Construction Management and Economics

ISSN: 0144-6193 (Print) 1466-433X (Online) Journal homepage: https://www.tandfonline.com/loi/rcme20

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To cite this article: Gul Polat & David Arditi (2005) The JIT materials management system in developing countries, Construction Management and Economics, 23:7, 697-712, DOI: 10.1080/01446190500041388

To link to this article: https://doi.org/10.1080/01446190500041388

Published online: 17 Feb 2007.

Construction Management and Economics (September 2005) **23**, 697–712

The JIT materials management system in developing countries

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Received 3 March 2004; accepted 9 December 2004

The just-in-time (JIT) approach to materials management appears to be superior to a just-in-case (JIC) approach in terms of reducing cost and improving productivity under most circumstances encountered in industrialized countries. However, is it truly more advantageous than the more commonly used approaches in developing countries? Contractors in developing countries may be compelled to keep excessive inventory under some circumstances to help manage uncertainty in the supply chain and production process, high inflation rates, available discounts on prices of large amounts of materials, and price cuts in case of early purchasing. This study presents a comparison of the JIT and JIC materials management systems in terms of total cost of inventory by means of a simulation model that makes use of actual data obtained from an ongoing trade centre project in Istanbul, Turkey. The study suggests that had the JIT system been used in the project in Istanbul the total cost of inventory would have been 4.4% higher than the total cost of inventory in the JIC system currently used.

Keywords: Materials management systems, just-in-time, developing countries, simulation modelling

Introduction

Contractors are profit-seeking organizations; hence their major aim is to minimize the total cost of a construction project, which roughly consists of material, labour and equipment costs. Materials constitute a large proportion of the total cost of construction. The precise proportion varies from project to project. For instance, in new housing projects materials constitute 43% of the cost of all construction work (Agapiou *et al.*, 1998). The cost of materials and equipment amounts to almost 50–60% of the project cost (Akintoye, 1995; Wong and Norman, 1997; Ibn-Homaid, 2002). Moreover, the absence of materials on site when needed is one of the most commonly experienced causes of delays (Arditi *et al.*, 1985; Abdul-Rahman and Alidrisyi, 1994; Ibn-Homaid, 2002). Proper management of the material flow may play a significant role in enhancing the effectiveness of a contractor.

The generally acknowledged rules of materials management are small orders (lot sizes), frequent deliveries and reduced inventory (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), also known as zero inventory policy (ZIP) and the Toyota Production System (TPS) 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. JIT attempts to achieve smooth production by providing the right materials, in the right quantities and quality, just in time for production, and by assuring that the materials are delivered to the site on the actual day of use or the day before (Pheng and Chan, 1997; Tommelein, 1998; Pheng and Hui, 1999; Pheng and Chuan, 2001; Cua *et al.*, 2001). In other words, in the JIT environment, everything is ordered, made, and delivered just when it is needed

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Construction Management and Economics
ISSN 0144-6193 print/ISSN 1466-433X online
http://www.tandf.co.uk/journals
DOI: 10.1080/01446190500041388

(Willis and Suter, 1989; Pheng and Hui, 1999). JIT is intended both to optimize the timing of material delivery and to minimize inventories (Akintoye, 1995; Pheng and Hui, 1999).

In the traditional materials management system, also named the 'just-in-case' (JIC) system, materials and parts are pushed from one process to the next, regardless of whether they are needed by the next process. The emphasis in JIC is on uninterrupted high volume production. Large inventories ('buffer stocks') are kept just in case, to ensure a smooth production flow and to cope with rejected materials (Pheng and Hui, 1999).

The successful implementation of JIT in the manufacturing industry improved product quality, preventive maintenance, employee motivation and morale and worker involvement and commitment; it reduced lead time, throughput or set-up times, defects, ultimate costs, reworks, factory overheads, inventory levels and storage space; and it enhanced the competitive advantage of firms (Akintoye, 1995; Pheng and Chan, 1997; Pheng and Tan, 1998; Pheng and Hui, 1999). The implementation of JIT resulted in productivity increases in the construction industry too. A study conducted by Pheng and Chuan (2001) indicated that a 7–10% increase in productivity was measured via application of JIT principles in building logistics. Even though JIT practices provide several benefits, it also has a number of disadvantages. Elimination of inventory results in removal of costs related to inventory, but it also hinders the potential benefits associated with inventory (Shmanske, 2003). The possible benefits of keeping inventory are shielding downstream activities and workers on each activity from upstream uncertainty (i.e. faulty quality, machine breakdowns, late delivery of materials), supplying most requirements from stocks without delay, and taking advantage of lower shipping costs and discounts on prices of large amounts of materials (Howell and Ballard, 1997a, 1997b; Al-Sudairi, 2000; Sobotka, 2000; Shmanske, 2003).

Although several studies revealed that the JIT materials management system is superior to the JIC systems in terms of reducing cost and improving productivity (Pheng and Hui, 1999; Pheng and Chuan, 2001), there is a question of whether the JIT materials management system is truly more advantageous under special circumstances most commonly observed in developing countries, which may compel contractors to keep excessive inventory.

This study presents a comparison of the JIT and JIC materials management systems in terms of total cost of inventory by means of a simulation model that makes use of actual data obtained from an ongoing trade centre project in Istanbul, Turkey. The contract value for this reinforced concrete structure was $24 million. This project was selected as a case study because it is subject to the special circumstances described in the following section.

JIT under special circumstances

The decision to adopt the JIT system of materials management depends on the presence or absence of 'special circumstances', i.e. external conditions that are beyond the control of contractors and may exist regardless of local site conditions. It also depends on a number of factors including the readiness level of the contractor and the suppliers in practicing JIT, the workspace constraints that exist in a construction site and the contractor's experience in using JIT. However, the focus of the study reported in this paper was on the effects of 'special circumstances'. These 'special circumstances' exist despite workspace constraints or contractor readiness/experience to use JIT. One can observe the existence of some of these 'special circumstances' in varying degrees at different locations in the world; on the other hand, many of these circumstances are often encountered in developing countries. The 'special circumstances' that may compel contractors to keep excessive inventory are:

- *Uncertainty in the supply chain*: in the JIT production environment, the reliability of delivery, product quality and service, and communication and coordination with suppliers are vital for ensuring that the right materials in the right quantities arrive to site at the right time (Karpak *et al.*, 2001). In order to achieve this purpose, JIT requires reducing the pool of suppliers to single-sourcing, establishing long-term business relationships with individual suppliers based on mutual trust and benefits, and the involvement of suppliers at both pre-contract and post-contract stages in construction planning (Akintoye, 1995; Pheng and Hui, 1999; Pheng and Chuan, 2001). However, delays and botched transfers are sometimes experienced in both information and material flows (Polat and Ballard, 2003). The uncertainties can be caused by a contractor's defective ordering procedure (information flow) such as delay in the decision-making process, quantifying error, late ordering and/or supplier's errors in delivering the materials at the right time, sequence, quantity and quality (material flow) (Polat and Ballard, 2003). A large inventory masks the consequences of possible uncertainties in both information and material flows.
- *Variations and uncertainty in the production process*: low productivity caused by underqualified

workers may be a significant problem in the construction industry. In most developing countries, construction labour is not unionized or if they exist, unions are weak. While wages are low, workers' qualifications are generally below the standards encountered in industrialized countries. Great fluctuations in the expected durations of tasks and activities may likely occur due to reworks and low productivity of workers (Polat and Ballard, 2003; 2004). Safety stocks allow production to continue even when material and time wastes occur (Polat and Ballard, 2003).

