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Increasing productivity in ETO construction projects through a lean methodology for demand predictability

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***Abstract*—Construction is one of the main sectors of the economy, globally. In Italy this sector is highly fragmented and consists mostly of small and medium-sized enterprises (SMEs). During a traditional construction project many different disciplines interact causing high coordination efforts. The main problem is a weak planning of on-site construction processes. Especially shared resources (like tower cranes) are often the bottleneck processes on-site. The paper presents a methodology for demand predictability which is based on the Rolling-Forecast approach and consists of three modules: "Planning", "Actualization" and "Progress". Within the module "Planning", tasks are assigned following budget specifications. By the module "Actualization" the deviation from budget is measured. By the module "Progress" the construction progress is measured and a reliable budget monitoring is performed. For aligning the engineering, prefabrication and installation of Engineer-to-Order (ETO) components a Constant Work in Process (CONWIP) control loop is described. For increasing the productivity on-site a continuous improvement process which is based on the plan-do-check-action (PDCA) cycle is presented. A practical implementation of the methodology for demand predictability within the expansion project of the central hospital of Bolzano in North Italy is included. Scientific findings up to now and the expected outcomes are presented.**

Keywords ETO; SME; PDCA; JIT; JIS; CONWIP; lean construction;

I. INTRODUCTION

The construction sector is worldwide one of the main sectors of economy. In Italy and generally in Europe it is highly fragmented and consists mostly of small and medium-sized enterprises (SMEs). According to the annual report on European SMEs, 99,8% of total enterprises in Europe were SMEs in 2012 [1]. So, during a traditional construction project many different disciplines (small craft-trades) interact causing high coordination efforts.

In addition, the construction sector is characterized by a weak planning of on-site construction processes. Time schedules are generally used just for the purpose of tendering and therefore they don't contain detailed and up to date information needed for coordinating construction works. So, the success of construction projects is mostly based on individual competences of figures responsible for managing the execution process (project managers or site managers). Another peculiarity of construction is the high variability or unpredictability of future events. Often, during a project requirements are changed or new ones added and therefore a re-planning or re-scheduling of construction works is needed. So, delays of construction works are unavoidable and a once created planning of the construction process cannot be used as a tool for supporting the coordination process. Repeatedly, when the project goes on, the actual duration exceeds the planned duration as defined in the construction schedule. Within the end phases of the project, for reducing the exceeded time, increasing costs of problem elimination become necessary. Due to limited time margins an overlapping of different construction works becomes necessary and the quality of services provided for erecting the building deteriorates (Fig. 1).

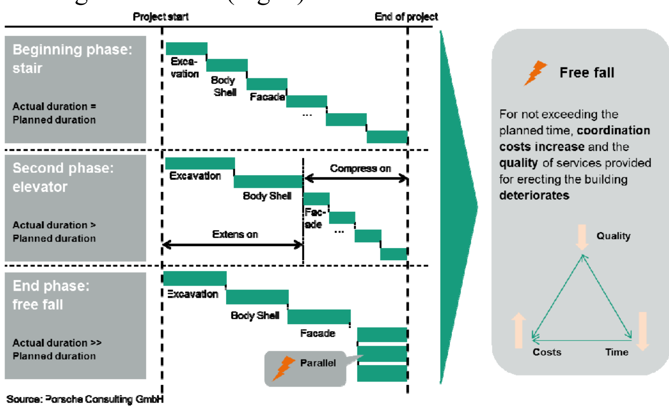

Fig. 1. Life Cycle of a construction site

The management of shared resources is one of the key factors for an efficient and fluent construction execution process. One example of these shared resources are tower cranes which are daily involved in many construction operations and contemporary needed by different companies. However, the planning of shared resources is normally performed in an intuitive way and based on first-come, first-served policies.

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Moreover, during execution detailed information about the progress of construction work is almost missing and difficult to obtain within a reasonable amount of time. For actors which are directly involved in the execution process this is a precondition for preventing construction interruptions. Moreover, since supplier lead times are, for the most part, much greater than the possible accurate foresight regarding construction work completion, a Just in Time (JIT) delivery of Engineered to Order (ETO) components from production to the construction site is not possible.

The challenges/problems that SMEs have to face are usually different from those of big companies. SMEs are usually involved in projects of small and medium size, which entail shorter time spans and smaller budgets. Moreover, delays in construction processes cause significant additional costs, which can compromise the survival of an SME.

II. State of the art in Construction Management

A. Construction process planning

The planning of construction projects is often of little detail resulting in high coordination effort, low productivity rates and delays in overall progress [2]. Larger project plans in construction contain thousands of activities and therefore a detailed planning of construction works is hardly possible within a reasonable amount of time. Linear construction projects are characterized by repetitive activities such as highways, tunnels, railways, pipeline networks, high rise buildings where crews repeat the same work in various sections of the construction project. Computerized project management in construction is traditionally based on precedence diagrams such as Critical Path Method (CPM) or Program Evaluation and Review Technique (PERT) [2].

