CSABA TAPLER

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PERFORMANCE ANALYSIS OF LOGISTIC PROCESSES IN CONSTRUCTION INDUSTRY

Abstract:

Construction managers are interested in the efficiency of a certain material flow control mechanism applied at construction processes. Realistic strategic planning can only be achieved if the decision makers know the exact value of process efficiency. Therefore the measurement of relevant features and the setup of adequate data collection and representation system are needed. This paper deals with the applicable performance analysis tools and data collection methods regarding different production and material flow control mechanisms operating on construction sites. It is demonstrated, how the activity based costing procedures should be adjusted to the project management system. The effect of the PMFC method choice on different logistic cost factors is described.

Keywords:

material flow control, construction industry, performance analysis, activity based costing

JEL Classification: L79, D24

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1 Introduction

Previous researches verified that the application of PMFC (Production and Material Flow Control) mechanisms on construction sites is beneficial among certain circumstances. It was demonstrated how the MRP, kanban, adaptive kanban, CONWIP systems can contribute to the efficient material flow and production management at a construction of a multi storey business center (Tapler, 2014). In order to select the suitable PMFC mechanism objective efficiency measurement tools are needed. Since usually the constructions are single projects without historic data to be collected on the site, some estimation has to be done and this estimation has to be objective too.

The performance measurement of different control mechanisms may raise many queries. This research examines the opportunities of setting up a general performance measurement system capable for the evaluation of different control methods.

"Performance measurement is critical to the success of almost any organization because it creates understanding, molds behavior, and leads to competitive results". Fawcett and Cooper's (Fawcett & Cooper, 1998) research showed the managers' exact preference order regarding the importance of logistric performance indexes, of which the two most important were:

- Total logistic cost
- On-time delivery

Although this research was published in 1998 it is still correct according to my practical experience even if we transpose it to construction industry.

The theoretical background of PMFC mechanisms are frequently applied in manufacturing processes. In construction industry the release of building tasks are determined by the project plan, minor schedule modifications can be made with the approval of the site foreman. The registering method of the modifications is also very strict. The initiative planning phase of building projects puts an emphasis on the in-site logistic infrastructure and operation schedule. This logistic planning puts the emphasis on the adequate scheduling of supply of materials, vehicles, storage areas and devices, tools and human resources. However according to my non representative survey and experiences of interviewed construction professionals the coordination of material handling on construction sites are not that strictly controlled as at manufacturing plants. In many cases the material movements are carried out based on ad-hoc decisions of the siteman or the operative worker himself.

The ad-hoc control processes seem chaotic for an outsider or for a newly hired. If the workers can't overview the whole process they become under-motivated and are not likely to provide any constructive ideas to develop the system. If the control and management is carried out by one worker the organization starts to depend on one critical human resource which means a great risk and disables teamwork to improve the processes.

During the recent decades the territorial decrease of the construction sites could be observed. The limited size of the construction area means a serious constraint and forces the scheduled delivery of building materials. Besides storage area problem the quality preservation of the accumulated building materials causes extra expenses. Other considerable costs are the packaging against weather effects and the guarding against thievery which increase in case of overstocking.

The above factors led to the spreading of JIT (Just-In-Time) construction which aims to support the building activity with minimal amount of material storing, human labor, tools and machinery.

2 Analogy Between Construction And Conventional Assembly Processes

A tight analogy can be observed between a construction project and a conventional assembly system thus the theories of production logistics may be successfully applied. The aim of both activities is to produce a product for the customer with the best efficiency available. The product may be for example a car, food, telephone or in construction industry a flat, motorway, etc.

Both the construction industry and the manufacturing follow a long time plan created on a strategic level. The process system of both areas can be represented by complex activity network. Although diverse structural features exist in both we can define a general system structure with standard processes.

The demand forecasting has a high importance on long and short term as the rough and detailed plans and schedules are built upon it. The demand forecast is not just quantitative but qualitative (e.g.: how many and how big flats to build, how many and what kind of telephone to assemble).

The set of available resources and the demand forecast determine the aggregated planning. The aggregated planning is the basis of the production schedule, inventory plan, shift and overtime schedule. In the short term the MPS (master production schedule) is set up which is the basis of material resource planning, detailed capacity plan, production job release and scheduling. This short term planning is often called “MRP running” referring to the MRP (Material Requirement Planning) logic used by ERP (Enterprise Resource Planning) systems. The long, medium and short term planning phases of construction projects are very similar; the difference is that they operate with activity time length not with inventory. The connection between the two approaches is the cycle time of activities. Even the graphical representation is similar (e. g.: Gantt chart).