- *Unavailability of materials on local market*: two forms of materials unavailability need to be addressed: (1) the materials cannot be provided from the local market, and they should be obtained from distant locations (including foreign countries); and (2) the required materials do not have standard dimensions and they should specifically be engineered and fabricated. In those cases, the lead times get long and deliveries are frequently delayed. Contractors may tend to increase lot sizes and buffers in order to take advantage of shipping economies and avoid possible delays (Pheng and Hui, 1999; Polat, 2003; Polat and Ballard, 2003).
- *High inflation rates*: high inflation is reported to be the most important reason of large inventories in developing countries (Bleakley, 1994). Contractors may have a tendency to purchase materials early and protect themselves from rapid and unpredictable changes in the prices of materials, and the suppliers' likely tendency to increase prices in case of material shortage (Norris, 1994).
- *Discounts on prices of large amounts of materials*: generally, suppliers and shippers make large discounts in case large amounts of materials are ordered. This is particularly true in developing countries because suppliers tend to protect themselves against demand fluctuations caused by an unstable economy. In these circumstances, contractors have a tendency to purchase large quantities of materials in order to take advantage of the discounted prices and shipping economies (Sobotka, 2000; Polat, 2003).
- *Price cuts in case of early purchasing*: when suppliers have cash flow problems or when demand for a particular material rapidly decreases, suppliers may be eager to sell the goods in their inventory immediately at greatly discounted prices. In such situations, contractors may prefer purchasing the low-priced materials early and take advantage of the good deal.

As the JIT philosophy considers inventory to be waste, all circumstances that require large buffers should be removed. However, eliminating some of these circumstances may sometimes be either very expensive or beyond the control of contractors. Therefore, the assertion that keeping a small inventory is always more economical than keeping a large inventory is questionable.

The economics of using the JIT materials management system is investigated in this study by focusing on the supply chain of a single material, namely reinforcing steel bars (rebar) used in the construction of a reinforced concrete trade centre building in Istanbul, Turkey. The reasons why only rebar was used in this investigation as opposed to using multiple materials across the production process are presented below:

- Rebar appears early in the basic sequence of constructing a reinforced concrete structure that involves preparing formwork, installing rebar, pouring concrete, waiting for curing, performing activities related to the structural framework and all the finishings. If rebar is not supplied to site on time, the many succeeding activities are delayed and serious budget overruns may occur. Therefore procuring rebar in required quantities when needed is one of the primary goals of contractors (Polat, 2003; Polat and Ballard, 2003).
- Rebar constitutes a significant portion of the cost of reinforced concrete structures and is subject to wildly variable prices in developing countries. Fluctuations in rebar prices such as those observed in the period January 2000 to November 2003 in Turkey (Figure 1) force contractors to shield themselves from the negative effects of sudden price increases by using the proper materials management strategy.
- Demand for rebar also fluctuates significantly in developing countries. Fluctuation in demand such as those observed in the Turkish construction market in the period 1997–2002 (Report on the Turkish Construction Sector, 2003) (Figure 2) force rebar suppliers to sell the rebar in their inventory as fast as possible and at greatly discounted prices when demand decreases significantly.
- Approximately 16–26% (by weight) of the total purchased amount of rebar is wasted during the construction process (Bossink and Brouwers, 1996; Formoso *et al.*, 2002). This waste is caused by problems in the production process, but also by inefficiencies in the supply chain.

Undoubtedly, any improvement in the management of the flow of rebar to the construction site may play a significant role in a contractor's profitability.

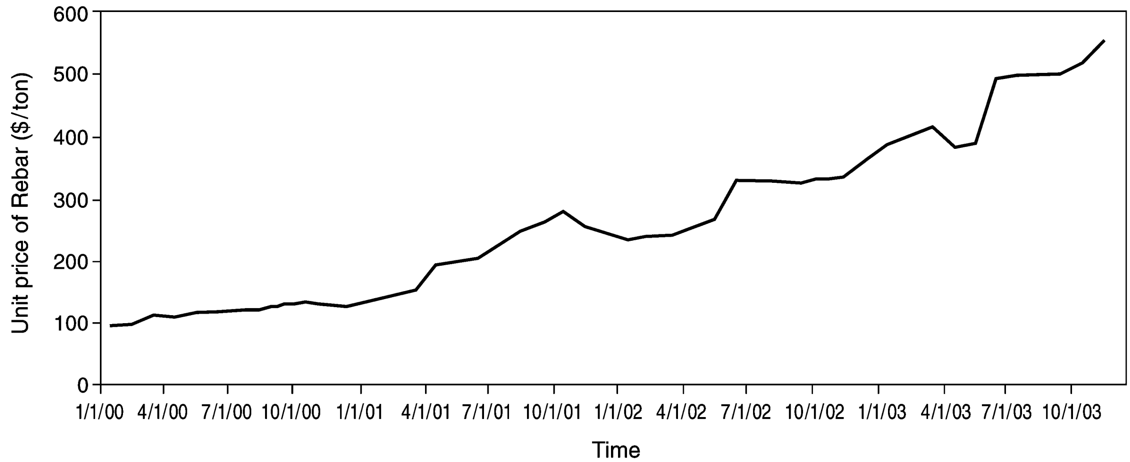

Figure 1 Price fluctuation of rebar in the period January 2000 to November 2003

Both the extensive survey of 116 Turkish contractors (Polat and Ballard, 2004) and studies that analyze the supply chain management of rebar by Turkish contractors (Polat, 2003; Polat and Ballard, 2003) reveal that the JIT materials management system is not frequently implemented in the Turkish building industry. While the JIT materials management system requires small stocks and frequent deliveries in small lot sizes, Turkish contractors appear to operate with large stocks delivered infrequently in large lot sizes. This system is referred to as the JIC materials management system in the remaining sections of this paper since it has been the standard traditional way of operating for many years. This paper presents a comparison of the JIC and JIT practices in the particular circumstances encountered in the construction of a trade centre project in Istanbul, Turkey.

Methodology

One way of conducting a JIT vs. JIC system comparison is to develop a simulation model that mimics the existing materials management system of rebar commonly performed by contractors, and to run the system by plugging in data applicable to the JIT materials management system.

Simulation is defined as the art and science of designing a model that acts in the same way as a real system does (Law and Kelton, 2000). In other words, simulation accurately represents actual processes of a real system by means of computer realization. The basic advantages of simulation are its generality, flexibility and power of simulating almost any behaviour of the real system (Kant, 1992; Schelasin and Mauer, 1995; Martinez and Ioannou, 1997).

