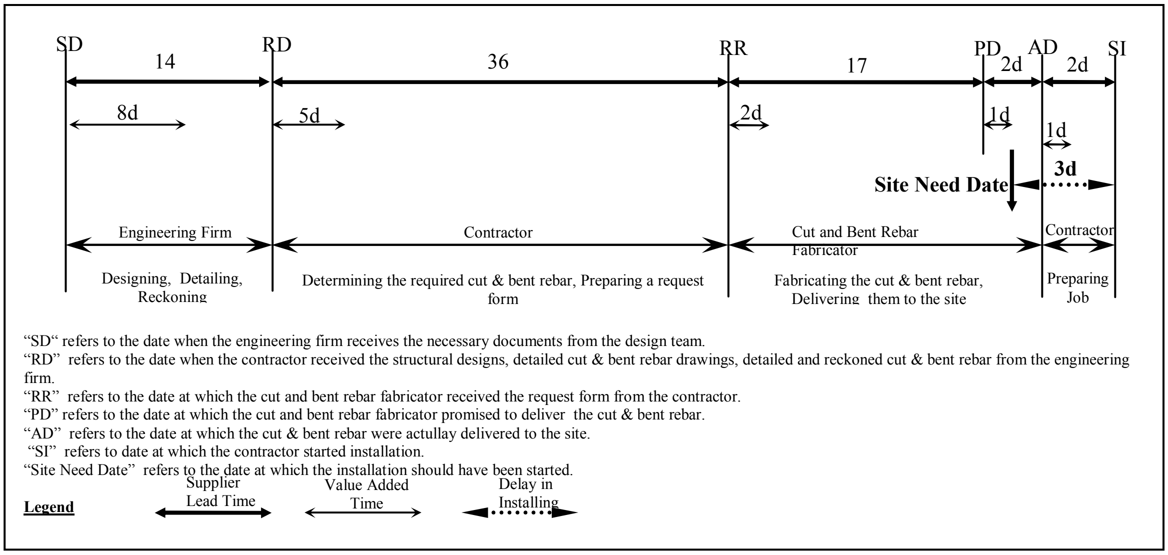


Figure 7: Lead times in procuring cut & bent rebar and installing.

In this configuration, only 17 days are spent on necessary, value adding activities while the whole delivery process takes 71 days. 76 % of total supply chain time is wasted. The wasted time percentages in all activities of the supply chain are summarized in Table 4.

Table 4: Wasted Time percentages in supply chain activities in Figure 7.

Activities	Value-add	Lead Time	W. Time (%)
Designing, Detailing, Reckoning	8	14	43
Determining the required cut & bent rebar, Preparing a request form	5	36	86
Fabricating the requested cut & bent rebar	2	17	88
Delivering the cut & bent rebar to the site	1	2	50
Preparing job	1	2	50
Total Values	**17**	**71**	**76**

The main reasons for this high amount of waste appear to be, delay in the supply of plain or deformed steel bar, priority changes, slipshod ordering procedure, inaccurate data transfers among the participants, inflexible production systems, etc.

EVALUATION OF SUPPLY CHAINS

Based on interviews with the practitioners, it was found that in the Turkish construction industry, the design-bid-build system is very prevalent and that “value” is defined in the designing phase (designing means preparation of the architectural, mechanical, electrical etc., designs by the design team). Thus, change orders are frequent.

Since the owner doesn’t trust in the honesty of the contractor and most of the contractors are not capable of accomplishing both designing and building activities, the handoffs and communication between the parties are provided by the owner. This means that the parties do not directly communicate and have no opportunity to collaborate. This system leads to interruptions and delays in the flow of information.

The case studies revealed that inaccurate data transfers between the parties due to the lack of data format standardization results in extended waiting for required information. This kind of time waste causes delays in the information flow. Furthermore, the documents received from the engineer are checked by the contractor once more for errors. Since calculation mistakes, contradictions in designs, obscure points and non-constructible details are very common, it is very necessary to recheck the documents before preparing a request form and beginning construction. Acquiring requisite / lacking data takes 1 – 3 weeks. These problems also resulted from non standardized format of data and lack of coordination between the parties.