Within the short run reasonable changes in the operation schedules may occur and the supply system have to adapt to these changes. The raw materials/building materials are transported to the plant/construction site through a complex supply chain.

The main differences between conventional manufacturing and construction process can be observed in the planning and the material flow management approach. The fundamental difference between the manufacturing plant and the construction project is that a manufacturing process can use a fix set of resources. The manufacturing system produces ineffectively if the system is not balanced properly. The underutilization is a serious source of waste and only limited opportunities exist to quicken the late activities in the critical path. In case of construction projects the duration time of activities can be altered in a wider range by involving or excluding external resources. As a consequence of this the manufacturing plants priorize the balanced production by dealing with demand forecasting and capacity planning on the long-, medium- and short term.

Construction projects focus on lead time minimalization by reconciling capacity needs and activity duration times.

The two industrial segments can mutually adopt techniques from each other with success. The construction industry owns the project management theories, hence the professionals recognized that it would be impossible to complete on time regarding the complex network of sequential and parallel activities and multi-participant interactions. The application of project management principles appeared in the last decade of production philosophy. Instead of extreme utilization of resources the lead time reduction became a major aspect of manufacturing which is one of the main pillars of Quick Response Manufacturing (Suri, 2008).

In construction industry the register of inventory transactions, the inventory analysis methods do not gain that much attention as in manufacturing. This is partly because of working with bulk materials and high volumes partly because of process planning and operating errors.

The value adding core activity of a construction project is the building itself. According to lean aspect any waste that emerges during the value chain causes system ineffectivity and must be eliminated. The insufficiency of construction supply process results waste and increases the cost price of the construction.

This way the seemingly irrelevant factors may have direct effect on the profit and the competitiveness of the company. The lean aspect emerged from the Toyota Production System aims to exclude the wastes from the value stream. The 8 basic types of waste are the following:

- Overproduction
- Waiting
- Excessive material handling/transportation
- Excessive motion of human resource
- Excessive processing
- Inventory
- Material and work defects

- Underutilization of workforce

The inadequate selection of control mechanism has a direct effect on the appearance of waste.

The WIP level and operation start signals, the flow of materials and information can be effectively controlled by the PMFC mechanisms widely used in assembly plants.

The original kanban system used cards - however the sign itself can be forwarded electronically. In E-kanban systems the lead time of replenishment process is shortened and the information forwarding is error-free: cards will not be lost and information will not be read-off. Only drawback of e-kanban is the IT infrastructure needs and the lack of physical visualization. Main advantage of e-kanban is that the maintenance of cards is a safe and quick moment in the database and the change of card sets on operation changeovers is an easy automatic process. There are no cards of the antecedent operation to be collected and cards of the upcoming operation to be handed out.

The stochastic feature of demands, the uncertainty of processes led to the emergence of adaptive kanban systems. The regulation of WIP level can be carried out by the adjustment of kanban number. In practice of conventional kanban the inadequacy of the inventory level indicates to the operators to change the kanban number so the feedback comes after the problem.

The schedule of building operations is similar to the MRP logic. The tracking, continuous modification of the schedule, the execution of the proper material handling process is slow and carries possible error. With the help of the visualized, inventory controlling PMFC systems the whole process becomes more transparent, the replenishment process become more unequivocal and simple to each participant on the site.

The pace of the production of building materials produced on the construction site can be controlled by the P kanban cards.

- Kanban ensures the following principles prevail:
- JIT inventory control
- Automatic replenishment
- Pull system
- Continuous development – Lean
- Process transparency

The kanban cards can be produced and handed out to sitemans even already at the project plan creation phase when the detailed scheduling of the operations is created. The kanban card might be the tool used for registering completed work.

The kanban sign itself does not necessarily mean a card. It can be a flag or other object that has an agreed meaning. The electronic kanban can be implemented by cheap mobile applications. A few years ago the implementation of e-kanban needed expensively installed, online data collection mobile computers. In the era of smart phones relatively reliable applications can be used to implement effective and cheap kanban operations on construction sites which usually lack the necessary infrastructure for IT system supporting online inventory handling.