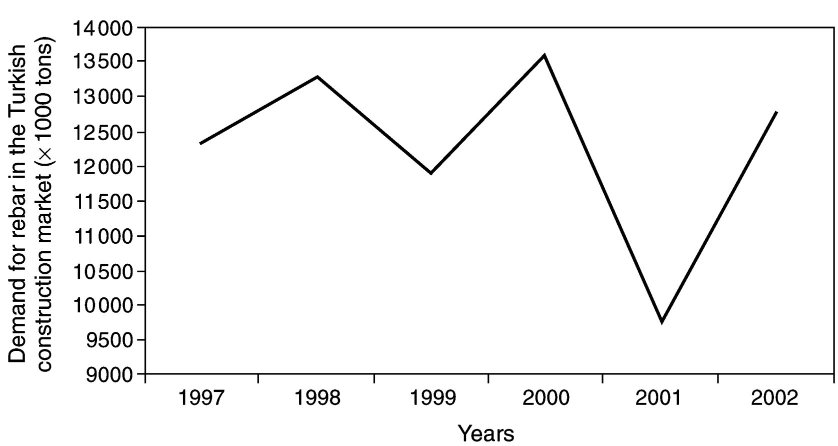

Figure 2 Demand fluctuation of rebar in the Turkish construction market in the period 1997 to 2002 (Report on the Turkish Construction Sector, 2003)

The methodology of this research consisted of the following phases:

- *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 two studies conducted previously on materials management systems of rebar in the Turkish construction industry. The first study focused on the different supply chain configurations of rebar prevalent in the Turkish construction industry, analyzed the value stream of rebar and evaluated the efficiency of the value stream in terms of wasted time percentages in supply chain activities (Polat and Ballard, 2003). The second study focused on the major problems encountered throughout the entire supply chain of rebar from raw material to finished product (Polat, 2003). The flow diagram of the JIC materials management system of rebar currently in place in most Turkish construction projects is illustrated in Figure 3. It should be noted that the details of the sub-activities associated with the fabrication phase including cutting, bending, tying the cut and bent rebar together, and placing them in formwork are not within the scope of this study. After the flow diagram was completed, a detailed field study was conducted in the trade centre project since this project was subject to most of the special circumstances described earlier. The field study was conducted by means of on-site interviews and observations. The same research techniques were found by O'Connor (1986) to be quite effective.
- *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 detail in the next section.
- *Dynamic simulation*: dynamic simulation refers to computer simulation that accurately represents causal events and the resulting actions in a system. While continuous simulation is used to model systems whose conditions and dependent variables change continuously with respect to time, discrete-event simulation is used to model systems whose conditions and dependent variables discretely change at specified points in time as a result of specific events (Kelton *et al.*, 2002). Discrete event simulation modelling 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. Abdulhadi (1997) and Al-Sudairi (2000) have used Extend+BPR in similar studies with great success.
- *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 total cost of inventory, the output of the model. 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).
- *Experimentation*: experimentation aims to determine the effects of variations in the controllable inputs on the output of the model. In this study, the effects of special circumstances in a developing country were observed on the total cost of inventory of rebar used to build a reinforced concrete structure.

A contractor can select one of the four possible materials management policies, which are:

- Large inventory and large lot size (JIC materials management system)
- Small inventory and large lot size
- Large inventory and small lot size
- Small inventory and small lot size (JIT materials management system)

Whereas fewer larger lot sizes save on delivery costs, the more frequent smaller lot sizes decrease inventory holding costs. Shmanske (2003) investigated the interrelation between inventory and lot size by means of an algebraic model. Shmanske's study (2003) revealed that maximum profitability is achieved by implementing a 'small inventory and small lot size'

