Automated Materials Management and Control Model

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An automated model for materials management and control

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Current, manual, materials management and control procedures are unsatisfactory: they are labour intensive, inaccurate and error prone. The result is waste and surplus of materials, delays, decrease in productivity and lack of up-to-date, real-time information regarding the status of purchase orders (PO), the levels of inventory, the actual vs. planned usage of materials, and others. The purpose of the present work was to develop an automated model, which alleviates some of these problems. Prior to developing the model, a field survey was conducted to learn, at first hand, what the typical problems with materials management and control are. The model initiates materials purchasing, follows up the status of PO, records materials data as they arrive to the site and their movement around the site, makes recommendations, generates reports and issues warnings. The model was implemented, tested and evaluated in an ongoing building construction project. The onsite experiments confirmed that automated materials management and control are feasible, resulting in real benefits, such as time savings, and availability of up-to-date and accurate information regarding stocks of materials on site.

Keywords: Automation, data collection, feedback control, control methods, materials management, monitoring

Introduction

Materials usually constitute a major portion of the total cost in a building construction project, which makes control of this resource important. In spite of their weight in construction projects, not enough attention is given to materials control and management. While the general industry invests c. 1% of the production cost in materials management and control, the construction industry invests only 0.15% (Formoso and Revelo, 1999). Hence, it is not surprising that a recent workshop on data exchange standards at the Construction Job Site sponsored by the National Institute of Standards and Technology (NIST), in co-operation with the Fully Integrated and Automated Technology (FIATECH) consortium, came to the conclusion that 'materials tracking remains a very big problem on the current construction job site' (Saidi *et al.*, 2003). In addition, in studies involving 125 projects, the most frequently documented cause of disruption was problems associated with materials management (Thomas *et al.*, 2005). The Construction Industry Institute (CII) (1987), as well as other researchers (Bell and Stukhart, 1986, 1987; Gould and Joyce, 2000; Makulsawatudom and Emsley, 2003) assert that lack of materials is the major cause for low productivity and delays in construction projects. One of the reasons for this is the absence of the right materials before commencing an activity, or the inability to effectively plan the work according to the materials available on site due to lack of up-to-date information.

Waste of materials represents a large percentage of production costs (Formoso *et al.*, 2002; Li *et al.*, 2005). This waste is due to the poor control on construction sites (Poon *et al.*, 2004). Researchers have tried to assess the potential savings as a result of effective materials management by conducting controlled experiments. Agapiou *et al.* (1998) conducted an experiment involving two sub-contactors (Framing

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and Plumbing) whose cost accounted for 30% of the total project cost. The researchers developed a logistics model and appointed a Materials Co-ordinator. The results of the experiment showed that 8% of the total cost was saved, using the model, and 3% were added (net saving of 5%). The breakdown of the savings showed that 3% was saved due to reduced wastage and breakages and 5% by a reduction in working days. The extra costs were due to the Materials Co-ordinator (1%), equipment (1.5%) and administration (0.5%).

In other research, Thomas and Sanvido (2000) examined three case studies of subcontractor-fabricator relations. In two cases, there were work stoppages due to lack of materials. The researchers calculated baseline productivity and the loss of labour efficiency in each case. Their conclusion was that inefficient materials management could lead to an increase in the field labour hours of 50% or more.

Two groups of researchers have proposed the use of bar code and/or radio frequency identification (RFID) to monitor materials on-site. Jaselskis *et al.* (1995) proposed a conceptual model using RFID technology. According to their concept, RFID tags would be attached to the vehicles transporting the materials, to the materials-handling equipment and to the materials themselves. All relevant data would be read from the RFID tag to enable tracking of materials delivery and materials movement about the site. Echeverry and Beltran (1997) proposed a model for labour and materials tracking using barcode. Their model records data including the date of materials arrival to the site and materials consumption. The model requires manual data entry regarding the planned consumption of materials to compare actual vs. planned data.

Hand held computers are commercially used for a variety of purposes in construction, one of which is collecting data regarding materials usage. The advantage of such a use is that data are entered only once – digitally – eliminating multiple data entry and thus minimizing the mistakes.

It seems that the current state of research does not fully automate the process of materials management and control. The present paper describes a model that automatically initiates materials ordering and follows it up, including the arrival of the materials to the site and their movement about the site. The research methodology included studying the state-of-practice (next section), development of a theoretical model, implementing it in an experimental prototype, testing and evaluating it in an ongoing construction project, and comparing the current and the proposed methods of materials management and control.

State-of-practice review

A field study was conducted to discern the current materials management state-of-practice in Israel. The study was conducted, in open interviews, among 15 professionals including company presidents, purchasing managers, and project managers. The study was conducted in two stages: the first stage sought to complete the literature review and identify the major problems and needs of materials management and control – these problems served as guidelines to the development of the model described in the next section. The second stage was conducted to evaluate the model under real conditions. This section reports the findings of the first stage of the field study.