It is well documented that network scheduling methods such as CPM and PERT are not suitable for scheduling linear construction projects [3]. These techniques are the basis of commercial systems that are quite diffuse in construction project management, such as Microsoft Project [4] and Oracle Primavera [5]. However, these approaches are not specifically conceived for project management in construction processes because they are not able to capture all the needed details in a satisfactory way. First of all, the progress of a task is computed from the starting date and the foreseen productivity, without considering the actual progress of work on the construction site. So, delays can be discovered only when a task will be finished and therefore intervention possibilities are limited. Secondly, they do not support the representation of the building structure which impose constraints on the execution of tasks. Thirdly, they do not allow a collaborative modelling of the process needed to improve collaboration among the actors involved in the construction. Fourthly, they do not allow a modelling of multiple links between the same tasks. So, logic loops, which are very practical for repetitive activities, cannot be represented. An example is Slab Formwork and Slab reinforcement as explained by [6].

This may led to the definition of construction schedules which are not executable on-site.

The greatest difference of CPM and PERT is that the latter one is used just as a review technique which does not require a network to be constructed at the start or indeed in its entirety, rather it is only necessary to model from a given point of time (the time of review) onwards [6]. Another difference is that CPM considers a project like a list of jobs whereas PERT organizes it in a list of activities. In the case of CPM a job consists of simply typing a report or encompassing all the development work leading up to the report plus the typing. In the second case, PERT has functionality for the incorporation of variation in job duration as a distribution [6]. In CPM durations are considered as deterministic (non-variable) whereas in PERT durations are considered as non-deterministic (variable). Normally, in the construction sector, durations are non-deterministic, because the processes are subjected to delays and unpredictable events from the design phase to the realization on-site.

Furthermore, resources for the execution of activities are usually scarce and therefore provide additional constraints to the predecessor-successor relationships, which are normally not considered in construction schedules [2]. Horenburg described a method to simulate construction schedules continuously based on the current progress considering all relevant resource capacities [7]. The actual construction progress on site is recorded in an automatic way using geo-fencing technology or photogrammetry. To analyse the consequences of schedule changes, or if the project meets all predefined requirements, the execution process is simulated based on the actual progress and within different schedule options project makespan and total resource costs are minimized. A technological inspection of the construction progress with a high level of reliability is just applicable on early stages of a construction project (excavation, shell construction) when large work packages occur. Within the phases where the building envelope (façade), interior finishing, and the building technology is installed, first-tier and second-tier suppliers are involved in the project. Here a higher parallelization of construction works becomes possible and therefore a detailed and highly reliable measuring of the construction progress becomes necessary.

Traditionally, schedules in construction are similar with Manufacturing Resource Planning (MRP) systems (in manufacturing) which try constantly to maximize capacity utilization independently of what may be happening upstream or downstream [8]. Therefore, schedules are not tools to synchronize demand and supply [8].

Considering the façade installation process, especially coordinating it with other activities is a challenge because [9]:

a) it is uncertain when or where trades will work (so shared resources cannot be planned);
b) it is a challenge for contractors to define and communicate their needs to their suppliers and subcontractors (so construction interruptions occur due to incorrect or missed materials on-site);

Due to a weak construction execution planning, assignments are not kept, which cause an extension in the construction duration. Durations are fundamental to be considered by stakeholders, because there is a strictly relationship between them and costs: the longer a project lasts, the more money is needed for its realization.

B. Innovative systems for supporting the construction execution process

In large dimension projects especially the management of shared resources is one of the key factors for an efficient and fluent construction execution process. The traditional system of workflow is composed of many phases: (a) transport to site, (b) off-loading to ground, (c) intermediate staging, (d) vertical transport to floor, (e) transport to floor staging, (f) staging on floor, (g) transport to installation and (h) installation [10]. Due to the fact that different companies often need to use held systems contemporary, the transportation of materials from the intermediate buffer on-site to the single parts of installation stands often for the bottleneck-process. According to a senior façade specialist *"Transport of frames is the most critical element of managing a project. If the PM gets it wrong, the job always ends up losing money. Any builder welcomes the chance of having his building less relying on the crane time. Downtime of crane time can cause havoc on a building programme"* [10] [11].

Tower cranes are one of the most important resources of a building site because they are daily involved in many construction operations. However, the planning of operations is normally performed in an intuitive way and based on site managers' experience. The number of cranes is dimensioned following technical, schedule and financial factors, as the site area, the number of levels, the complexity of the project, the number of workers etc.: these parameters have to be considered during the planning of global site layout, to prevent problems and errors in the construction phase.

In [12] researchers have demonstrated that simulation can be used to improve scheduling strategies. In [13] the authors presented an integrated 3D visualization with simulations as new methodology to planning cranes utilization. Moreover, in [14] researchers improved crane performances following lean principles and showed a new approach for cranes management, also purposing other technical innovative elements as a two jib tower crane and wireless video monitoring technology. More in detail, an innovative system for handling and installing facades is presented by [15], the so-called Beeche System. Here, panels are moved laterally to their installation point using a monorail system which is attached to the building columns and which surrounds the building. According to [15] the system is particularly suitable for avoiding/minimizing damages throughout the installation of glass facades. Industry practitioners estimate a 5-7% of glass elements damaged throughout installation of a traditional glass façade [10]. The Beeche system was implemented within the building of the Trump World Tower where the percentage of damages was reduced at 0.32%. For the installation of the facades of the Trump World Tower, researchers estimated savings of around 226.000$ using the so called Beeche System [15].

