ADDRESSING INFORMATION FLOW IN LEAN PRODUCTION MANAGEMENT AND CONTROL IN CONSTRUCTION

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ABSTRACT:

Traditionally, production control on construction sites has been a challenging area, where the ad-hoc production control methods foster uncertainty - one of the biggest enemies of efficiency and smooth production flow. Lean construction methods such as the Last Planner System have partially tackled this problem by addressing the flow aspect through means such as constraints analysis and commitment planning. However, such systems have relatively long planning cycles to respond to the dynamic production requirements of construction, where almost daily if not hourly control is needed. New solutions have been designed by researchers to improve this aspect such as VisiLean, but again these types of software systems require the proximity and availability of computer devices to workers. Given this observation, there is a need for a communication system between the field and site office that is highly interoperable and provides real-time task status information. A High-level communication framework (using VisiLean) is presented in this paper, which aims to overcome the problems of system integration and improve the flow of information within the production system. The framework provides, among other things, generic and standardized interfaces to simplify the "push" and "pull" of the right (production) information, whenever needed, wherever needed, by whoever needs it. Overall, it is anticipated that the reliability of the production control will be improved.

KEY WORDS:

Lean Construction, BIM, Information, Communication Systems

INTRODUCTION

Koskela (2000) has discussed the importance of TFV (Transformation, Flow and Value) in construction, where it is argued that the flow aspect in traditional production management has generally been neglected and this also applied to the flow of information. The flow of information is one that affects all other resource flows significantly, and hence quite important to manage from lean production management perspective (Dave et al, 2010; Sacks et al, 2010).

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In the Last Planner® (Ballard, 2000) process of production planning, the site team needs accurate resource information about the construction tasks in order to effectively conduct Look-ahead and weekly planning activities. However, this information often lies in disparate systems, which are not always available to the site team or even interoperable to one another (Soibelman and Kim, 2002). This affects the reliability of the planning process and, in turn, the efficiency of the overall production management system. Ballard (2000) emphasises the importance of pull based information systems that release the information based on system status and can be automated, as essential requirement for lean construction delivery systems.

Traditionally, this problem of disintegration has been addressed by explicit, one-to-one connections between stakeholder's information systems, with the recent trends of implementing Enterprise wide resource planning systems (ERP) as an answer to integration (Rezgui et al, 1996; Froese, 2009; Caldas and Soibelman, 2002). The traditional approach of integrating individual applications requires significant development work for each connection, and due to the time and costs associated they are seldom created. Also, major ERP system implementations have not been able to address the problem of information integration and, in most cases, do not extend to site based processes (Tatari et al., 2007). Most projects have to work with manual processes and traditional methods of communication such as phone calls, faxes and emails to obtain such information (Zhai et al, 2009). Even though this problem has been discussed extensively over the last two decades, the issue still somewhat remains unsolved as the information systems are still disintegrated.

The location based scheduling (and the Line of Balance) method helps visualise the flow view of production by associating tasks with the physical locations on the project and by depicting them as being continuously performed across the duration of the project. This highlights problems such as discontinuity and clashes between activities, and also partially helps perceive the flow of information and resources while performing planning operations. Recently, Seppanen (2009) has attempted to improve the location based planning tools and their processes. Some recent case studies have reported successful implementation of software systems that support the Line of Balance method (Kala et al., 2010; Kala et al., 2012). Such systems perform better in situations where repetitive work is being performed and it demands relatively higher effort in initial production system design. However, these solutions still do not address the information push to the field and communication pull back to the system to support real-time production control and may benefit from solutions put forward by this research.

The paper begins by describing the importance of information flows in construction, and the main problems in achieving it. Mapping of main information flows for production related information is then provided, followed by the proposed communication framework. Finally, two scenarios describing the implementation of proposed framework is provided followed by conclusions.

IMPORTANCE OF INFORMATION FLOWS IN CONSTRUCTION

An efficient production management system relies on accurate and timely information availability. There are many information flows that need to be managed for an efficient production management system. Caldas and Soibelman (2002) mention that information flows about directives, criteria, prerequisites, availability, commitment and resources are essential to production control and work structuring. Soibelman and Kim (2002) mention that in a fragmented and dynamic environment such as construction, the integration and exchange of information between various organisational information systems and sources is crucial for efficient process management. Ballard (Ballard, 2000) provides the seven pre-requisite or constraints when planning or scheduling a task within the Last Planner™ system.