Deciding the number of kanbans is a classical logistic trade off. By reducing the number of kanbans the average inventory level of the consumption point is reduced but the probability of inventory shortage grows (Csik & Foldesi, 2011). If kanban number is increased the inventory holding costs would also increase. By the application of kanban system a WIP cap can be assigned to the operation and the probability of waiting for inventory can be minimized.

MRP control may result in an alternating inventory level, unexpected material shortages and extra replenishment processes may occur.

3 Simulation Aided Logistic Cost Calculation

With the help of simulation tools we can estimate the total logistic cost of a construction process. The logistic simulation softwares offer opportunity to construction professionals – not being computer professionals – simulate the work, material and information flow on a construction site. Such softwares are for example:

- Technomatix Plant Simulation
- Witness
- Taylor
- Simul8

The application of simulation is twofold. First simulation can be involved in the site layout design process. Second the work and material management system, the applied PMFC mechanism can be verified and the total logistic cost can be calculated.

One of the main tasks of site layout design is to solve the problem of building material storage. Certain technologies cannot be applied at the point of consumption and also need to be placed on the site. The selection of logistic parameters and scheduling of building materials is a complex task. The types of the materials handled at the site are the following:

- Bulk materials (e.g.: gravel, ground, etc.)
- Pallets (e.g.: tiles, bricks)
- Prefabricated elements (e.g.: ferro concrete beams)
- Precious and weather sensitive goods (e.g.: copper wires, machinery)
- Finished or semi-finished goods (e.g.: doors)

The allocation problem can be handled by metaheuristic algorithms. The advantage of the simulation is that specific costs can be attached to transport operations and to the resources that assist for the material handling process. These resources can be forklifts, cranes, worker, etc. Multiple resources are assigned to construction operations and material movements. The cost of a certain material movement varies as the allocation changes. For example an allocation run puts the administration building and the tool warehouse on the edge of the construction site the traveling costs of a worker will be higher.

The simulation results show that the key factors that affect the efficiency of a PMFC mechanism are the following:

- Number of parallel building operations
- Material holding cost at a certain operation
- Duration of replenish signal
- Cost and duration of replenishment process
- Cost and duration of reverse material flow
- Number of operations supplied by one replenishment cycle
- Cost of reaction to an unexpected operation changeover
- Volume transported by a vehicle
- Number of materials in a SKU (e.g.: pallet)
- Pace of consumption (pcs/h)

When running the same construction supply model operating with MRP and Kanban show that MRP contribute to inventory accumulation, underutilization of workforce, excessive material handling/transportation and waiting.

Deciding about a PMFC may be influenced by other circumstances like the nature of the construction. The material flow processes are different at the construction of a new building and at a building restoration. At a new building the building materials can be easily moved by cranes in large batches. Stocks accumulated and not used up at a building operation should not be taken back immediately, guarding, cleaning causes less problem and costs.

In this paper I present results for the simulation of the most commonly used MRP and Kanban control systems at the restoration of a business center (Fig. 1).

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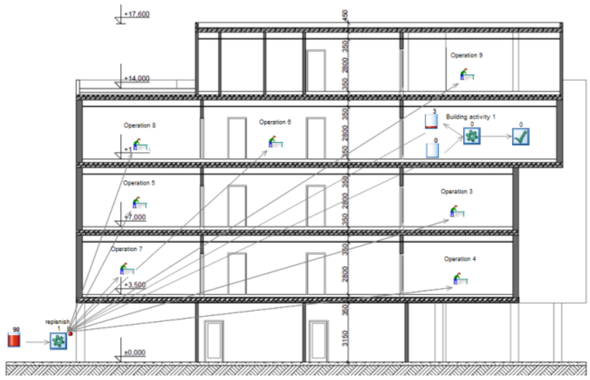

Figure 1. Simulation of kanban supply system at the restoration of a business center

In this case the outcome of the simulation is that it is worth to use kanban if more than 6 parallel operations are run together and these operations.

The starting of new packaging units caused a minor problem and extra cost at MRP system. In Kanban the units were transferred to the place of operation in smaller units. If these smaller units were not used up because the operation was interrupted only smaller quantities had to be moved back to the storage area. Figure 2 demonstrates a case when excessive consumption took place at the operation and the builder realized a need for replenishment.