In [8] researchers present the Brunkeberg Industriutveckling (BI) System which comprises techniques for material handling, installation and maintenance that illustrate the use of lean construction practices for the external installation of façade elements. The system allows to reduce five different types of waste: (a) *Inventory*: No on floor staging will be needed; (b) *Transportation*: On-site transportation will be minimized by lifting the façade elements directly from the truck onto the system without an intermediate storage on-site; (c) *Waiting:* Installing the façade independently of the site crane reduces the waiting caused by a weak availability of shared cranes; (d) *Defects:* Due to the fact that façade elements are not stored on site, damages derived from other trades can be avoided; (e) *Motion:* Unnecessary handling or reliance on potentially unsuitable lifts will be avoided through the integrated system. Furthermore, the equipment for façade installation serves also for future maintenance as permanent part of the building. To simulate the use of the integrated installation system consulting engineers have been studied two high-rise buildings in Sweden [10]. Installation time could be reduced by 20% just by eliminating security buffers needed for unpredictable events on-site (e.g. bad weather conditions). Within the reference building 21 fixers were needed throughout the façade installation process whereas using the BI-system the number of fixers could be cut by half at least. By comparing the reference building´s overall façade cost with the BI-system a saving of around 5% of the overall façade cost could be reached.

The Beeche and the BI System are both based on decoupling the cladding installation from other trades, reducing uncertainty and variability in the construction process. The utilization of cranes is bypassed by the installation of monorails exteriorly the facades, which run both in vertical and horizontal direction.

III. SYNCHRONIZATION OF DEMAND AND SUPPLY ACROSS ENGINEER-TO-ORDER PROJECTS

Costly labor delays result when the required quantity or quality of materials is not on hand when needed on the construction site. For aligning the manufacturing or prefabrication to the installation process on-site, a JIT ordering system has to be introduced. The JIT approach started in the late 1980's to improve competitive chances of manufacturing companies. It's a technique developed by Taichi Ono for the famous automotive company Toyota: the goal was to change production's directives from forecasts to effectively demand.

According to [8] challenges for synchronizing demand and supply in construction systems are: (a) the product in construction is not repetitive, so production systems have to be designed every time a project starts (b) there is a high degree of Engineered-to-Order (ETO) components with long lead times, (c) the product is assembled in a fixed-position environment, and therefore an excessive amount of materials inventories laying around the fixed position environment should be avoided in order not to have a negative impact on performance and safety.

Push systems are those where production jobs are scheduled, whereas Pull systems are those where the start of one job is triggered by the completion of another. In Push systems, like material requirements planning (MRP), an error in demand forecasts causes bullwhip effects. However in JIT ordering systems, amplifications are avoided because the actual demand is used instead of the demand forecast [16].

Two types of JIT ordering systems are generally used for supply chain management, the KANBAN and the CONWIP system.

There are some aspects which limit Kanban applications, as non-repetitive activities, dimension of batches and sites to stock. According to [17] it will not work in a shop controlled by job orders". According to [18], Kanban is impossible to use when there are (a) job orders with short production runs, (b) significant set-ups, (c) scrap loss, (d) large and unpredictable fluctuations in demand.

A Constant Work in Process (CONWIP) production line sets the WIP (Work in Process) levels and measures throughput [19]. The fundamental difference/advantage is that WIP is directly observable while capacity, which is needed to appropriately release work in a push system, must be estimated. Hopp and Spearman [20] resumed the CONWIP advantages in five points: (a) WIP levels are directly observable, as difference with push systems that are static and difficult to respect. (b) It requires less WIP on average to attain the same throughput. (c) It is more robust to errors in control parameters. (d) It requires setting one pull signal only. (e) It is more flexible in terms of handling different product types for each signal. When the Pull signal has been released, the same amount of work flows through the production system, meaning the WIP levels are the same for each signal [8]. According to [8] the challenge in construction is the definition of the production unit because the product going through the production system changes constantly. Arbulu suggests to define CONWIP as days of work instead of a number of units [8].

In the case of production and assembly of components, CONWIP needs to sequence the backlog for different lines because components should arrive together for assembly at the same time. The method has some problems if the bottleneck processes are located in fabrication and there are significant set-ups, because backlog creation could become very complex [19].