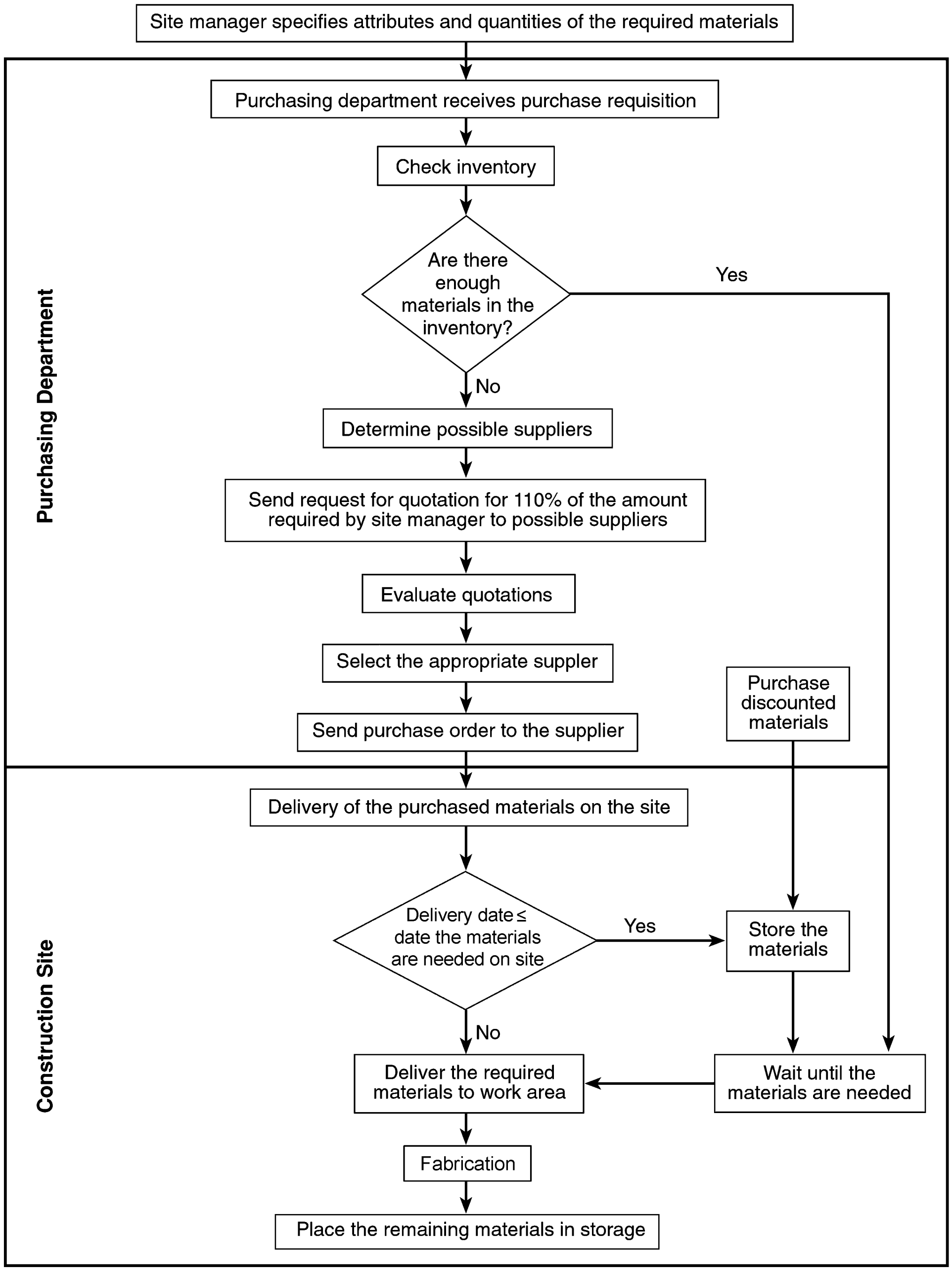

Figure 3 Flow diagram of the JIC materials management system

policy (corresponding to the JIT materials management system), while the next highest profitability is achieved by carrying out a 'large inventory and large lot size' policy (corresponding to the JIC materials management system). That is why, only the JIC and JIT materials management systems are compared in this study in terms of total cost of inventory. The framework of the simulation model used to compare the total cost of inventory in the JIC and JIT materials management systems are presented in Figure 4. The inputs, the transitional outputs, and the final outputs of this model are described in the next sections.

Inputs of the simulation model

The input variables are presented in Table 1 and are described in detail below. The data associated with the variables (last column in Table 1) were collected from the trade centre project undertaken in Istanbul, Turkey.

- *Characteristics of the rebar required by the site manager*: this input consists of the information specified by the site manager on the purchase requisition sent to the Purchasing Department. It includes type of rebar (rebar of $\leqslant 20$ mm in

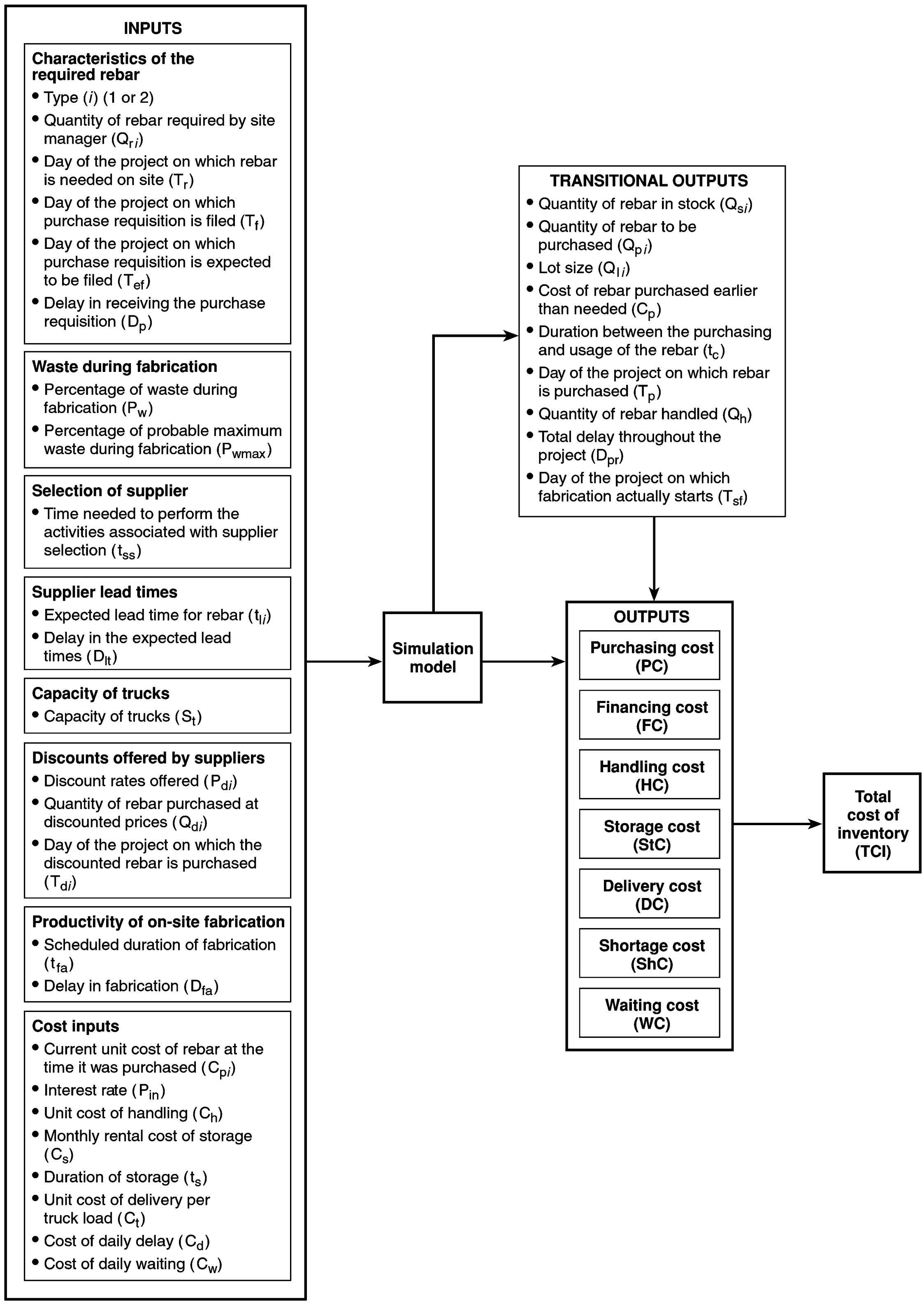

Figure 4 Framework of the simulation model

Table 1 Input variables used in the simulation model, in alphabetical order

Symbol	Unit	Input variables	Value
C_d	\$/day	Cost of daily delay	\$714/day
C_h	\$/ton	Unit cost of handling	\$0.36/ton
C_{pi}	\$/ton	Current unit cost of rebar at the time it was purchased	See Figure 5
C_s	\$/month	Monthly rental cost of storage	\$357/ton
C_t	\$/truckload	Unit cost of delivery per truckload	\$536/truckload
C_w	\$/day	Daily cost of idle crews	–
D_{fa}	Days	Delay in fabrication of rebar for one floor	1–3 days (random variable)
D_{lt}	Days	Delay in supplier lead time	1–2 days (random variable)
D_p	Days	Delay in receiving purchase requisition by Purchasing Department	1–4 days (random variable)
i	–	Type of rebar (thin or thick)	1 for thin, 2 for thick
P_{d1}	%	Discount rate offered by supplier when large quantity of thin rebar is purchased	5%
P_{d2}	%	Discount rate offered by supplier when large quantity of thick rebar is purchased	10%
P_{in}	%	Interest rate (average overnight reverse rate)	0.14%
P_w	%	Waste during fabrication	5–10% (random variable)
P_{wmax}	%	Probable maximum waste during fabrication	10%
Q_{ri}	Tons	Quantity of rebar required by site manager	See Table 2
Q_{d1}	Tons	Quantity of thin rebar purchased at discounted prices	250 tons
Q_{d2}	Tons	Quantity of thick rebar purchased at discounted prices	300 tons
S_t	Tons	Capacity of the trucks	26 tons
T_{d1}	–	Day of the project on which the discounted thin rebar is purchased	Day 110
T_{d2}	–	Day of the project on which the discounted thick rebar is purchased	Day 50
T_{ef}	–	Day of the project on which a purchase requisition is expected to be filed by site manager	See Table 2
T_f	–	Day of the project on which purchase requisition is filed by site manager	See Table 2
T_r	–	Day of the project on which rebar is needed on site	See Table 2
t_{fa}	Days	Scheduled duration of fabrication of rebar for one floor	6 days
t_{l1}	Days	Supplier lead time for thin rebar	1–3 days (random variable)
t_{l2}	Days	Supplier lead time for thick rebar	7–10 days (random variable)
t_s	Months	Duration of storage	8 months
t_{ss}	Days	Time for the supplier selection process	1–2 days (random variable)

