EVALUATION OF VARIOUS PRODUCTION AND MATERIAL FLOW PROCESSES IMPLEMENTED ON BUILDING SITES

Dr. Z. Abdul Rahim
Associate Professor, Department of Civil Engineering,
Maulana Azad National Urdu University, Hyderabad
Email id: dr.zabdulrahim@gmail.com

Abstract— **This study presents a comprehensive evaluation of diverse production and material flow processes implemented in the construction industry, with a specific focus on building sites. The construction sector, characterized by its complex logistics and the need for efficient material management, faces significant challenges in optimizing production flows to minimize waste, reduce costs, and improve project timelines. This research aims to identify, analyze, and compare various strategies and methodologies employed across different construction projects to manage production and material flows effectively. Utilizing a mixed-methods approach that combines qualitative case studies and quantitative data analysis, the research examines several key factors influencing material flow and production efficiency on construction sites. These factors include the adoption of lean construction principles, the implementation of just-in-time (JIT) delivery systems, the application of advanced planning and scheduling tools, and the integration of technology-driven solutions such as Building Information Modeling (BIM) and automated material tracking systems.**

Keywords- material flow control; construction; simulation; reverse material flow;

I. INTRODUCTION

The theoretical background of production and material flow control (PMFC) mechanisms are frequently applied in manufacturing processes. In construction industry the release of building tasks is 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.

II. 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. The building 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 (QRM – Quick Response Manufacturing).

In construction 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 inefficiency 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. Later in this paper simulation results are shown. 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.

Of course, my statement about PMFC selection above is not axiomatic and among other circumstances the outcome of simulation may the other way round. In the followings I analyze the application of different PMFC mechanisms controlling construction supply process. I determine the key parameters that define the selection of a certain PMFC.

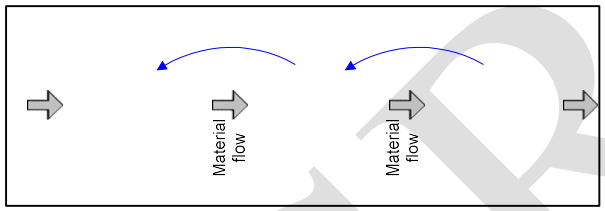

Figure 1. Kanban flow

The original kanban system uses cards but the sign itself can be forwarded electronically too. 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 general kanban the inadequacy of the inventory level indicates to the operators to change the kanban number so the feedback comes after the problem.

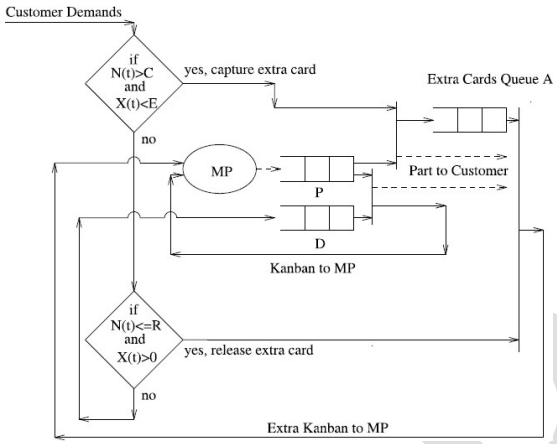

Figure 2. Adaptive kanban

Tardif and Maaseidvaag created a technique for adaptive kanban control. The schematic model of adaptive kanban control is shown on Figure 2.

III. Simulation Aided Material Flow Design At Construction Sites

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.

A. Construction site layout design

There is an organizational layout plan approved during the authorization process which specifies the certain building material inventory points at the site. The layout design itself can be aided by logistic simulation using any of the transport performance minimalization methods. The layout design techniques of a construction resemble to manufacturing layout design.