Materials-related problems

The problems associated with materials management can be divided into two categories: (1) problems relating to the purchasing and supply of the materials – this category includes scheduling the supply of materials to the site, and disparity between the order and the materials actually arriving to the site – and (2) logistical problems, such as monitoring materials on-site, follow up the movement of materials around the site and hauling of materials.

Problems relating to the purchasing and supply of the materials. Problems in this category have sometimes caused work stoppages and last minute orders. As a result, not only cost escalates, but if the material is not available, additional delays are caused. The problems found in this category are:

- Materials arriving to the site at the wrong time – late arrival causes a delay to a specific activity, or to the subsequent activities. Early arrival, on the other hand, requires additional storage spaces, double handling and, sometimes. additional equipment. Double handling can damage the materials and increases waste and handling costs.
- Materials that do not match the purchase order – if unsuitable materials are discovered on time, they can be changed and the damage is minimal. If, on the other hand, upon arrival they are stored without checking and retrieved just when needed, the work can be delayed until the correct materials arrive.
- Forgetting to order materials – due to the dynamic nature of construction projects and the stress under which construction personnel operate, sometimes materials are not ordered. The effect of not ordering materials is similar to the one of late arrival.

- The wrong quantity of materials arriving to the site – if the quantity of the materials arriving to the site is smaller than the needed quantity, the effect is similar to late arrival of materials. If, on the other hand, the quantity is higher, either the excess has to be sent back or stored for later usage. In the latter case, the effects are similar to early arrival.
- Information regarding the status of the orders is not available – all too often project management does not have accurate and up-to-date information regarding expected arrival of materials. Additionally, sometimes the suppliers decide to supply different materials, which are thought to be equally suitable. When these materials arrive to the site, or worse still, when they are needed for use, it turns out that they are not suitable. This state-of-affairs makes planning very difficult and disrupts work planning and activities.
- Incomplete, or erroneous definition of materials – when materials are not defined accurately, the supplier may misinterpret the order, and hence supply the materials in the wrong quantity or adhering to different specifications.
- The specific conditions of the site are ignored when ordering materials – ordering materials hasto take into account all the specific conditions of the site at the time of the expected arrival of the materials. Conditions such as the availability of hauling equipment, accessibility and weather affect the ordering of materials, e.g. non-availability of a crane on-site will require that the materials are brought to the site by atruck having its own unloading capacity; access roads which might be suitable in the summer may need different equipment in the winter.

Warehousing.
Even when the purchasing and supply of materials are managed properly, there still might be problems relating to on-site control. The problems identified in the field study were:

- Wastage of materials – the main reasons were: unsuitable storage conditions, double (or even multi) handling, theft and loss of materials.
- Lack of space for storage – this problem is becoming increasingly serious in urban projects. The solution is normally just-in-time (JIT) delivery strategies, which are very sensitive to delivery delays and changes in the work schedule. These strategies are problematic and require higher managerial resources.
- Lack of complete and up-to-date information regarding on-site stocks – this is a typical problem on large projects where materials are not concentrated in one location. It is all too often that appropriate materials are available on-site, but because information about supply and location is not available, the same materials are ordered again, resulting in waste.
- Incomplete, or erroneous, information regarding all the materials arriving at the site – the materials arriving at the site are sometimes not registered or they are logged erroneously. As a result, when the vendors' bills arrive, additional resources have to be used to check what exactly arrived (sometimes this is not trivial, or even possible), causing delays in payment and subsequent problems with the suppliers.
- Untargeted materials – sometimes materials arrive to the site and no one knows who ordered them or what their destination is. The person who receives the materials does not know whether to accept or return the materials.

Monitoring materials receipt and distribution on-site

All the 15 participants in the study think that each shipment should be checked for correctness in relation to the order and the bill of lading (quantity, quality, etc.). On some of the projects, there was a dedicated storekeeper who checked each shipment and approved receipt if everything was in order. On other projects, there was no formal procedure for receiving materials, which meant that in many cases the shipments were received without checking. All the participants, including the storekeepers, said that even though it is intended that the materials be checked upon arrival, in many cases it is not done.

The participants reported that management of the project, and in the main office, lacked accurate and up-to-date information regarding the arrival and the availability of materials on-site. Even companies who recorded the materials upon their arrival experienced this problem. One of the companies, for example, stated that the foreman maintains these records and every few days sends them to the main office to be entered to the computer. At the end of the month, when the foreman checks the records, he always finds mistakes. Another company, on the other hand, which computerized the entire process and had a dedicated storekeeper, reported that they had quite accurate information, which improved their managerial process. They concluded that they received a return on their investment.

Management and control model

General

Both the literature review and the field study showed that, in most cases, materials management and control are unsatisfactory, which leads to waste of materials, delays in project progress and, as a result, cost escalation. Because materials can account for a high portion of the construction cost, every attempt to improve management and control of materials should be made. An automated model for materials management and control has been developed. The model encompasses materials purchasing, follow-up of the status of orders, recording materials data upon their receipt and monitoring movement about the site.