diameter is named 'thin' (i=1) and >20 mm 'thick' (i=2) rebar), quantity (tons) of rebar required (Q_{ri}), the day of the project on which rebar is needed on site (T_r), the day of the project on which a purchase requisition is expected to be filed (T_{ef}) by the site manager, the day of the project on which a purchase requisition is filed (T_f) by the site manager, and the delay (if any) in receiving the purchase requisition (D_p).

In the system used in the trade centre project, the site manager specified the quantities of the rebar and the date of the delivery, and then sent the purchase requisition to the Purchasing Department. The site manager was expected to send the purchase requisition to the Purchasing Department at least 15 days before the materials are needed on site ($T_{ef}=T_r-15$). However, the site manager was often delayed by D_p=1–4 days in sending the purchase requisition to the Purchasing Department and this led to delays in the procurement process. The quantities of the required rebar (Q_{ri}), the day of the project on which rebar was needed on site (T_r), and the day of the project on which the purchase requisition was filed (T_f) are presented in Table 2. The simulation program used a random whole number in the 1–4-day range for D_p to run the model. The same conditions are expected to prevail in the JIT management system.

- *Waste during on-site fabrication*: the amount of rebar waste (P_w) during fabrication was observed in the trade centre project to be of the order of 5–10%. Consequently, it was normal practice for the Purchasing Department to always order

Table 2 Characteristics of rebar required by site manager at trade centre project

Floor	Quantity of thin ($\leqslant$20 mm in diameter) rebar required (Q_{r1}) (tons)	Quantity of thick (>20 mm in diameter) rebar required (Q_{r2}) (tons)	Day of the project on which rebar is needed on site (T_r) (days)	Day of the project on which purchase requisition is expected to be filed (T_{ef}) (days)	Day of the project on which purchase requisition is filed (T_f) (days)
1	2.86	226.23	15	0	2
2	38.92	44.14	45	30	30
3	72.33	86.62	75	60	64
4	64.73	90.26	105	90	93
5	109.82	126.33	135	120	120
6	95.59	86.55	165	150	151
7	96.80	86.18	195	180	182
8	47.01	37.89	225	210	212
9	2.55	0.11	255	240	244

P_{wmax}=10% more than the quantity required by the site manager. Any time rebar was taken from stock and sent to a work area, 10% more than the required quantity was always delivered in order to prevent shortages caused by workers' mistakes and misuses. The actual waste (P_w) was taken by the simulation model as a random whole number within the range of 5–10%. The same conditions are expected to prevail in the JIT management system since the skills of the workers available in Istanbul are the same regardless of the materials management system used.

- *Selection of rebar supplier*: serious delays and cost overruns are experienced in the construction industry caused by suppliers' delays (Arditi *et al.*, 1985; Abdul-Rahman and Alidrisyi, 1994; Ibn-Homaid, 2002). This input includes the time needed (in days) to perform the activities associated with the supplier selection process (t_{ss}). In the JIC system used in the trade centre project, the Purchasing Department prepared a request for quotations, sent this request to possible suppliers, received quotations from suppliers, analyzed the quotations, and selected the most appropriate supplier. The most important criteria in supplier selection were price and discount deals. The supplier's delivery record was not considered. As a result, the requested rebar was sometimes delivered to the site earlier or later than the scheduled time. The contractor did not commit in any way to the supplier for future orders. The Purchasing Department was free to order every batch from a different supplier. The supplier selection process (t_{ss}) took 1–2 days. The simulation system used either 1 or 2 days randomly in every run. In the JIT system, the contractor selects the most appropriate supplier at the beginning of the project based on the supplier's capacity, reliability, price and lead time. The contractor signs a contract with one supplier for the delivery of all the rebar needed in the project. A long-term relationship is established between the contractor and the supplier that lasts until the end of the project. Therefore, no time is spent on the activities associated with supplier selection every time an order is put in (t_{ss}=0).
- *Supplier lead times*: this input consists of the expected lead time of the rebar (t_{li}) and delay in lead time (D_{lt}). In the trade centre project, 12 m long deformed rebar of 8–26 mm was needed. While the lead time of thin rebar (t_{l1}) was 1–3 days, the manufacturer could supply thick rebar (t_{l2}) in 7–10 days. Delays (D_{lt}) of 1–2 days often occurred. All three variables were taken by the simulation model as a random number in their respective ranges. In the JIT system, as a long-term relationship is established between contractor and supplier, it is expected that the requested rebar will be delivered to the site at the time it is specified in the purchase order. The lead times of thin (t_{l1}) and thick (t_{l2}) rebar are assumed to be 1–3 days and 7–10 days, respectively, as was the case in the JIC system, but with no delay (D_{lt}=0).
- *Capacity of trucks*: this input involves the capacity of trucks used for the transportation of rebar from the supplier's warehouse to the site (S_t). The capacity (S_t) of the trucks that were available for the transportation of rebar in the trade centre project was 26 tons. The very same conditions are expected to prevail in the JIT management system.
- *Discounts offered by suppliers*: sometimes suppliers may find it more economical to sell their goods in their inventory as fast as possible in order to

protect themselves against drastic fluctuations in demand. They achieve their objective by offering discounts (P_{di}) to induce buyers to purchase larger quantities (Q_{di}) immediately (T_{di}) rather than on specific days dictated by the project work schedule.

In the trade centre project, the contractor purchased Q_{d1}=250 tons of thin rebar at P_{d1}=5% discount on day T_{d1}=110 of the project even though only 110 tons of thin rebar was needed on day 135 of the project. In the JIT system, the discount rate is zero because the purchase of rebar is not dependent on discounts but rather on the work schedule.