In SMEs, especially in those working in the field of construction or construction supply where the customer order usually determines and triggers the design and consequently the production, lean tools and methods known from repetitive production usually do not fit [21]. However, recent studies show that there are some lean concepts that can be broadly applied in most industrial environments, such as "elimination of waste" and "JIT-deliveries" [22]. In 1-tier construction supply chains the site stands for the consuming process where ETO-components are installed to the building. The shop floor stands for the producing process. A JIT ordering system (control loop) can raise productivity levels in the fabrication shop and on the building site. The JIT philosophy can be applied for logistics management on worksites to help raise productivity levels [23]. In Denmark, Bertelsen [24] reported a 10% increase in productivity in the first phase of a social housing project that experimented with the use of the JIT philosophy in building logistics; the second phase of the project resulted in an average 7% increase in productivity. Furthermore, Marsh developed a study where he indicated that an effective material supply management system not only enhanced productivity by 6-8% but also improved supplier performance, reduced the storage space required and cut the amount of equipment idle time [25].

Tommelein studied how construction information sharing affects construction inventories and project progress. The results of the study demonstrated that pull-driven scheduling combined with real-time information feedback of site progress could help resolve the material buffer problem and yield a shorter project completion time [26]. The high uncertainty in activity duration or output also enlarges the inventory of material and work-in-progress [27]. These studies implied that the so called "bullwhip effect", seen in the manufacturing industry, is also present in the construction industry [28].

IV. METHODOLOGY FOR DEMAND PREDICTABILITY

The approach followed in this article is based on subdividing installation jobs with the final aim of measuring the installation performance and progress on the building site. Moreover, the approach is focused on handling unpredictable events on-site in an efficient way. Therefore, the rolling forecast approach is used to increase the planning reliability of construction works (Fig. 2).

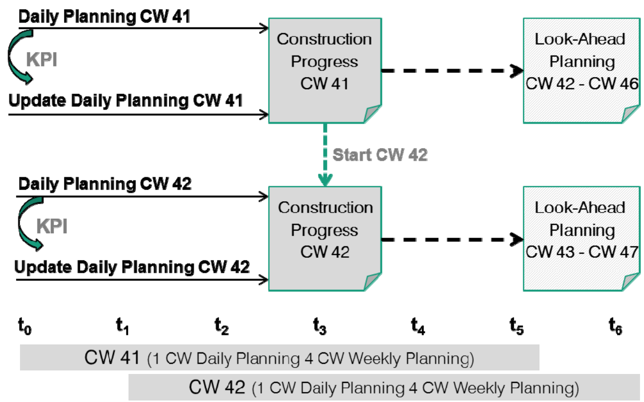

Fig. 2. Rolling planning for increasing demand predictability [29]

As described in [29] the installation process of ETO components on-site is planned in a daily granularity. At the end of the week an update of the planning is done by recording the effective realized tasks within the construction sections. This allows an accurate measuring of the construction progress on-site. Based on the detailed construction progress a Look Ahead Planning of 4-6 calendar weeks is done. The Look Ahead Planning is done in a weekly time interval and is needed for triggering the prefabrication of components which are stored in a Lean Manufacturing supermarket. ETO components are released in short-time intervals from production to construction. The concept for aligning manufacturing to the construction site is explained in [29].

The methodology for demand predictability is subdivided in three different modules (Fig. 3): 1) Planning, 2) Actualization and 3) Progress.

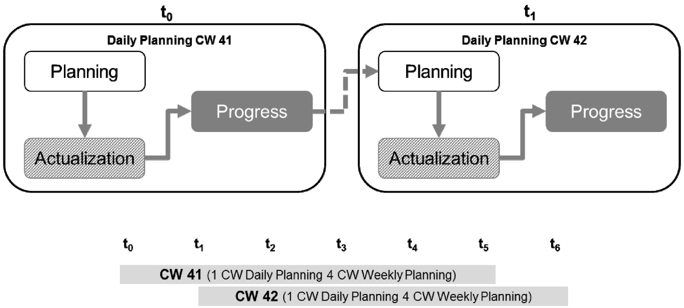

Fig. 3. Methodology for demand predictability

Within the planning module the work assignment is given to the construction crew. By the actualization module the effectively realized work is recorded and a detailed measurement of the construction productivity is elaborated. In the progress module the up-to-now carried out work is recorded which allows an accurate budget-monitoring.

A. *Process Planning*

The Process Planning approach is focused on planning and controlling work procedures on the building site.

An activity could be defined through eight chances: (a) by area of responsibility, (b) by category of work as distinguished by craft or crew requirements, (c) by category of work as distinguished by equipment requirements, (d) by category of work as distinguished by materials (such as concrete, iron, timber…), (e) by distinct structural elements (such as footings, walls, columns) (f) by location on the project, (g) with regard to owner's breakdown for payment purposes (h) with regard to the contractor's breakdown for cost accounting purposes [30].

A task is defined as the aggregation of all activities of the same type that repeat in multiple locations. Tasks have common resource requirements but quantities, crews and productivity will vary between locations [31].

In this context a task is defined as a working process on the construction site which contains defined job content and has to be fulfilled in a specific construction section. Job content means the work type and amount in terms of hours and number of needed resources [32]. A task contains just one work type and requires to be fulfilled by one or a multiple of same crews in terms of competencies and number of personnel resources.