The following considerations were made in developing the model:

- Flexibility – the model should be an integral part of the company's managerial process. As companies differ in the way they operate (e.g. centralized purchasing vs. each site doing it independently), the model should be flexible enough to fit all managerial styles. Moreover, various construction managers or different conditions on each site may require different policies (e.g. stock levels), which emphasizes the need for flexibility.
- Tracking, monitoring and controlling materials require large and complicated databases. These databases should be organized in such a way that it is easy to store, organize and analyse the data, as well as present them in a way that will support decision making.
- The model should be able to check and verify data entry for completeness, consistency and integrity to reduce errors to a minimum. This can be done in two ways: first by comparing each data entry with a standard database; second, errors regarding incoming materials and their movement about the site can be significantly reduced by automated data collection technologies (such as barcode and RFID).
- The model should be updated frequently to enable real-time operation. The advantages of a real-time materials information system are numerous, e.g. when receiving a shipment at the site, the data just entered regarding the arrival of the materials can be compared to the data in the purchase order (PO), thus avoiding acceptance of the wrong materials or enabling alerts regarding changes in quantities.
- The model should be able to compare planned to actual values to alert about discrepancies and enable corrective measures to be taken on time. No less important is an update of historical databases that will record 'problematic' suppliers, or in decentralized managerial systems to identify suppliers who deal with a number of the company's projects in order to negotiate better purchasing terms. The historical records will also help future estimating of the quantities more accurately.

Model description

The model comprises of five units (Figures 1 and 2): (1) Input Unit, (2) Purchasing Unit, (3) Tracking Unit, (4) Analysis Unit and (5) Output Unit. The Input Unit uses data stored in the Planning Database (PD). The PD includes data regarding the schedule of the project, the planned quantities and inputs associated with each activity, as well as catalogues of construction materials. It is assumed here that all these data are up-to-date, which means that this database is updated every time there is any change in the schedule, or a change order is issued, etc.

The Input Unit periodically calculates the materials needed for pending activities ('PD Interface'). The pending activities are all the activities whose predecessors are completed and the ones whose early start falls within a specified time duration (defined by the user). The result of this calculation is recorded in the Required Materials file, which lists the activities in the specified time duration, the quantities of materials, the time when the material is scheduled to arrive, or be used, etc.

The Purchasing Unit determines which materials are to be ordered, based on the data in the required materials file, Decision Rules and the inventory of the materials on the site. The algorithm of the Purchasing Unit is detailed in Section 'Purchasing unit' and in Figure 3.

The Tracking Unit records the incoming materials and the ones dispatched for use. The data relating to the arrival of materials and their use are collected with Automated Data Collection (ADC) technologies such as barcode or RFID. The Unit follows up the rolling and the dead inventories. The algorithm of the Tracking Unit is detailed in Section 'Tracking Unit' and in Figure 4.

The Analysis Unit receives data from the Purchasing and from the Tracking Unit and generates the data for the Output Unit. The Unit compares between the planned and the actual quantities of materials and,