- *Productivity of on-site fabrication*: this input includes the scheduled duration of fabrication (t_{fa}), and the delay (D_{fa}) caused by worker inefficiencies, equipment breakdowns, and poor job and management conditions. The contractor's records in the trade centre project show that the productivity of on-site fabrication and installation was approximately 8 tons/day/worker. The fabrication of rebar for one floor was scheduled to be completed in t_{fa}=6 days regardless of the amount of rebar required in each floor. The contractor adjusted the number of workers in the fabrication process in order to complete the fabrication on schedule. However, productivity went down to 6 tons/day/worker due to reworks and priority changes in the production line, and the duration of this activity had to be extended by D_{fa}=1–3 days. The simulation model used 1, 2 or 3 days randomly in each run. It is expected that in the JIT production environment the waste in material and time will be reduced and ultimately eliminated. Successful implementation of JIT depends on workers' ability to eliminate waste, to multitask, to detect problems at the source, to be innovative when solving problems, to always seek better performance in terms of time, quality and cost and to participate in the traditional duties of top management (Pheng and Hui, 1999). However, workers are underqualified in all respects and across the construction industry in Istanbul regardless of the materials management system used. Training programs may overcome this problem in the long term, but production productivity in the JIT system was considered in this study to be the same as in the JIC system in order to reflect the actual state of the Turkish construction workforce.
- *Cost inputs*: this input includes the current unit cost of rebar at the time it was purchased (C_{pi}), interest rate (P_{in}), unit cost of handling rebar (C_h), monthly rental cost of storage (C_s), duration of storage (t_s), unit cost of delivery per truckload (C_t), daily penalty for delay (C_d), and cost of daily waiting for crews (C_w).

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 materials management systems. The transitional outputs and some of the inputs were later used by the simulation model to calculate the outputs of the model. The transitional outputs are presented in Table 3.

- *Quantity of rebar in stock (Q_{si})*
  This output indicates the quantity of rebar in inventory at any time during the project.

  $$Q_{si} = \Sigma Q_{li} + \Sigma Q_{di} - \Sigma(Q_{ri}*(1+P_{wmax})) + \Sigma(Q_{ri}*(P_{wmax}-P_w))$$

  The parameters in this relationship are listed in alphabetical order in Tables 1 and 3 along with their units and values. The summation sign in front of each term accounts for the several deliveries throughout the project.
- *Quantity of rebar to be purchased (Q_{pi})*
  Once the purchase requisition was sent to the Purchasing Department, the inventory was

Table 3 Transitional outputs generated by the simulation model, in alphabetical order

Symbol	Unit	Transitional outputs	Value
C_p	\$	Cost of the rebar purchased earlier than needed	$C_{pi} * (Q_{li}-Q_{pi})$
D_{pr}	Days	Total delay throughout the project	$\Sigma\ [(T_r-T_{sf})+D_{fa}]$
Q_h	Tons	Quantity of rebar handled	$Q_{li}+Q_{di}+(Q_{ri} * (1+P_{wmax}))+[Q_{ri} * (P_{wmax}-P_w)]$
Q_{li}	Tons	Lot size	$[\text{roundup } (Q_{pi}/S_t)] * S_t$
Q_{pi}	Tons	Quantity of rebar to be purchased	$[Q_{ri} * (1+P_{wmax})]-Q_{si}$
Q_{si}	Tons	Quantity of rebar in stock	$\Sigma Q_{li}+\Sigma Q_{di}-\Sigma\ (Q_{ri}*(1+P_{wmax}))+\Sigma\ [Q_{ri} * (P_{wmax}-P_w)]$
t_e	Days	Duration between time of purchase and usage	T_r-T_p

checked. In case the amount of rebar in the inventory was not sufficient to meet the required amount, a purchase order was issued. The quantity of the rebar to be purchased was calculated as:

$$Q_{pi} = [Q_{ri} * (1 + P_{wmax})] - Q_{si}$$

The parameters in this relationship are listed in alphabetical order in Tables 1 and 3 along with their units and values.

- *Lot size (Q_{li})*
Because the shipping cost in Turkey is high, infrequent delivery of large lot sizes is commonly preferred. As the trade centre project was located at the heart of Istanbul, traffic congestion constituted an additional reason for the infrequent deliveries. Lot size is calculated as follows:

$$Q_{li} = [\mathrm{roundup}(Q_{pi}/S_t)] * S_t$$

The parameters in this relationship are listed in alphabetical order in Tables 1 and 3 along with their units and values. The calculation of Q_{li} reflects the fact that extra rebar was delivered to the site earlier than needed in order to make use of the full capacity of the trucks.

As JIT requires frequent delivery of small lot sizes (exact amount that is required), the lot size equals the quantity of rebar to be purchased ($Q_{li} = Q_{pi}$). In these instances, the 26-ton trucks are utilized below capacity. Consequently, shipping costs increase.

- *Cost of the extra rebar purchased earlier than needed (C_p)*
In the trade centre project, rebar was purchased earlier than it was needed in order to take advantage of discounts and the full capacity of trucks.

$$C_p = C_{pi} * (Q_{li} - Q_{pi})$$

The parameters in this relationship are listed in alphabetical order in Tables 1 and 3 along with their units and values. In this relationship, Q_{li} is replaced by Q_{di} when rebar is purchased at discounted prices.

Because in the JIT system the rebar is purchased when it is needed, this input is zero ($C_p = 0$).

- *Duration between the time of purchase and the time of usage of the rebar (t_e)*
In the JIC system, early purchasing of rebar increases financing cost. Financing cost depends on the duration between the time of purchase and the time of usage of the rebar.

$$t_e = T_r - T_p$$

where T_p is calculated as follows:

$$T_p = T_{ef} + D_{pr} + t_{ss} + t_{li} + D_{lt} \text{ for purchases at regular price}$$

$$T_p = T_{di} \text{ for purchases at discounted price.}$$

The parameters in these relationships are listed in alphabetical order in Tables 1 and 3 along with their units and values.

Because in the JIT system rebar is purchased when it is needed, this input is zero ($t_e = 0$).

- *Quantity of rebar handled (Q_h)*
In the JIC system, because the purchased rebar is delivered to the site earlier than it is needed; it stays in storage until it is needed. When fabrication starts, the required quantity of rebar augmented by $P_{wmax} = 10\%$ is taken from the inventory and sent to the work area. Even though 110% of the required quantity of rebar is sent to the work area, not all of it is used in the production since only $P_w = 5\%–10\%$ is wasted. Therefore, the remaining rebar is sent back to inventory. The quantity of rebar handled (Q_h) includes therefore the rebar sent to inventory every time a delivery is received from the supplier, the rebar sent to the work area from inventory, and the unused rebar sent back from the work area to inventory.

$$Q_h = Q_{li} + Q_{di} + (Q_{ri} * (1 + P_{wmax})) + (Q_{ri} * (P_{wmax} - P_w))$$

The parameters in this relationship are listed in alphabetical order in Tables 1 and 3 along with their units and values.

Because in the JIT system the rebar is purchased when it is needed, this input is zero ($Q_h = 0$).

- *Total delay throughout the project (D_{pr})*
Shortage cost was considered to be zero in the JIC system, because adequate stocks ensure that no shortage ever occurs.