A task should contain the following type of data:

- *Job type:* defines the required qualification for fulfilling the job. It can be classified in Value Adding (VA), non-value adding (NVA) or supporting operations (like movement of material). Furthermore, it can be classified in predictable and non-predictable operations. Non-predictable work could be special activities which cannot be planned in advance or additional work commissioned by the customer/planning actors;
- *Resources* (personnel, equipment or material):
  - *Personnel:* it defines the minimum number of work force which form one crew
  - *Equipment:* tools needed for value-adding activities (like drilling of walls) or assets needed for material handling operations (like cranes)
  - *Material:* certain (not all) tasks require construction material or prefabricated components
- *Shared resources* (personnel, equipment):
  - Shared personnel ("Springer"): work forces which can be used by different crews for a specific time period;
  - Shared equipment: expensive equipment which has to be shared between different construction participants. An example could be cranes which, due to cost and space restrictions, have to be shared within different project participants.
- *Construction section:* for every task at least one location has to be assigned. It defines in detail where the work has to be performed.
- *Dependency logic:* for every task predecessor and successor information have to be provided;
- *Pitch:* for controlling and measuring the efficiency degree every task should have information of how much construction progress has to be fulfilled in a defined time period. The job amount is calculated based on the available number of hours defined in the budget of the project contract.

  So, in the planning process not just the needed operation has to be assigned to personal resources but also the construction progress (physical areas) to be reached. A detailed description is done in [33].

In Fig. 4 the Value Stream Engineering (VSE) notation for describing a task is visualized.

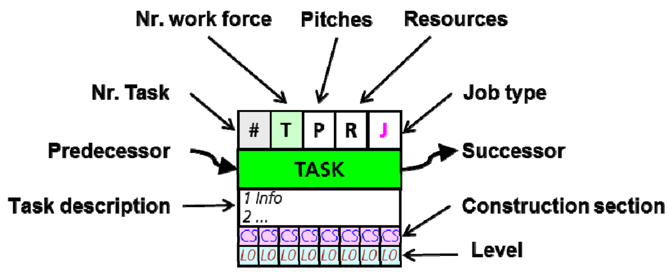

Fig. 4. Value Stream Engineering notation for Task

B. *Process Analysis*

Within the module *"Actualization"* the effectively realized construction progress is compared with the planned one. Here, the previously planned tasks are measured according to the construction progress on-site. Based on the industrial engineering theory measuring units of different tasks (pieces/construction section) are converted in working units (hours/construction section). So, different tasks can be compared with each other and the final productivity can be calculated for a given time period (e.g. 1 week). In Fig. 5 four tasks (A, B, C, D) are visualized and the final productivity results in 20h. Tasks which are colored in dark gray visualize an increase in productivity. Tasks which are colored in light gray visualize a decrease in productivity. Task A has an increase in productivity which could be reached through learning curve effects. On the other hand, task C has a decrease in productivity due to certain problems (e.g. bad weather conditions). The zero line defines the limit derived from budget availabilities. In Fig. 5 task B has neither an increase nor a decrease in productivity which means that it was performed as defined in the contract. So, budget deviations can be calculated and used for quantifying losses of productivity. Furthermore, this allows a transparent documentation of problems and their causes.

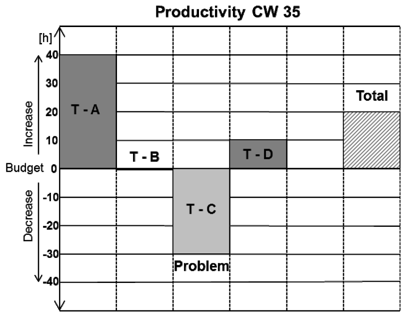

Fig. 5. Productivity measure of different tasks

Considering Task-A (e.g. installing the glass module for the façade) in calendar week 35, six construction sections (room nr. 1 till room nr. 6) are planned with a crew composed of three employees. If Task A was elaborated according to Budget 120h (3 FTE per 5days) were needed in CW35. So, the Budget consumption would equal the construction progress and therefore no increase or decrease in productivity would be registered. However, eight construction sections were completed and therefore an increase in productivity of 40h is recorded.

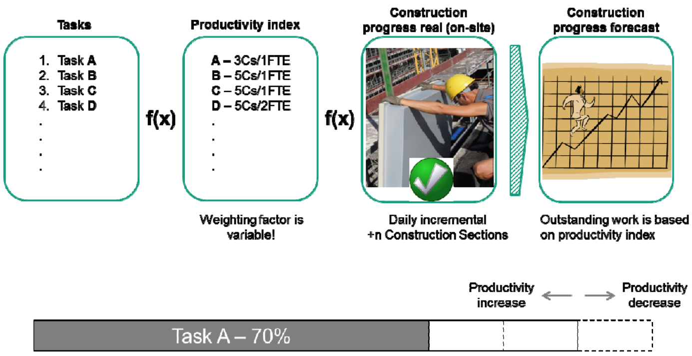

Fig. 6. Concept for measuring the construction progress

The module “Progress” is needed for measuring the construction progress based on the productivity of construction works on-site. In Fig. 6 the concept for measuring the construction progress is visualized. The construction progress is calculated in function of the completed tasks and of the productivity index on-site. The productivity index is defined according to the “Pitching” concept [33]. It is calculated per task and returns how many construction sections should be fulfilled by a specific crew size in a given time period (day or week). So, the production unit is defined within a fixed time period. According to [8] the production unit (CONWIP unit) is defined in time periods of work.