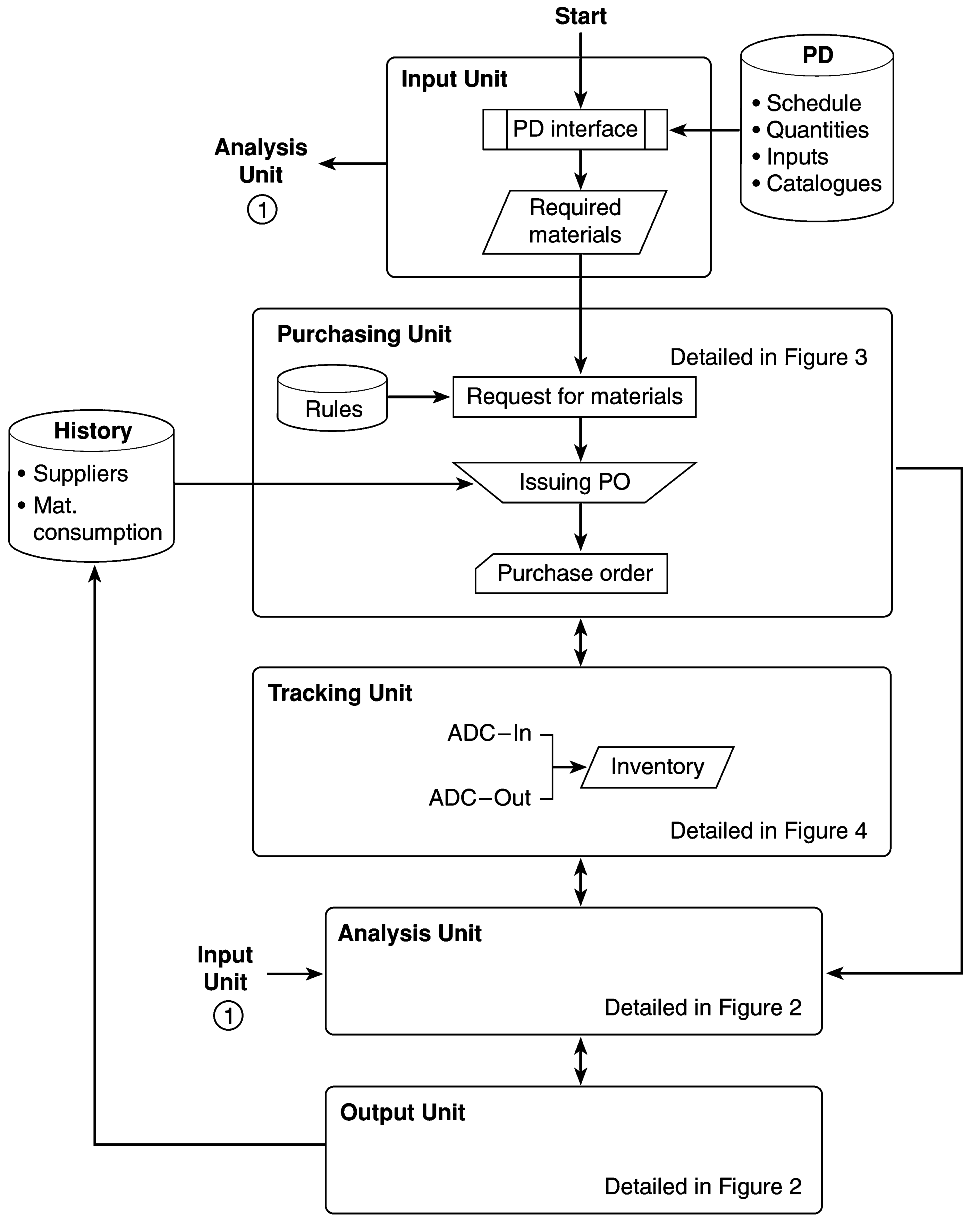


Figure 1 Model architecture

based on this, makes recommendations. The Unit calculates, or compares the following:

- Planned vs. ordered quantities. This monitors the function of the Purchasing Unit, i.e. it checks if all the materials needed at the current stage were ordered and whether the ordered quantities were correct. The importance of this comparison stems from the fact that issuing a PO includes a manual step and hence can include mistakes.
- Ordered materials compared to the ones actually supplied to the site, as recorded by the Tracking Unit. This comparison includes not only the quantities but also the specifications of the supplied materials vs. the ones in the PO, as well as arrival time vs. time for supply mentioned in the PO.
- Planned vs. actually used quantities. This is important to monitor the planning process and for future planning, such as scheduling and estimating.
- Ordered vs. the actually used quantities. This data is needed to know if all ordered materials were used.