The site layout design considers and assumes the followings:

- mapping the present features of the construction site
- transportation connections of the territory
- mapping of the functionally different types of opportunities for external territory usage during the project implementation phase
- location of present buildings and neighboring buildings

The project plan defines those phases of the construction when the organization and the re-organization of the site layout are to be executed. These organizational operations of the construction have to be authorized and have to cover the following matters:

- Temporary approach of the territory
- Temporary inner transportation routes
- Utilities and energy supply
- Installation of temporary buildings
- Denotation of storage areas
- Location of technological operations (e.g.: concrete plant)
- Location of fix and mobile machines (cranes, forklifts)
- Fencing

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)

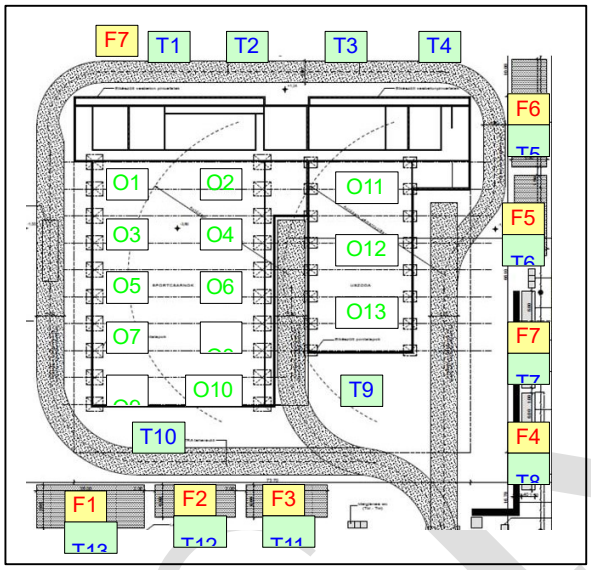

Figure 3. Allocation problem of site layout design

The allocation problem can be handled by meta-heuristic 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 running of simulation showed a considerable difference between the best and a random allocation in this case.

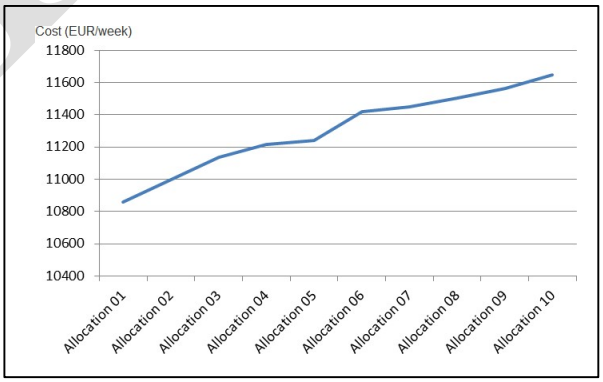

Figure 4. Allocation runs

A. Simulation of Material Flow Control

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
- Number of materials in a SKU (e.g.: pallet)
- Pace of consumption (pcs/h)

The scope of my simulation was to reveal how the different PMFC mechanisms behave in case of real circumstances. So, I examined scenarios when problems emerged during the building process. A problem for example is when an operation is interrupted and stopped because of any reason.

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.

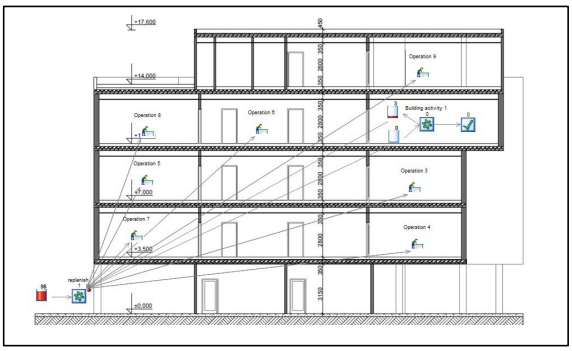

Figure 5. Simulation of kanban supply system at the restoration of a business center

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. 7. Figure demonstrates a case when excessive consumption took place at the operation and the builder realized a need for replenishment.

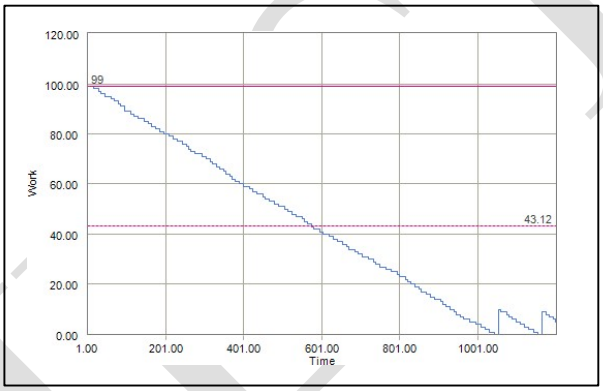

Figure 6. Inventory diagram of MRP operation

The ergonomic 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.

IV. CONCLUSION

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 . 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.

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