The ergonomical requirements of a restoration are much higher. Meanwhile the construction people may use the building and do not accept disorder, too much packaging material and unused building material stocks. Punishment costs were built in the simulation to model such effects.

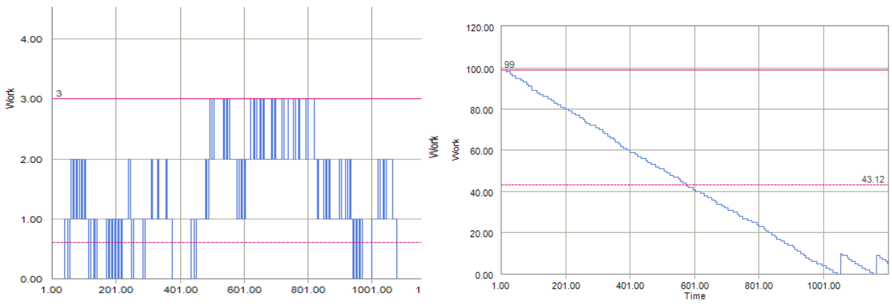

Figure 2. Kanban and MRP inventory level

The problem with kanban is the lead time of replenishment process. The number of parallel operations and the capacity of a replenishment cycle have the largest influence on the profitability of kanban application.

4 Performance Measurement

4.1 Wide-spread performance measuring tools

There are several performance measurement tools - probably the most widely spread one is the Balanced Scorecard e.g.:. Huan et al., 2011; Lee et al., 2008; Bentes et al., 2012). This aspect gives a general overview of the company's performance considering financial, customer, internal process and adaptivity prospects.

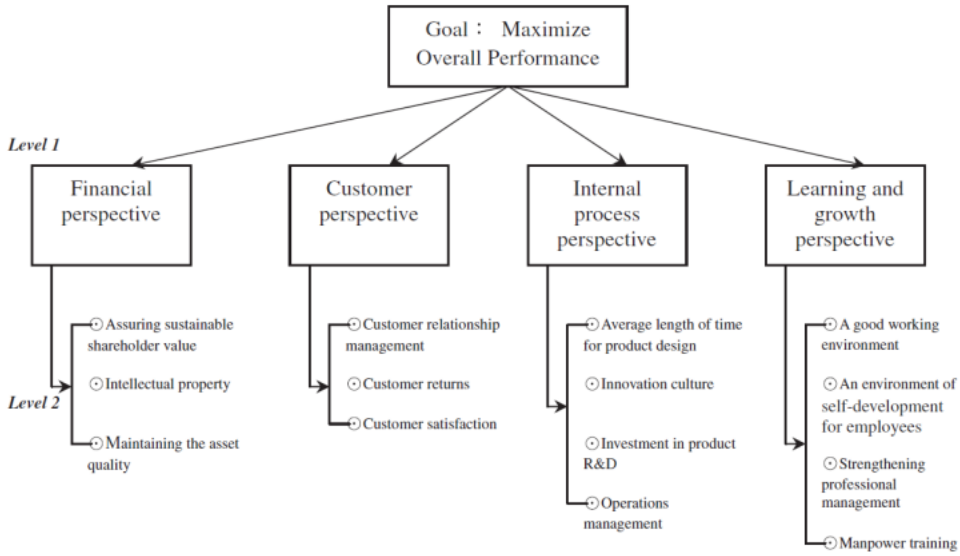

Figure 3. Huang et al. (Huan et al, 2011)

Several calculation methods of Key Performance Indicators are demonstrated in the literature (e.g.: Jonsson and Mattsson, 2005). Several KPI's have been determined like the delivery reliability, delivery dependability, stock availability see equations (1) - (3).

$$R_{Delivery} = \frac{N_{OnTimeDeliveries}}{N_{AllDeliveries}} \quad (1)$$

$$. \ D_{Delivery} = \frac{N_{DeliveriesWithoutComplaints}}{N_{AllDeliveries}} \quad (2)$$

$$. \ R_{Stock} = \frac{N_{CompletedOrders}}{N_{AllOrders}} \quad (3)$$

The PMFC selection has a direct effect on the following system outputs:

- WIP level
- Lead time of operation
- Efficiency
- Efficiency of bottleneck (system)
- Agility

- Controlling tasks
- Applicable product diversity (multi-functional feature of a construction unit)
- Late operations

Management systems are usually prepared for constant monitoring of KPI's demonstrating the output performance of the above factors.