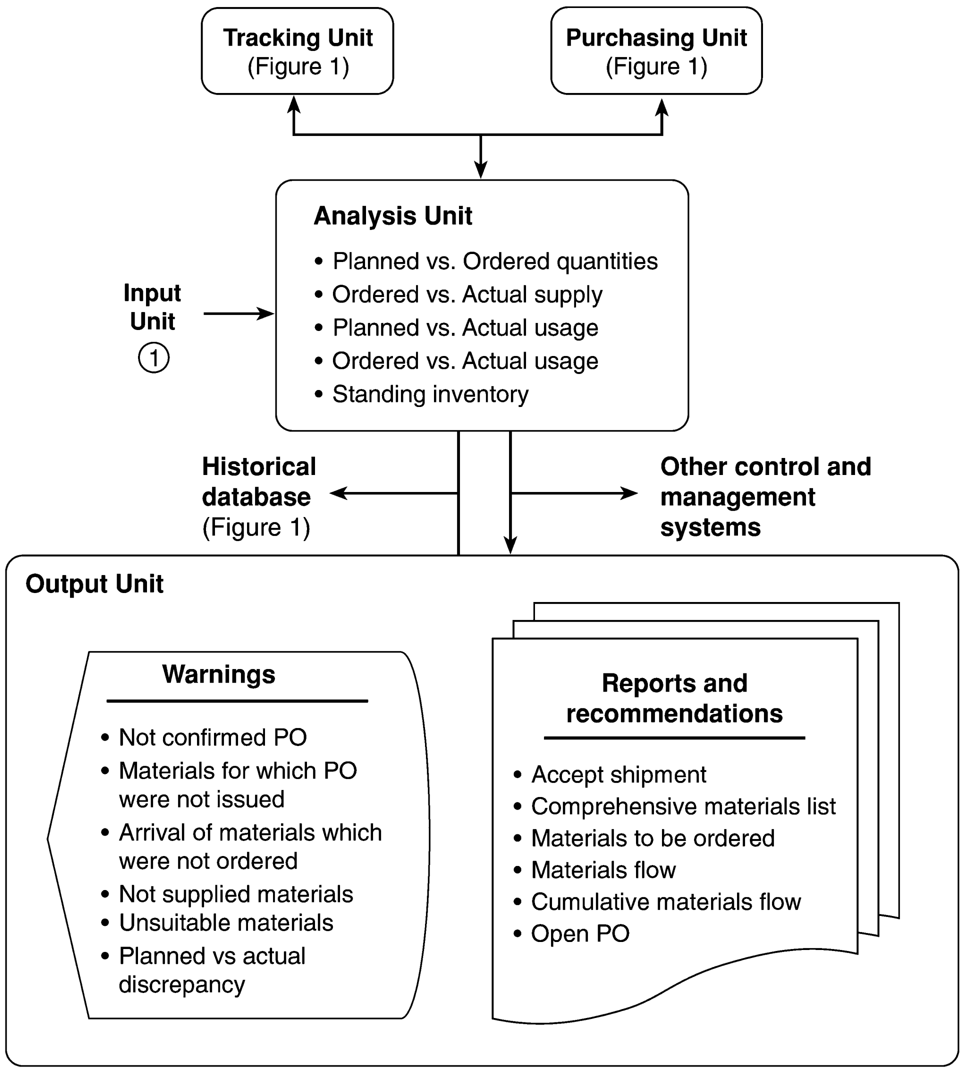


Figure 2 Model architecture (continued)

- Standing Inventory – materials that were not taken for use for a long time. This is calculated based on arrival times of materials, times of issuing materials for use and the difference in quantities between the incoming and outgoing (issued for use) materials.

The planned quantities are taken from the PD, the ordered quantities from the Purchasing Unit and the actual quantities from the Tracking Unit. Based on the above analysis the Unit recommends whether a shipment should be accepted – the data regarding the materials in the shipment are collected using ADC techniques and automatically compared to the corresponding data in the PO. If the shipment fits the order, the recommendation is to accept the materials (Output Unit), otherwise a warning defining the discrepancy (Output Unit) is issued and the shipment or part of it can be returned. The Unit also logs problems arising from the above, such as late supply, mismatch between specifications in the PO and the ones of the actually supplied materials, etc. Thus, the Historical Database can include data regarding 'problematic' suppliers – this information can be used when issuing new PO.

The Unit supplies data to other automated control and managerial functions, such as accounting. These data can be used in other control functions for cross referencing. E.g. a control system that during its operation has to determine completion of the 'Formwork Installation and Rebar Erection' activity based on decision rules, will be able to verify its determination if it receives data about arrival time of concrete mixers to the site.

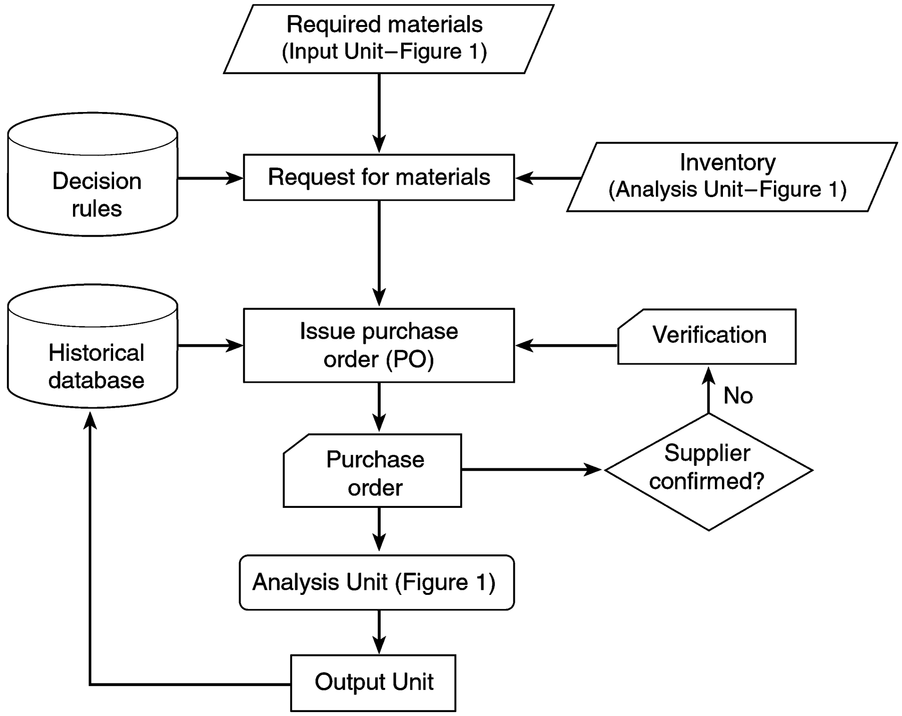


Figure 3 Materials purchasing process (expanded from Figure 1)