Cheng et al (2013) claim that the use of information and tracking technologies can be beneficial to lean processes, especially when applied to improve the information flow. Caldas and Soiberlman (2002) claim that the current information management systems are mostly "push" based and only release information based on demand as opposed to "pull" systems, which release information based on system status or event occurrence.

From an opposite perspective, in production management one of the key contributors to improving workflow reliability has been the application of lean construction techniques, especially the comparison between ongoing review of production performance measurement such as the Percentage Plan Complete (PPC) (Abdelhamid et al, 2010).

PROBLEMS OF INFORMATION FLOWS IN CONSTRUCTION

As mentioned above, in the Last Planner System™, one of the most important aspect is the "make ready" process, which is a function of the medium term planning (often called look-ahead planning). However, there is currently no mechanism to track or anticipate the impact of identified constraints on workflow reliability before the execution week or even until the Performance Plan Complete (PPC) is measured (Abdelhamid et al, 2010). Additionally, the tracking of constraints availability is quite hard as the information related to their current status is not aggregated or synchronised by any function or a system (Dave et al, 2010).

Confirming the above view, Formoso and Isatto (2008) describe the main flaws in production management (from an information management perspective) as following:

- Production management and planning is interpreted simply as preparing a Gantt chart and not much effort is made to synchronise accurate project information (Laufer and Tucker, 1987), which is made even more difficult due to several organisations involved in a single project, where in most cases each stakeholder uses their own information systems.
- There is a general lack of formal systems dedicated to the control aspect in production management, where it usually depends on verbal exchanges between site teams and supervisors/managers (Formoso, 1991).
- Many construction companies tend to emphasise the control related to global project aims, and fulfilment of contracts, rather than production control. In this context, spotting problems in the production system and defining corrective lines of action often become problematic (Ballard and Howell, 1997).
- Traditionally, information systems are implemented in an isolated fashion where they are not integrated with other internal or external systems.
- Due to some of the problems outlined above, such as a lack of a systematic approach to synchronise and present production information and also due to

the “T” based approach in management, most construction managers rely on their own experience, intuition to take decisions leading to further uncertainty (Lantelme and Formoso, 2000).

Navon and Sacks (2007) also criticise the monitoring systems in construction industry as slow due to; a) dynamic project systems for construction product delivery; b) ad-hoc organisation of disparate companies with limited or no long term working relations; c) and the control processes relying on manual data processing methods, which are, slow, inaccurate and expensive.

The above indicates that although managing information flow (and management) is significantly important from production management perspective in construction, there are still a number of problems/challenged that need to be overcome.

MONITORING AND CONTROLLING PRODUCTION IN CONSTRUCTION – MAPPING THE IMPORTANT EXCHANGES

Howell and Ballard (1996) provide an overview of workflow control on construction projects from a lean perspective as shown in Figure **1**. According to the authors, the planning function provides directions to the governing execution (construction) processes, while controls provide measurement of conformance to directives and in turn provide input for future planning. The authors emphasise the role of information availability to the planning and control processes and mention that the project teams can better predict the reliability of the planning process if the information upstream is available.

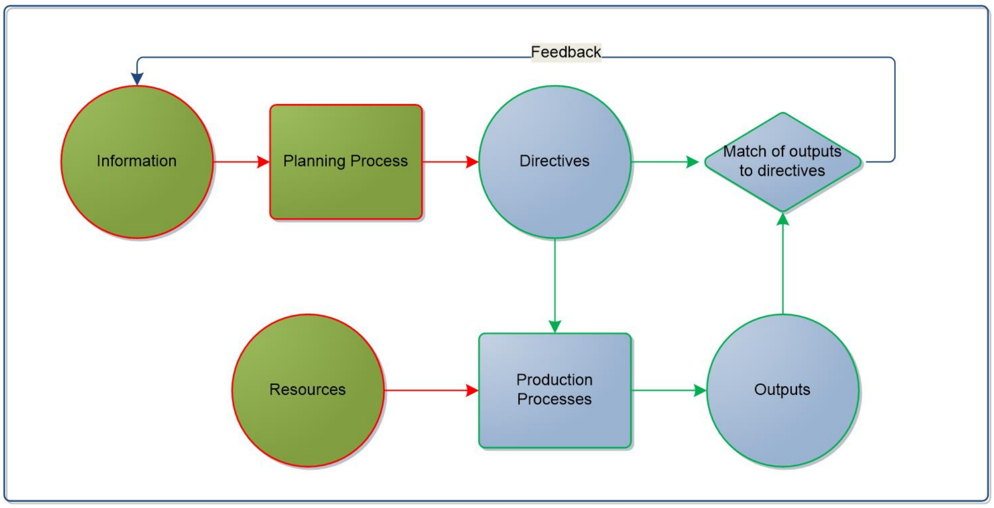

Figure 1. Relationships between planning and control (Howell and Ballard, 1996)