In the trade centre project, the contractor was obligated to pay a penalty in case concrete could not be poured on the scheduled day.

$$D_{pr} = \Sigma[(T_r - T_{sf}) + D_{fa}]$$

where T_{sf} is calculated as follows:

$$\text{when } Q_{si} > Q_{ri}: \quad T_{sf} = T_r$$

$$\text{when } Q_{si} < Q_{ri}: \quad T_{sf} = T_r \quad \text{for } T_r > T_p$$

$$T_{sf} = T_p \quad \text{for } T_r < T_p$$

The parameters in these relationships are listed in alphabetical order in Tables 1 and 3 along with

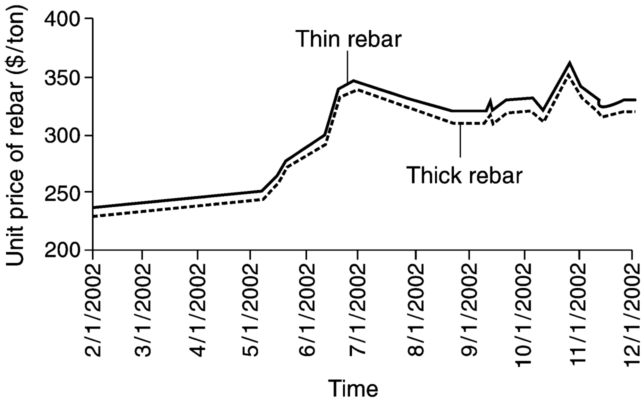

Figure 5 Unit price of rebar in the period of February 2002 to December 2002

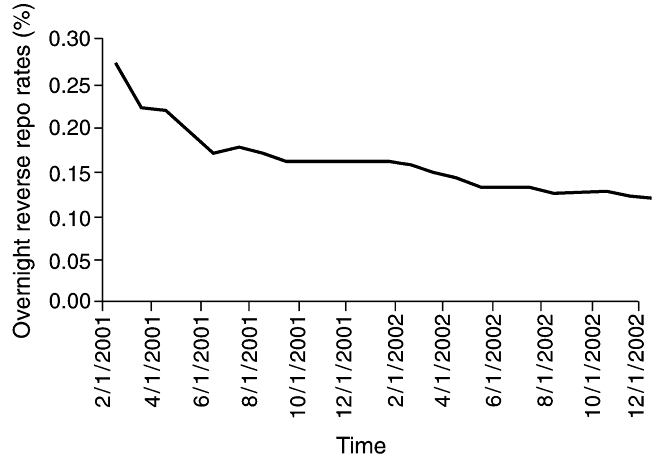

Figure 6 Daily reverse repo rates in the period of February 2001 to December 2002

their units and values. The summation sign accounts for the different deliveries.

Outputs of the simulation model

The output of the materials management system is taken as the total cost of inventory (TCI). The components of TCI include the costs of purchasing, financing, handling, storage, delivery, shortage and waiting.

- *Purchasing cost (PC)*
  The unit price of rebar fluctuated throughout the trade centre project located in Istanbul, Turkey (Figure 5).

  $$PC = (C_{pi} * Q_{li}) + [C_{pi} * (1 - P_{di}) * Q_{di}]$$

  The parameters in this relationship are listed in alphabetical order in Tables 1 and 3 along with their units and values.

  Purchasing cost is calculated in exactly the same way in the JIC and JIT systems, but no rebar is purchased at discounted prices in the JIT system ($Q_{di}=0$) effectively rendering to zero the term in the square brackets.
- *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.

  $$FC = C_p * [(1 + P_{in})^{te} - 1]$$

  The parameters in this relationship are listed in alphabetical order in Tables 1 and 3 along with their units and values.

  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 effective reverse repo rates in Turkey in the period of February 2001–December 2002 are shown in Figure 6 (www.tcmb.gov.tr). The overnight repo rates varied throughout the trade centre project between 0.12 to 0.16%. In this study, an average overnight repo rate of $P_{in}=0.14\%$ was used.

  While financing cost is an important component of the total inventory cost in the JIC system, it has no effect in the JIT system as any stocks or negligibly small stocks are carried in the JIT system.
- *Handling cost (HC)*
  This is the cost of moving the rebar from the trucks to the storage area, from the storage area to the work area, and delivering the unused rebar from the work area back to the storage area.

  $$HC = C_h * Q_h$$

  The parameters in this relationship are listed in alphabetical order in Tables 1 and 3 along with their units and values.

  In the case of the JIT system, the handling cost is taken as zero as the exactly required amount of rebar is delivered on each shipment and is shipped directly to the fabrication area.
- *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.

$StC = C_s * t_s$

The parameters in this relationship are listed in alphabetical order in Tables 1 and 3 along with their units and values. Based on the records provided by the project manager of the trade centre project, C_s was $357 per month. Because there was always rebar in stock in the JIC system, t_s equals the project duration.

There will be no storage cost in the JIT system since any stocks or negligibly small stocks are carried.

- *Delivery cost (DC)*
This is the cost of moving the rebar from the supplier's warehouse to the construction site. The delivery cost includes the transportation cost and the costs of loading and unloading the trucks.

$DC = C_t * [(Q_{li}/S_t) + \text{roundup}(Q_{di}/S_t)]$

The parameters in this relationship are listed in alphabetical order in Tables 1 and 3 along with their units and values. Based on the records provided by the project manager of the trade centre project, C_t was $536 per truckload in the JIC system. In the JIT system, DC is calculated slightly differently because lot size Q_{li} is exactly equal to 1.1 times the quantity of rebar specified by the site manager in the purchase requisition, and of course no rebar is purchased at discounted prices ($Q_{di}=0$).

- *Shortage cost (ShC)*
This is the cost of delay in the project in case the supplier does not deliver the materials on time.

$ShC = C_d * D_{pr}$

The parameters in this relationship are listed in alphabetical order in Tables 1 and 3 along with their units and values. In the trade centre project, the contractor was obligated to pay a penalty of $714 per day in case concrete could not be poured on the scheduled day.

Shortage cost was considered to be zero in the JIC system, because adequate stocks ensure that no shortage ever occurs.

- *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 they are needed.

$WC = C_w * D_{pr}$

The parameters in this relationship are listed in alphabetical order in Tables 1 and 3 along with their units and values. In the trade centre project, if the rebar did not arrive on time, other tasks were assigned to the workers. The absence of strong unions allowed the contractor to reassign workers to different activities without problem. Because workers were never idle, this cost is not taken into account either in the JIC or the JIT system. The total cost of inventory is, therefore as follows.

For the JIC system:

$$\begin{aligned} TCI = & \left\{ \left[C_{pi} * Q_{li}\right] + \left[C_{pi} * (1 - P_{di}) * Q_{di}\right] \right\} \\ & + \left\{ C_p * \left[(1 + P_{in})^{te} - 1\right] \right\} + \left[C_h * Q_h\right] + \left[C_s * t_s\right] \\ & + \left\{ C_t * \left[(Q_{li}/S_t) + \text{roundup}(Q_{di}/S_t)\right] \right\} \end{aligned}$$

For the JIT system:

$$TCI = \left[C_{pi} * Q_{li}\right] + \left[C_t * (Q_{li}/S_t)\right] + \left[C_d * D_{pr}\right] + \left[C_w * D_{pr}\right]$$

Results of the simulation analysis

For good results, Chase and Brown (1992) recommend a coefficient of variance below 5% when conducting experiments. A coefficient of variance of 0.3% was targeted in this study and was reached when the model was run 100 times. The cost components and the total cost of inventory for JIT and JIC materials management systems in the trade center project are presented in Table 4.