The progress is measured in how many construction sections are completed per task on-site. In this sense, the productivity index can be defined as the weighting factor between the planned tasks and the construction progress. If the productivity index increases, the outstanding work on-site (construction progress forecast) decreases. On the other hand, if the productivity index decreases the outstanding work on the construction site increases. At the same time the percentage of work completion increases in the first case and decreases in the second case.

As visualized in Fig. 6 the construction progress cannot be interpreted as a linear function due to a high variability of construction processes and unpredictable events on-site.

In Fig. 7 the concept for a plan-do-check-action (PDCA) cycle on the construction site is visualized. Based on a detailed measuring of the construction progress on-site (Fig. 5), a PDCA-cycle can be used as guideline for introducing a continuous improvement process. According to Lean Manufacturing the PDCA-Cycle is defined as follows [34]:

1) Plan: define the problem, analyse for root cause, plan countermeasure implementation;
2) Do: implement countermeasure;
3) Check: confirm countermeasure implementation and effectiveness;
4) Action: future activities dependent on results of check;

As mentioned in the previous chapters within the module “Planning”, tasks are assigned based on budget specifications (e.g. for Task-A 80h are allowed). Within the “Actualization” module the deviation from budget is measured (Over-Budget, On-Budget or Under-Budget). Here, problems are identified and at the same time a monetary quantification is calculated. In the module “Progress” the construction progress is measured and a reliable Budget Monitoring is performed. Furthermore, the impact of identified problems in the general construction process is calculated (e.g. due to a certain problem the Forecast at completion increases of 30%). Finally, the module “Improve” closes the loop by defining countermeasures for solving problems within the next planning phase. Moreover, the productivity indexes are adjusted (based on last performances) for the planning of the following time periods.

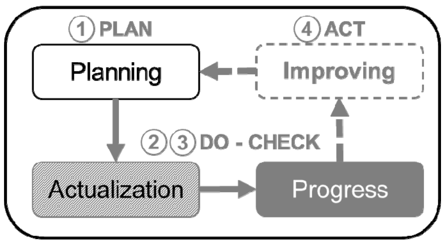

Fig. 7. PDCA-cycle on the construction site

C. *Control loop for aligning demand with supply*

In the ETO industry every product is unique and therefore engineering design, production and installation is made to the specific customer order (batch-of-one production). Even if the final product can involve some standard parts every customer order requires individual engineering designs and bill of materials, individual production routings and individual installation procedures. Traditionally, in the ETO-environment engineering, fabrication and installation work as separate departments connected in series. This means that the engineering department elaborates drawings which are pushed to fabrication. The fabrication department manufactures according to drawings delivered from the engineering department. Afterwards ETO-components are pushed from fabrication to the site for installation. As a result, in the traditional approach customer orders are pushed from engineering to the installation on-site which causes long lead times. So, high and uncontrolled levels of Work in Process occur between the three departments which are the main causes of long lead times.

On the other hand, the concept for aligning demand with supply uses the CONWIP regulation circuit. Here, before the detailed planning starts, the installation department hands over to the engineering department information about the installation sequence and performance. So, the engineering department designs ETO-components in the right sequence needed for installation. The quantity is also derived from the "Pitching" concept and defines how many drawings have to be prepared for a defined time period (e.g. one week). So, drawings are handed to the fabrication shop which produces ETO-components in the right sequence and quantity needed for installation on-site. Thanks to the feedback loop between installation and engineering a constant work in process (e.g. work for one week) flows from the engineering department to the installation on-site. More in detail, ETO-components arrive on the construction site Just-in-Sequence (JIS) and JIT for installation.

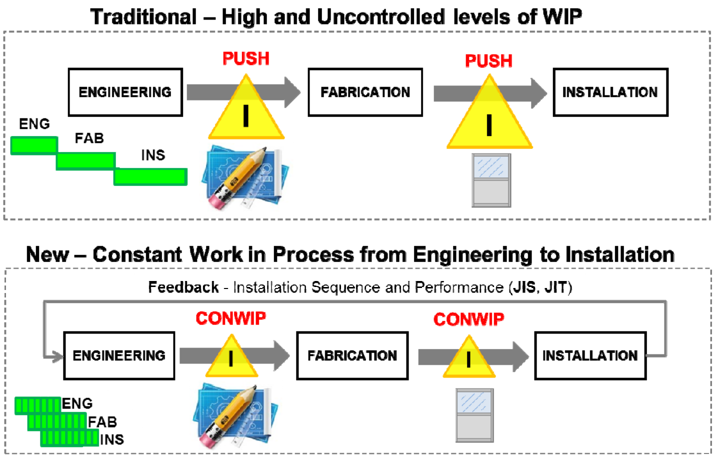

Fig. 8. Concept for aligning demand with supply

V. CASE STUDY

A. *Project description*

The case study is based on the expansion project of the central hospital of Bolzano in North Italy. The enlargement project consists of an additional erection of a new clinic and stands currently for the biggest construction site in the region.