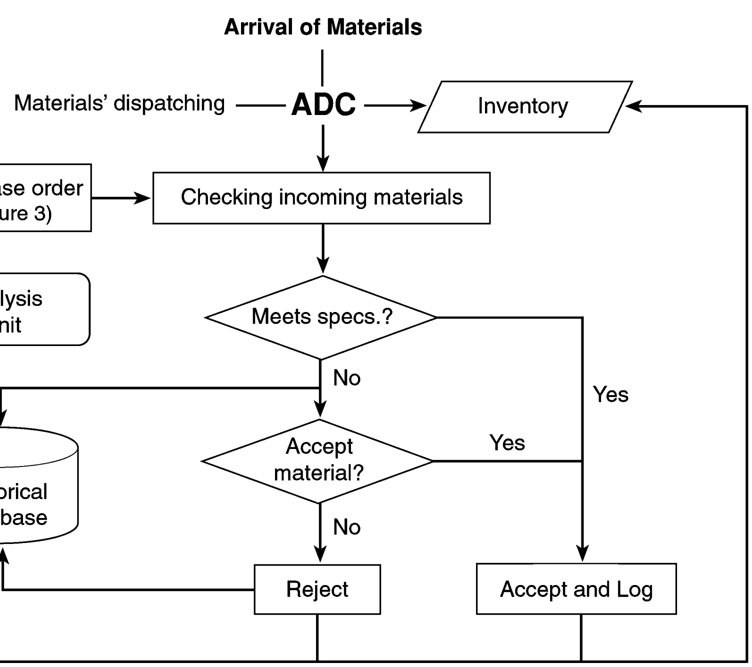
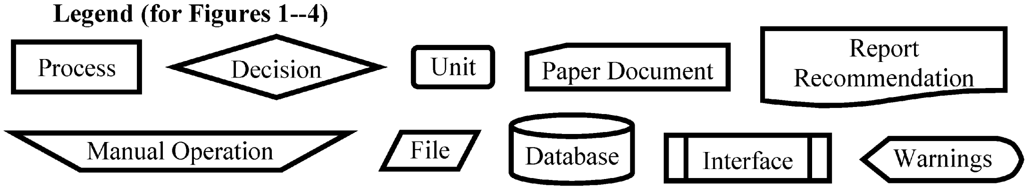


Figure 4 Tracking unit (expanded from Figure 1)

Legend (for Figures 1--4)



The detailed algorithms of the Purchasing and the Tracking Units are described in the 'Purchasing unit' and 'Tracking Unit' sections below.

The Output Unit generates various types of output: reports, warnings and historical data. The *reports* provide information regarding the flow of materials to the site and around it, the *warnings* alert about differences between the plans and the actual performance, and the *historical data* are gathered for use both in the current and in future projects.

The main reports are:

- A comprehensive list of all the materials needed in the project, their quantities and their planned time of usage. This list is useful for planning purposes and for negotiating purposes.
- List of materials to be ordered. In contrast to the comprehensive list, this list includes the materials that are needed to be ordered in the near future. In composing this list, the model considers the required materials, based on the pending activities, the inventory of these materials on-site and the lead-time for supply.
- A detailed list of materials flow. This list includes all the materials that arrived to the site, the ones dispatched for use, and the ones remaining in stock. This is not a cumulative list, but rather it shows the dates and quantities of each shipment (into and around the site).
- A cumulative list of materials flow. This list includes the same items (arrival of materials, departure for use and inventory) in a cumulative format. This list can be broken down in various ways, such as all the materials arriving for a given activity or from a specific supplier, materials consumed for a given activity, etc.
- A list of all open PO and the materials in each PO. This output helps in avoiding duplicate orders, which happens all too often in practice.

The main warnings are:

- PO not confirmed by supplier. This is an important warning to avoid problems of late supply, or other vendor related problems.
- A list of materials that should have been ordered, but were not (called 'materials for which PO were not issued in Figure 2). As the PO are issued manually, such a warning can avoid late ordering of materials.
- A list of expected materials that were not supplied. This list can avoid discovering the late arrival only when the materials are already needed.
- Materials arriving to the site that are incompatible with the PO (called unsuitable materials in Figure 2). The materials could deviate in quantity or specification. Such a deviation is, in many cases, discovered too late (when the materials are already needed), which causes delays and additional costs, due to last minute order and double handling (when the wrong material arrives and need to be returned).
- A deviation between planned and actual quantities. If discovered on time, the causes for such a deviation can be found and corrective measures taken, to reduce future waste already in the current project.

Materials monitoring and control is also important for gathering historical data, the lack of which causes the repetition of the same mistakes both in the current and future projects. The model focuses on two items: suppliers and actual quantities.

- All problems with the *suppliers*, such as late supply, or deviations in quantities or quality, are logged in the historical database. The project, or materials, manager can consult this database before issuing a new PO. Thus, suppliers with bad record would not continue working with the project, or the company altogether.
- The *actual quantities* of materials, and the materials waste, in each project, broken down to activities, are indispensable for future cost estimating. These data are project and company specific and hence much more accurate than generic databases, or rules of thumb (which are used in many cases).