From this perspective, there are two types of information flows that are important from production management perspective as shown in Figure **1**. Information flows needed to efficiently carry out long, medium and short term planning activities (shown in green), and information flows needed to efficiently execute and control production in the field (shown in blue). There is also an information flow loop connecting the control operations to the planning operations.

The information needed for both these aspects may reside in the same or different information systems (e.g., in a production management system, Enterprise Resource

Planning system, procurement system) however they may be consumed in different contexts and environments. While long, medium and short term planning activities occur in the site office, where access to desktop computers with large size projectors or displays may be available, the execution and control processes occur in the field where use of mobile devices may be more suitable. Table 1 outlines the information requirements from production planning and control perspective.

Table 1 Information Sources for Production Management

Constraint	Information system	Remarks
Material	Estimating, Inventory, Procurement	Mostly handled by ERP type applications, which handle purchase requisitions, purchase orders and supplier management
Equipment	Asset management, resource booking, plant hire (externally)	Possibly through ERP systems
Manpower	Human Resource Management, Subcontractor’s payroll, ad-hoc	In most cases ad-hoc site based communication
Space	Project Plans, Drawings and Building Information Models	Currently no systems cater to the need of space management for project execution
Design/ Specifications	Individual or merged design models (BIM, i.e. Architectural, Structural, MEP), Drawings, Tendering and Estimating, building regulations such as local or national authorities	BIM systems and Tendering and Estimation systems. Project extranets.
Predecessor	A production management system	Currently an ad-hoc verbal communication system, or through the Last Planner™ collaborative “huddle” meetings
External conditions	Weather forecast engines, safety management system	These are indicative/predictive systems, but their integration to the production system at the task level may still be beneficial.

Recently, researchers have attempted to develop production management systems such as VisiLean (Dave, 2013) and KanBIM (Sacks et al., 2010) that addresses some of the requirements raised above. Both systems address the aspect of lean production management workflow while being integrated with the product model (Building Information Model) in a visual way. While both systems help realise production management at site, the problems of communication between heterogeneous information sources remains to be tackled. From this perspective, this paper aims to suggest a communication platform for a production management system such as VisiLean and beyond.

Also, even though these production management systems are supporting site-based processes, there are still gaps between actual field based processes (i.e. actual construction processes and associated field based activities) and site-office based processes. It can be argued that the need for a communication system or a platform should address the end-to-end construction process, from head office to the site office to the field, with feedback loops to each other, as depicted in Figure 2. The following sections outline the information requirements and exchange in communication between important production processes.