The purchasing cost was found to be $405 000 in the JIT system and $372 143 in the JIC system (Table 4). In other words, the use of the JIT system added an extra purchasing cost of $32,857 in the trade center project. It was observed that while the early purchase of materials in the JIC system shielded the purchasing cost from unpredictable changes in materials prices, the JIT system made the purchasing cost more vulnerable to price changes. On the other hand, the early purchase of materials added an extra financing cost of $13,571 in the JIC system (Table 4). Although the interest rate was very high (0.14% per day), the sum of the purchasing and financing costs was still lower by $19 286 in the JIC system ($385 714) than in the JIT system ($405 000). The main reason for this situation was that in the JIC system, the contractor preferred purchasing the materials early and at discounted prices. This decision provided the contractor with an advantage of $19 286 in the JIC system.

Table 4 Output variables and total cost of inventory of JIC and JIT materials management systems

Output variables	JIC system	JIT system
Purchasing cost	$372 143	$405 000
Financing cost	$13 571	–
Delivery cost	$30 714	$34 286
Handling cost	$714	–
Storage cost	$5714	–
Shortage cost	–	$2143
Total cost of inventory	$422 857	$441 429

While the delivery cost was found to be $30 714 in the JIC system, it was $34 286 in the JIT system (Table 4). The savings of $3572 was obtained in the JIC system by the contractor purchasing large lot sizes and consequently taking advantage of shipping economics. On the other hand, purchasing large lot sizes in the JIC system brought about double handling ($714) and storage costs ($5714), while these costs were zero in the JIT system. Indeed since the trade centre project was located at the heart of Istanbul, it was impossible to store the excess material on the construction site; the contractor had to rent a storage area in the neighborhood of the construction site, which explains the extra storage cost of $5714 in the JIC system. On the other hand, systematically purchasing small lot sizes made the production more vulnerable to possible delays in material supply, which explains the shortage cost of $2143 in the JIT system; shortage cost was zero in the JIC system as the early purchase of materials shielded the production process from possible delays in the supply chain.

While TCI was found to be $422 857 in the JIC materials management system, it was $441 429 in the JIT materials management system. Obviously, implementation of the JIT materials management system in the trade center project adds an extra cost of $18,571. This corresponds to an increase of 4.4% in TCI.

According to the results plotted in Figure 7, in the JIC system, the total cost of inventory (TCI) shows sharp changes on days where large amounts of rebar are purchased at discounted prices. On the other hand, the distribution of TCI in the JIT materials management system follows a smoother S-curve (Figure 7). The smooth distribution of TCI may keep contractors away from severe financial bottlenecks, because of the fact that periodic payments received from the owner also follow a smooth S-curve (Kaka and Price, 1993) and allows the contractor to synchronize material expenditures with revenues.

Conclusion

Materials account for a significant proportion of the total cost and duration of a construction project. Proper management of the material flow may therefore have potential benefits for contractors. The main objective of a materials management system is to lower the amount of capital tied up in inventory while at the same time making sure that the production process never slows down or stops because of unavailable materials. The JIT materials management system was developed to provide the right materials, in the right quantities and quality, just in time for production, eliminating the need for stocking materials on site. Several studies

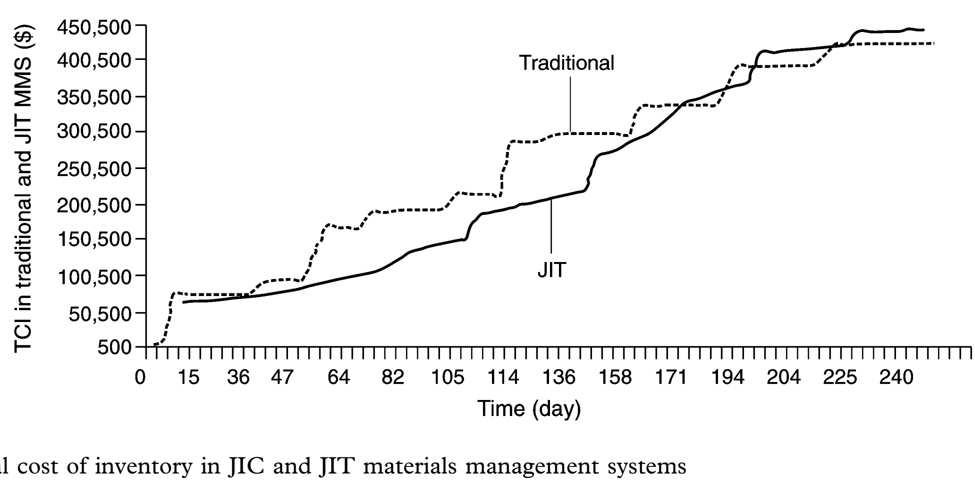

Figure 7 Total cost of inventory in JIC and JIT materials management systems

revealed that the implementation of the JIT materials management system in the construction industry lowers project cost and duration. On the other hand, contractors may be compelled to keep inventory under some circumstances that may include uncertainty in the supply chain and production process, high inflation rates, available discounts on prices of large amounts of materials, and price cuts in case of early purchasing. These circumstances are often encountered in developing countries. Under these circumstances, JIC systems may provide contractors with some benefits that may include shielding downstream activities from upstream uncertainty, supplying most requirements from stocks without delay, and taking advantage of lower shipping costs and discounts on prices of large amounts of materials. It appears that while JIT removes inventory, it also eliminates the possible benefits related to inventory particularly in the presence of the special circumstances mentioned above. Therefore, the assertion that the JIT materials management system is always more advantageous than JIC systems is doubtful.

This study presented a comparison of the JIT and JIC materials management systems in terms of total cost of inventory via actual data obtained from a trade centre project located in Istanbul, Turkey, which is subject to the circumstances commonly prevalent in developing countries. While the JIT materials management system requires small stocks and frequent deliveries in small lot sizes, the actual practice in the trade centre project was to operate with large stocks delivered infrequently in large lot sizes. A simulation model was developed to mimic the actual materials management system of rebar used by the contractor and to see how the JIT system would perform under the same special conditions. The total cost of inventory (TCI) was calculated in the JIC and JIT systems by running the simulation model 100 times. It was found that the total cost of inventory in the JIT system would be 4.4% higher than the total cost of inventory in the JIC system. Since contractors are profit-seeking organizations and profit margins are generally low, advocating the implementation of the JIT system under special circumstances such as those encountered in Istanbul, Turkey does not appear to be reasonable. The conclusion of this study is that the indiscriminate use of the JIT system disregarding the circumstances of the operation is neither effective nor economical.

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