In the case studies, the highest percentage of wasted time occurs in fabricating the requested cut & bent rebar in Configuration 3 (88 %). From interviews with the practitioners, it was found that 25% of the delay resulted from inaccurate data transfer, 31% from workers' mistakes, 19% from defective supplies, 19% from lack of coordination and collaboration between the workers, and 6% from equipment and machine obstructions. It is obvious that inaccurate data transfers lead to considerable time waste in the supply chain.

In the case studies examined, the ordering procedure is slipshod. The request forms were received by fax, verbally, hardcopy and e-mail. Misunderstandings are very common. This situation causes mistakes and rework.

Interviews with practitioners and observations revealed that the supply of non standard steel bars takes approximately 10 – 15 days, while the supply of steel bars with standard dimensions takes 1 – 2 days. Since the rolling mills are structured for mass production, producing goods out of standard dimensions requires re-setup of the machines and the production process stops for a while. Therefore, the delay occurs because of the inflexible production systems.

The main reasons for the wasted time in the supply chain activities presented in Figures 6 and 7 are summarized in Tables 5 and 6 below.

Table 5: Main reasons for the wasted time in the supply chain activities in Figure 6.

Activities	**Reasons of Wasted Time**
Designing, Detailing, Reckoning	Inaccurate data transfers, lack of coordination among the parties
Determining the required steel bars, Preparing a request form	Lack of coordination among the parties, lack of data format standardization
Milling the requested steel bars	Inflexible production systems
Delivering the manufactured steel bars to the site	Infrequent deliveries due to high cost of shipping
Preparation for fabrication	-
Fabricating the cut & bent rebar	Priority changes, reworks due to worker's mistakes
Preparing job	-

Table 6: Main reasons for the wasted time in the supply chain activities in Figure 7.

Activities	**Reasons of Wasted Time**
Designing, Detailing, Reckoning	Inaccurate data transfers, lack of coordination among the parties
Determining the required cut & bent rebar, Preparing a request form	Lack of coordination among the parties, lack of data format standardization
Fabricating the requested cut & bent rebar	Delay in the supply of plain or deformed steel bars, priority changes, misunderstandings and rework due to slipshod ordering procedure, inflexible production systems
Delivering the cut & bent rebar to the site	Infrequent deliveries due to high cost of shipping
Preparing job	Priority changes

Although the total waste percentage in Configuration 1 (68 %) is lower than in Configuration 3 (76 %), the delay in starting installation in Configuration 1 (14 days) is bigger than that in Configuration 3 (3 days). This seems unreasonable at first glance. However, while value-adding time is mainly related to the properties of production unit and production system such as setup time, capacity, technology, flexibility of the production system, etc., supplier lead time is mostly influenced by the information flow such as handoffs of the necessary documents among the participants, pulling the required data from the supplier or customer, and accurate data transfers. Besides these factors it is also affected by batch sizes, shipment availability, etc. Therefore, in Configuration 3, the rebar fabricator takes advantage of machines with a high level of technology, and this shortens the total work time. In this case, the supplier lead time is extended due to the late arrival of supplies, priority changes and extended setup time.

CONCLUSIONS

The configuration of construction supply chains vary with the specific project requirements and the capabilities of participants. This paper has presented five different configurations for cut & bent rebar in reinforced concrete structures.

The case studies presented reveal that interruptions and delays in information flow, slipshod ordering systems, inaccurate data transfers and long delays for required information can generate a high level of waste in the total chain.

The problem in the rebar supply chain starts in the design phase and continues throughout the delivery process. Designing cut & bent rebar requires loads and architectural, mechanical, electrical etc. designs. Detailing and reckoning cut & bent rebar requires structural designs. And so on. These interdependent and interrelated activities are performed by the different supply chain participants, and the material and information flows are often interrupted.

Two future studies of the Turkish rebar supply chain are proposed by the authors. Industrial sponsors will be sought for this extended research:

1. More detailed measurement and analysis of waste and its causes. In addition to the waste of time, there is also wasted capacities and possibly production of poor quality work, with the attendant risk to safety of occupants and performance of investments. Value stream mapping will be extended upstream into structural engineering.
2. We also intend to develop a data transfer system for information flow needs in order to improve supply chain performance through avoiding misunderstandings, delays and interruptions in information flow.

Additional research is also warranted into a number of other issues that have emerged from this study; e.g., the potential for further development of fabrication and installation capabilities and exploration of viable means for promoting the structural changes needed to radically improve performance of the Turkish rebar supply system.

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