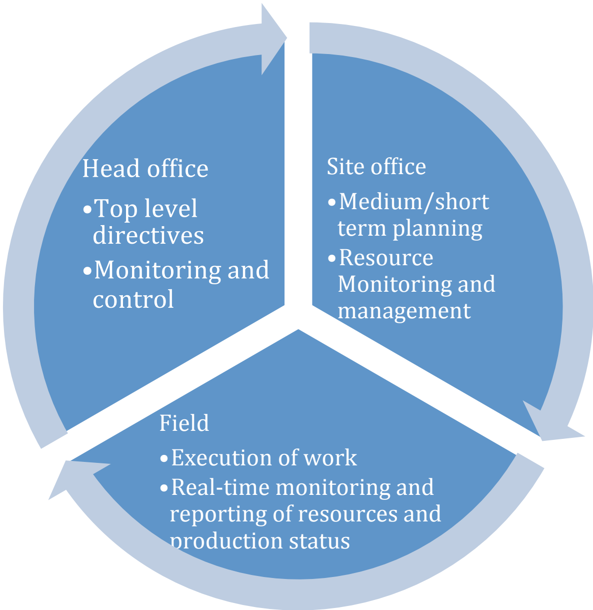

Figure 2 - Communication loop between different locations in a project

Communication Framework for Production Management

The design of high abstraction-level communication interfaces is a strong requirement in production management to increase information integration and interoperability among all building stakeholders and devices used in the field. Indeed, such interfaces play a major role in integrating varied groups of stand-alone applications and systems to form a common construction management system, an example of which can be found in modern intelligent buildings (Nguyen, 2013). In this regard, very few attempts have been made to propose Messaging Interface standards that provide the kind of inter-organizational information exchange needed for production management. Two relevant proposals have been identified in our research, oBIX (Open Building Information Exchange) (MacKenzie, 2006) and QLM (Quantum Lifecycle Management) messaging standards (Framling, 2013). This paper does not describe in detail such standards but previous research showed that QLM (Kubler et al., 2014) provides a larger number of standardized interfaces or, at least, more flexible communication interfaces that enable high-level system integration.

QLM messaging standards provide the necessary interfaces and operations to enable any actor and system to communicate with each other, regardless of the device, technology and data model used by the application. Figure **3** illustrates such an environment where QLM is used as communication infrastructure to enable communications between Ressource Management, Production Control, Field Production Management “Apps” and other external systems. Ultimately, QLM is intended to integrate all types of systems, applications, and people into a single entity so as to provide systems and organizations with the ability of exchanging any type of information with each other in a comprehensible form.

In the QLM world, communication between QLM nodes is done by using interfaces defined in QLM-MI. A defining characteristic of QLM-MI is that QLM nodes may act both as a “server” and as a “client”, and therefore communicate directly with each other or with back-end servers in a peer-to-peer manner. Typical examples of exchanged data are sensor readings, lifecycle events, requests for historical data, notifications, etc. The main properties of QLM are listed in (Framling, 2013), among which the subscription mechanism is a cornerstone of that standard. Two types of subscriptions can be performed, a) *subscription with callback address*: the subscribed data is sent to the callback address at the requested interval. Two types of intervals can be defined: *interval-based* or *event-based*; b) *subscription without callback address*: the data is memorized on the subscribed QLM node as long as the subscription is valid. The memorized information can be retrieved (i.e., polled) by issuing a new QLM read query by indicating the ID of the subscription.

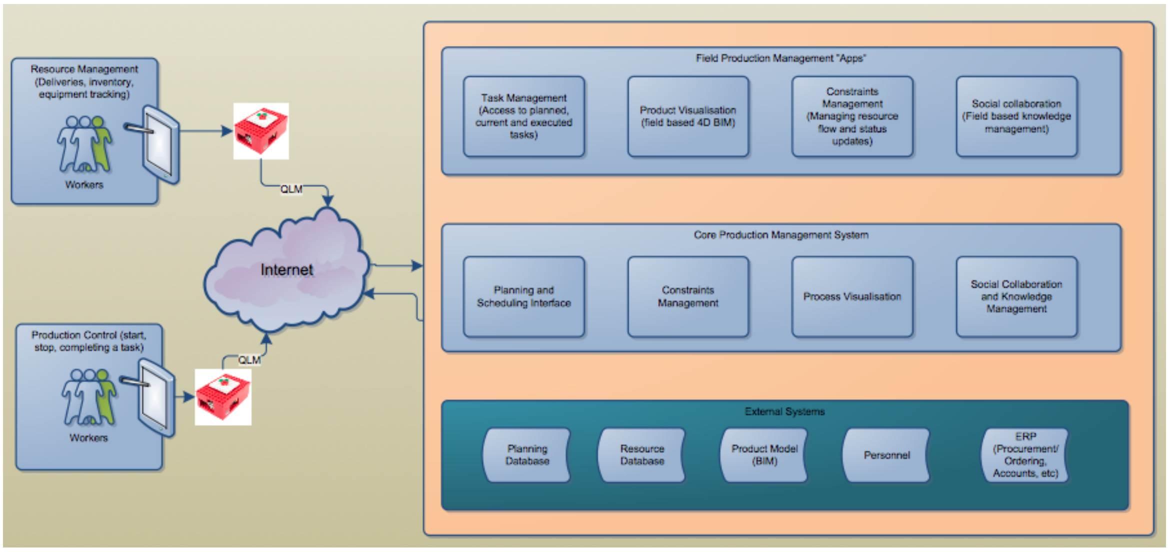

Figure 3 - A schematic diagram of the proposed system

A SCENARIO WITH THE PROPOSED SYSTEM

In this section, a scenario relying on the system previously described (i.e. a combination of a field production management application whose communications are handled by the QLM messaging standards) is proposed. In this scenario, a magnetic board, a fixed camera linked to a low powered computer (Raspberry Pi) and image recognition engine is used in conjunction with a production management system to track production status. The key actors involved in this scenario are described in Table 2 Key actors involved in the scenario and Figure **4** details the workflow/process related to the proposed system:

- The process starts once the collaborative weekly planning process is concluded (see Figure **4**). The main function of the weekly planning session is to select constraint free tasks for execution and (for the team) to make commitments to each other that they will execute the tasks in the decided sequence. The result will be a list of tasks for execution for each foreman.
- Following the weekly planning process, each task foreman will list their respective tasks on the magnetic chart. Each task will have a unique identifier (*task_id*) that helps identifying the task in the production management system. Each location on the project will have one or more magnetic boards (depending on the task list) and the tasks will be listed as columns whereas the days will be listed as rows.
- Once the magnetic board is setup, the project team will use it to update the status of the task as appropriate.
- As shown in the workflow in Figure **4**, once the task starts, the foreman will put the yellow triangle symbol against it to indicate "work in progress".
- If there are problems emerging during the task, for example, material or labour shortages, equipment breakdown, *etc.*, the foreman will update the task status with the "stop" (red octagon) symbol to mark work stoppage. This symbol can also be used to indicate imminent problems even before they occur.
- If there are no further problems, and if the task is completed as planned, the foreman will update the status on board as "complete" with the green checkbox symbol.
- Following the final quality check by the QC engineer, the task will be updated with the "QC approved" symbol.

Table 2 Key actors involved in the scenario

Key Actors	Role in the Scenario
Project manager	Wants to have an overview of the process. Reacts to problems. Subscribes to certain tasks depending on their criticality
Foreman/ Site manager/ Last Planner	Responsible for preparing the magnetic charts with the tasks. These tasks are generated following the Last Planner Weekly planning session from the weekly planning module of the production management system.
Workers/ Task Manager	Responsible for managing individual tasks on the status boards. Updates the status of individual task when needed.
Subcontractor manager	Responsible for their own work packages. Also reacts to problems according to the tasks status that he/she is responsible for. Subscribes to his/her tasks, and gets a notification for the task status connected to his/her work package.
Quality manager	Responsible for checking the quality of each task after they are complete. Gets a notification automatically for the tasks under his/her supervision once they are complete. Checks the tasks and then updates the status on the board accordingly.
Safety manager	Only responds to issues that are related to safety. If the task status has changed to indicate a safety related problem, receives a

	notification.