Purchasing unit

The unit initiates issuing purchase orders for pending activities – the materials required for these activities are calculated by the Input Unit and stored in the Required Materials file. The purchase order is issued on the strength of logical rules stored in the Decision Rules database (Figure 3). The rules relate to typical lead times for supply, minimal inventories and the current inventories for the required materials, as stored in the Inventory file. The Unit initiates an order if one of the following situations occurs:

- A new activity is scheduled to start.
- When the inventory level of materials required for activities in progress reduces below minimum.

Once the system initiates it, a PO is issued manually. This operation requires knowing the potential suppliers, the local current market conditions and the history of suppliers in other projects of the company. The latter information is available from the Historical Database.

In order to make sure that the PO is received by the supplier and s/he understands the order and has the materials available to be supplied on time, the Unit requires confirmation from the suppliers. If the supplier has not confirmed, another manual operation is required (verifying the reasons for not confirming) as a result of which the PO may be re-issued.

The rules in the Decision Rules database relate to items such as:

- Lead times for supply. The model includes typical values but accepts different values, which depend on the specific conditions of the project.
- Minimal inventory for the various types of materials. If the inventory reaches this level, the model initiates ordering the materials.
- Minimal quantity per PO to avoid ordering small batches, which increases transportation cost.
- Maximal time between arrival to the site and dispatch for use. This rule is used to determine Dead Inventory.

The above Decision Rules are given as examples, the model is flexible enough to change these rules, or add others to suit other work methods or changing circumstances for each project, or company.

Tracking unit

This Unit tracks incoming materials and their dispatch for use. To avoid manual data collection, which is labour intensive and error prone, ADC technologies, such as barcode and RFID (Jaselskis and El-Misalami, 2003), should be used – an example for data collection of Engineered-to-Order (ETO) components (here precast elements) using barcode is given in Cheng and Chen (2002). The downside of ADC for tracking materials is that it is not easy to log data regarding bulk materials, as barcode and RFID cannot be attached to them.

The present research used, at this stage, Personal Digital Assistance (PDA) technology. This technology is suitable for all types of materials, but it requires some manual data inputting. The incoming materials data are compared to the relevant data in the PO in real-time and transferred to the desktop computer (either by radio, or downloaded directly to it).

As soon as materials arrive to the site their quantity, specification and expected date of arrival, are compared to the relevant data in the PO. If all of these meet the specification in the PO, the materials are accepted and the data are logged. If they do not meet the specifications, a decision is made whether to accept the materials, or return them to the supplier. In such a case, if the materials are different from the ones that were ordered, or they arrive too early, they can be returned. If, on the other hand, the quantity is lower than the one in the PO, the materials can be accepted and immediate action be taken (e.g. re-order). All accepted materials are added to the Inventory file. Materials that are dispatched for use, either upon their arrival or later, are also registered and their quantity subtracted from the inventory.

Model implementation and on-site experiment

The model was implemented in a computer program using Access©. The objective of the implementation was threefold: *first*, the computer program is an important part of any model development as it details the algorithms and checks them. The *second* objective of the computer program, in this case, was to allow the algorithms to be used in an ongoing project ('demonstration project') under real conditions.[1] This added another dimension to the model development since real life situations, and follow-up using the computerized algorithms, proved to be useful in refining the algorithms. The *third* objective was to demonstrate the model to practitioners and receive their comments so that the model could be improved. The model presented in the earlier 'Management and control model' section is a result of all these improvement phases.

The Access© forms were used to input all the general data relating to the project itself, the suppliers and other data necessary for efficient operation of the model. Selected drawings can also be shown in these forms to allow a division of the project into defined work areas. Thus, the materials that are dispatched for use can be associated to work areas and the follow-up of consumed materials can be broken down according to this division – this permits generation of more accurate control information.

In order to extract most of the benefits from using the model, the incoming materials and the ones dispatched for use have to be logged automatically, or semi automatically. This can be achieved by using ADC technologies such as barcode, RFID, or PDA. As mentioned in the 'Management and control model' section, the implementation in this research used a PDA. The data in the PDA and those in the Access© database were synchronized frequently (at least once a day). This synchronization can also be done continuously by radio, or cellular, technologies, which due to budgetary limitations were not available to this research. Hence, the data in the PDA was up-to-date and before accepting the shipment the storekeeper could compare the specifications in the PO to those of the materials in the shipment. Based on this comparison s/he could make an informed decision regarding the acceptance of the materials and, if the shipment was incomplete, s/he could immediately take corrective measures.

After the initial data entry of the general data, the research team spent three days accompanying the storekeeper and the project manager performing all their activities in parallel to them, using the model with the PDA. This included, mainly, logging the data relating to incoming materials and the ones dispatched for use. The research team also followed up and observed the materials management and control activities performed by the project personnel. Table 1 summarizes the observations made by the research team and the project management personnel regarding the differences between the procedures used by the project and the ones using the model.

The implementation of the model confirms that it is possible to develop an automated system for materials management and control. The experience of using the model – though for a limited time – in an ongoing project leads us to believe that such a system has many advantages over customary methods of materials management.