The enlargement project consists over ground of tree wings (A, B and C) with respectively four levels, a north-wing with respectively three levels and a new entrance area (Fig. 9). The company Frener&Reifer GmbH (F&R) realizes as leader company in a bidder-consortium the facades of the tree wings (A, B and C). The construction site was launched by the bidder consortium at the end of April 2013.

The case study consists in implementing the previous described methodologies for demand predictability within the company F&R. A research team composed of researchers from Fraunhofer IEC and the Free University of Bolzano was involved by F&R in the planning and execution phase of the project to develop a planning and control concept at the construction site and its link to the fabrication shop. In Fig. 9 the rendering of the finished project at the end of 2016 is visualized. Furthermore, the actual progress for the installation of facades is visualized (mid of the year 2014).

Fig. 9. Expansion project central hospital of Bolzano (North Italy)

B. *Practical implementation*

The methodology for demand predictability (see Fig. 3) was implemented as a prototype using simple and common software as Microsoft Excel. The experienced site manager of the company F&R uses the tool without installing new software on his computer and without spending much time in learning how the system works. Once a week, normally on

Friday, the installation foreman plans the installation work in a daily granularity for the following week. He prints and puts the daily allocation sheets on the planning and control board which is located in the site trailer (see Fig. 10 on the left side). In the morning the installation crew meets up at the planning board to check which activity they were assigned and in which construction sections the activity has to occur. This lasts normally from 5 till 10 minutes. At the end of the day every participant of the installation crew records on the planning board the performed tasks, the required time (in hours) and which construction sections were completed. Furthermore, if the assignment (productivity index) could not be followed the problem has to be described in the field comments (see Fig. 10 on the right side). This allows increasing the process transparency because traditional problems come to the surface. Furthermore, an involvement of the construction crew in the construction management process is possible.

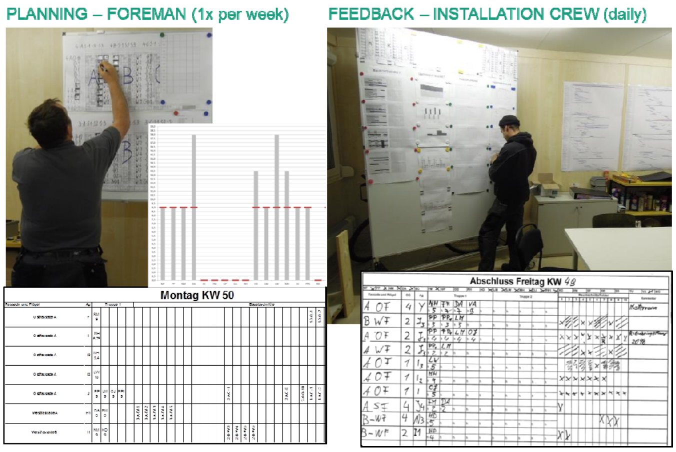

Fig. 10. Planning and control board in the site trailer of F&R

At the end of the week the installation foreman records the feedback from the installation crew in the Module "Actualization". The MS-Excel prototype calculates the Deviation from budget and in weekly meetings the research team discusses productivity increases and decreases with the construction foreman.

At regular milestones, normally once a month, a continuous improvement meeting is organized where the following figures of the company F&R participate: Project director, project manager, construction foreman, vice construction foreman and some key employees from installation. Within these meetings a complete resume of gained and lost working hours is prepared. Motivations of variation in productivity are elaborated. Percentages of finished works and forecasts of still required working hours are discussed.

The main objective of these "Continuous Improvement" meetings is that participants from the operational level report problems to the management level and that both try to find strategies to solve the problems. Therefore, during these meetings, actions for preventing the same problems in the next time frame are elaborated.

An example of a productivity report elaborated by the "Actualization" – Module is visualized in Fig. 11.

Here, task J – Installation of glazing modules had a negative Budget deviation of -33h in calendar week 50. Considering that in CW50 ten employees were present on the construction site (40h x 10FTE = 400h) this deviation had an impact of +8,25% (33h/400) in labor costs. Furthermore, this problem costed the company F&R in CW50 around 990 Euro (33h x 30Euro/h).

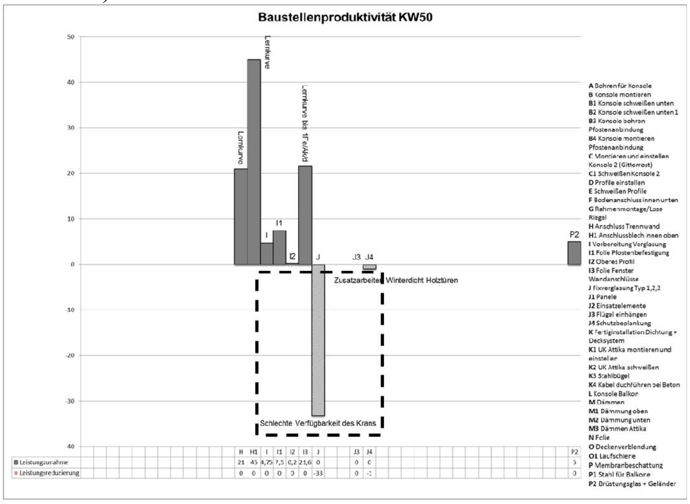

Fig. 11. Productivity report CW50

The problem associated to this Budget deviation was a weak availability of the tower crane. For task J – Installation of glazing modules the company F&R uses a suction cup system which is connected to the tower crane (see Fig. 12).