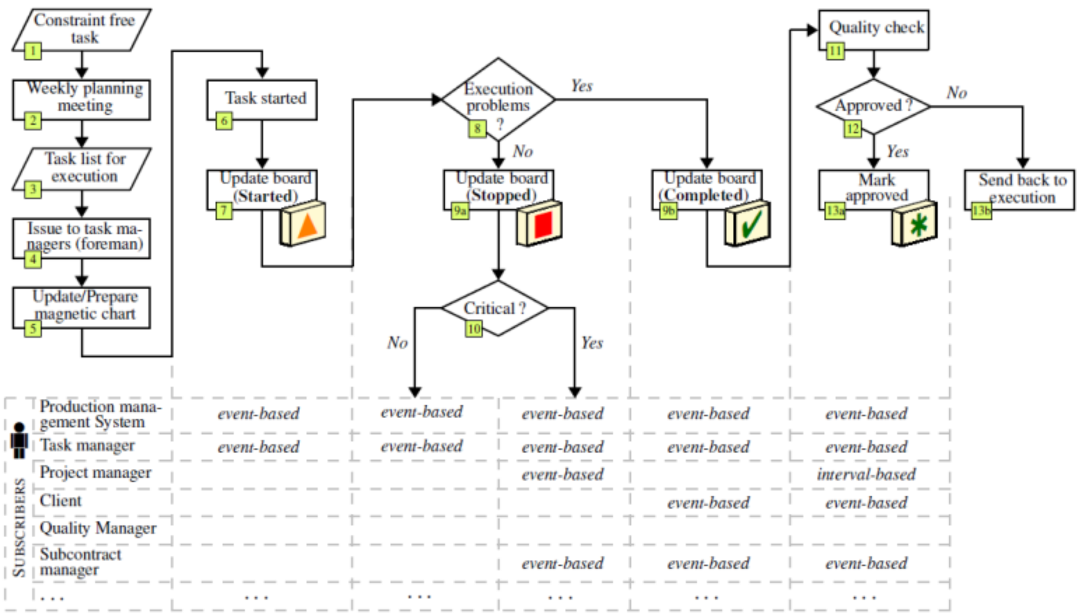

Figure 4 - Workflow depicting the scenario

A camera connected to a device (Raspberry Pi in our scenario) as depicted in Figure **5** will take a picture of the magnetic board every 10 minutes. The system will automatically interpret the picture and identify appropriate status from the list (i.e. started, stopped, completed and QC checked). With each update in the status of the task, the communication infrastructure (relying on the QLM messaging standards) will update the production management system or any other actor who subscribed beforehand to such information. A list of potential subscribers is provided as an example in the workflow (see Figure **4**), however this list is not meant to be exhaustive and any member of the team can initiate or cancel in "real-time" (i.e., when the person deems it appropriate) a subscription to a task or other information exchanged in the project/platform. Figure **5** gives insight into a QLM response generated in this scenario. This response relies on a simple ontology, specified using XML schema, which is generic enough for representing "any" object and information needed for information exchange in the application. The ontology is structured as a hierarchy with an "Objects" element as its top element, which can contain any number of "Object" sub-elements. In our example, a unique object of type *Task_01* (see row~5 of the XML message) is considered. "Object" elements can have any number of properties called InfoItem(s), as well as "Object" sub-elements. In our example, we forward the values related to *Task_01* that have been updated, namely that work related to *Task_01* that should be finished on Wednesday has been checked and validated by the foreman (see row 8-10 in the XML message) and that work related to *Task_01* that should be carried out on Thursday have been achieved (see row 8-10 in the XML message). The next step related to Task_01 is its validation (Thursday). The resulting Object tree can contain any number of levels.

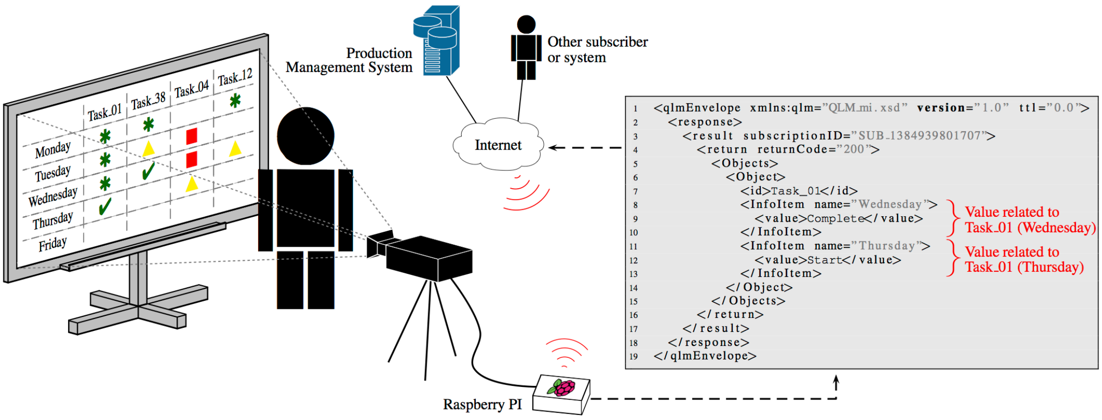

Figure 5 - Using A Magnetic Board to Track Production Status

This QLM response is described as a simple example, but more complex scenarios with more complex data structures could be defined.

CONCLUSIONS

Managing information flow within production management is one of the critical aspects that affects the efficiency of the whole project. Most organizations are not satisfied with their current level of data integration and interoperability with other partners and systems. This can be partly explained by the fact that companies do not implement Messaging Interface standards that provide high-level abstraction communication interfaces. Communication infrastructures and applications are often designed domain- or vendor-specific, which hinders the inter-operation inside and outside the organization. It is a fact today that without an appropriate Messaging Interface protocol as foundation of a production management system, organizations will not be able to evolve to meet the new business needs. The main emergent benefits of the proposed system seem to be improved information flow without additional burdens on workers (in updating information). Also the alignment between the planning and control operations is improved, and the system also supports "one piece flow" lean principle from communication perspective as the batch update of information is done away with.

The proposed framework aims to address explicit or descriptive information flows within the production management system. However, there is an opportunity to address more "softer" language/action type of information items such as commitments and requests between workers. Future research in this framework could be dedicated to this area.

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