4.2 The Total Logistic Cost Concept

Simulation methods can give a draft estimation of total investment and operating logistic costs in the planning phase in case the model is properly built and the input data is valid. Modeling of the temporary environment of a construction project is usually unnecessary since we don't have a chance to feedback the findings of the simulation on the live system. This kind of simulation could only support the decisions concerning the following construction project or the similar phrase of the current project. Either way the most critical factor of evaluation method is the collection and validation of input data. In case of adequate input data the simulation models is capable to give adequate outputs. It is generally agreed that measuring the total cost gives the most objective evaluation. The only question is what should be included in the concerning system.

Lambert and Stock have built a model to describe the total logistic cost (Lambert & Stock, 2001). They categorized the cost items of the whole logistic system into the followings:

- Carrying costs
- Holding costs
- Transportation costs
- Administration costs
- Other logistics costs (material costs, packaging costs, lot quantity costs and information costs)

As the construction process is analogical with the classic production process all of the above mentioned cost items can be observed at construction sites.

In case of construction processes IT and identification barriers appear. In a warehouse or a manufacturing plant built for mass production it is usually worth to install costly applications and hardware. However adequate online data collection is hardly feasible among the always changing circumstances. The accuracy of the information regarding the processes (timings, inventories, work loads, specific costs) can be increased by the usage of certain project management softwares (e.g.: MS Project, Smartsheet, etc.) and data input improvements. Cost effective mobile applications are available on the market to register inventory movements. Above a certain company size customized application development seem to be a reasonable way for online data collection. Many inventory management and replenishment functions can be handled by shared spreadsheets without investing in costly hardware or software.

In order to produce accurate specific norms the cost monitoring and the accounting system should be adjusted to the project management system. This way the timing and cost information of a single task needed for controlling purposes should be received from the representative of the given project unit (resource, department, etc.) and the principles of Activity Based Costing would prevail.

In the followings an activity based costing model of construction logistics is demonstrated.

It is practical to calculate the total logistic cost as follows in equation (4) :

$$TC = SPC + CC + RC \qquad (4)$$

Where:

- SpC: Supply costs – determined by the measured duration of sub-processes and specific costs of resources, includes initial supply and replenishment processes
- CC: Direct costs of effective construction process
- RC: Reverse material handling cost. Excessive material accumulation on the spot of consumption at the site causes extra reverse material handling tasks. We rarely have this information collected.

To achieve a proper total cost model the data for all the sub-processes need to be collected.

Supply costs can be calculated as in equation (5).

$$SPC = DSC + FC \qquad (5)$$

Where:

- DSC: Direct supply cost containing initial and replenishment processes
- FC: Flow management costs – indirect costs per time unit. Different PMFC's have different effect on this factor. E.g.: effective MRP requires lot of scheduling tasks, for proper Kanban we need to setup the system with signals and calculation of initial inventory levels

Construction industry operates with one of the highest material cost rate. However the logistic operations and decisions can contribute to additional costs. The total construction cost can be calculated by the following equation:

$$CC = FC + TRC + STC + DCC + EWC + WIP + DLC \qquad (6)$$

Where:

- FC: Flow management costs – indirect cost per time unit.
- StC: Setup cost – includes the time and resource requirements of starting an operation.
- DcC: Data collection cost

- EWC: Effective work for which the gross norms are usually known
- WIP: WIP cost factor which can be highly different in case of different PMFC's. E.g.: a well-organized MRP can operate by near-to-zero cost, meanwhile kanban systems have to be filled with a minimal inventory level
- DLC: Delay cost – it is one of the most common waste source on construction sites despite of this it's often not recorded properly

Unnecessary supplies of building operations increase the reverse material handling movements and cost within the construction site. Product (building material) returns can also be observed between the construction site and the building material depot. All of these contribute to high logistic costs (Stock et al., 2006). A basic calculation for reverse processes is shown by Equation (7).

$$RC = RMC + SCC \qquad (7)$$

Where:

- RMC: Cost of reverse material movements
- SCC: Secondary consumption cost - there is always a choice to transport materials back to the depot or decide over secondary consumption (waste, fuel, etc.). Secondary consumption usually never covers the disbursements of material purchase.

Future researches aim to collect more representative data about the total cost emerging on construction sites. The further investigation of the application of PMFC mechanisms is going to be achieved with co-operation of builder companies.

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