In order to gain the most out of such a system, detailed planning of the project's progress and the use of materials is needed. Additionally, the plans have to be up-to-date and to reflect all changes in the actual progress of the project and in the design – such level of

Table 1 Materials management procedure using the model vs. the procedure used by the project management team

Area of influence, or materials management parameter	Influence of using the model
Availability of materials	Minimizes the probability of missing materials since the model initiates materials ordering and gives an alert when they do not arrive, or if the shipment is incomplete.
Loss of construction time	Due to the availability of the right materials, at the correct quantity, at the right time, using the model minimizes unnecessary delays. Additionally, the time spent searching for materials, assessing inventory levels and tracking purchase orders is meaningfully reduced. Thus the model contributes to increased productivity (Thomas and Sanvido, 2000).
Supply timeliness	The model alerts when vendors have not confirmed the PO – a confirmation means that the vendor has received the PO, it is clear to him/her and s/he is able to supply the materials in time and according to the specifications. This procedure reduces the probability of vendors not supplying on time.
Ordering timeliness	The model initiates issuing the PO taking into account lead times. The PO is automatically generated according to the up-to-date schedule. If the PO is not sent, or confirmed on time, a warning is issued. This procedure reduces (if not eliminates) the possibility that the PO is not sent on time.
Problems receiving materials	The availability of all the up-to-date information in real-time when receiving the materials reduces the likelihood of receiving the wrong materials, or receiving incomplete shipments without knowing it immediately.
Inventory accuracy	The inventory is continuously calculated by the model. If the model is properly used, data regarding all incoming and dispatched materials are collected automatically, which is an accurate and error free method. Hence, information regarding inventory is accurate and up-to-date.
Surplus	The model prevents ordering materials when they already exist on-site. Additionally, the model automatically reduces inventory levels towards the completion of an activity. These two functions aid in reducing surplus to a minimum.
Comparison of actual vs. planned quantities	The model permits performing this comparison in real-time. This is a vast improvement compared to current practice, where data are collected once a month and processed during the following two weeks. The latter procedure is inefficient in an industry where a typical activity takes days, or very few weeks. As a result taking corrective measures on time is very difficult. Additional benefit is the generation of an objective and accurate historical database – an important feature for future planning.
Cashflow improvements	Because of the accuracy and timeliness of the information generated by the model, as well as improved communication with vendors, materials can be purchased at the latest possible time. In addition to improving cashflows, it can save on storage and double handling costs and on time-related waste of materials (especially some of the bulk materials like cement).

detail and frequent updating is not always available in construction projects. The plans have to be stored in an electronic database for the computerized algorithms to have all the needed data for smooth running. The area of Building Information Model (BIM), the principles of which serve the PD, is rapidly developing both in the structural steel and the precast concrete industries in North America (Sacks *et al.*, 2005).

Conclusions

Materials management and control are critical for efficient project management. Current materials management and control methods are unsatisfactory, and, as a result, the level of materials waste is high, progress is delayed and costs are increased. To alleviate (at least) some of the above-mentioned problems, an automated model for materials management and control was developed. The model deals with purchasing functions, it tracks materials and gives reports and alerts relating to the status of PO, materials arriving to the site and their movement about the site, materials consumption and others.

The model was implemented using Access©, for the algorithms and the databases, and a PDA for the data collection. The implementation helped in detailing the algorithms and checking, testing, demonstrating and evaluating the model. The demonstration and evaluation took place in an ongoing project under real conditions. After the initial entry of the project's specific data, the evaluation took three days, during which the research team worked together with the project personnel. The latter performed all their standard materials management and control activities, while the research team did the same using the model. A comparison between the two procedures (Table 1) can serve as an initial indication of the advantages of using the model.

The main benefits of using the model are: increased availability of materials on-site and resulting higher productivity; availability of up-to-date and accurate information regarding the inventory of available materials on-site; decreased surplus and waste of materials and real-time control information comparing the planned vs. the actual consumption of materials – the latter is also used to update historical databases, which enable more accurate planning in the future.

On the other hand, the efficiency of the control function performed with the model depends on the level of detailing and the resolution of the plans – and to the extent of how up-to-date they are – to which the data regarding the actual performance are compared. To make the use of the model even more efficient, the planning database has to be stored electronically, preferably in an object oriented format. As, in practice, it is sometimes difficult to constantly update the plans, in such a case the model will probably be less effective than we observed, e.g. if a decision to change the type of material is not reflected in the electronic database of the plans, when the material arrives, the model will issue a warning that the shipment is different from the PO.

Although the use of PDA yielded real benefits, we believe that more automated data collection technologies (e.g. barcode, RFID) can enhance the efficiency and accuracy of the model. Plans for further research include integrating such technologies with the prototype that implemented the model and experimenting with it in additional ongoing projects.

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Note

1. A commercial building site in Hod Hasharon: the building had two floors, amounting to 880 sq m. and a total cost of about $450 000

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