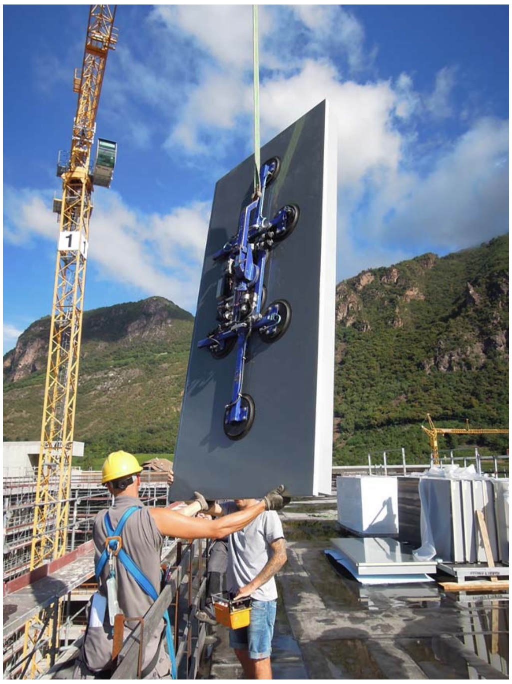

Fig. 12. Installation of modules with tower crane and suction cup system

This means, that four till five employees from F&R plus the crane operator (external) are involved in task J. The glazing modules have to be moved from the intermediate storage on-site between the scaffold and the building to the installation zone. In calendar week 50 four different construction companies (interior construction, facades and plant construction) worked simultaneously on site. It happened that sometimes two companies needed at the same time the tower crane. In the specific case the company responsible for the interior construction needed the crane for unloading the truck for material supplies. So, in sporadic time periods the company F&R had to uncouple the suction cup system and to hand over the tower crane to the interior construction company. This process for unloading the truck lasts normally a time period of 20 till 30 minutes. Due to this small time frame the installation foreman cannot change the tasks for the installation crew and therefore the crew responsible for task J has to wait until the crane tower is available again. At the end of the day this can cause a decrease in productivity of up to -50%.

C. Scientific findings and expected outcome

Having clear processes at the lowest levels permits to have transparency also to higher levels and decisions by the company could be made sustained by data and not exclusively according with good sense. At the beginning, the site manager was not sure about the usefulness of the planning prototype, because of unavoidable errors to which software development is exposed and the real utility about the new activities (planning and controlling) he was asked to do. During the project the entire installation crew discovered the advantages of an increase in process transparency for reporting problems to the management line.

Findings, up to now, have shown, that if the construction process is not disturbed (without replacing employees, without a lack of ETO-components on-site, without a weak availability of the tower crane), big learning curve effects can be reached. This is amplified in repetitive processes. Considering the example of the task G - Frame installation - a 100% increase in productivity on-site is possible in a time horizon of three weeks.

The problem of a weak availability of the tower crane can be solved using two strategies: 1) Improving the organization by introducing a time plan for the utilization of the tower crane; 2) Decoupling the façade installation process from the tower crane and so from other companies by introducing a new material handling system;

At the moment the company is pursuing both strategies. Considering strategy 1) the company F&R suggested during the site consultation meetings to introduce a time plan for using the tower crane. The involved companies neglected this approach because it affords an accurate process planning (in a daily time frame) of the works to be performed on-site. At the moment just the company F&R uses the methodology for demand predictability.

Fig. 13. Installation of glazing modules with prototypical handling system

2) The second strategy consists in developing a new material handling system which allows an installation of façade modules from the interior of the building. Here, the company F&R developed a prototypical handling system which allows a decoupling of the tower crane (Fig. 13). Furthermore, this system allows for the task J – to reduce the crew size from 4-5 to just 3 employees. On the other hand, due to manually operations this system has minor productivity of around 35% compared to the installation with the tower crane. Every glazing module has a weight of around 320kg. Therefore, from the point of view of the job safety the material handling-prototype is not ready for an implementation in daily work.

VI. CONCLUSIONS

An efficient coordination of different crafts works only if the participating companies use the same work process structure. Only then interfaces between different trades can be aligned and costly construction interruptions be avoided.

A technological support (material handling systems) can just optimize the construction execution process, if it is supported by the organizational process. Without a synchronization of Engineering, Fabrication and Installation an automation of construction works cannot solve the problem of costly project interruptions.

VII. OUTLOOK

At the moment the methodology for demand predictability is going to be implemented at the company F&R. More in detail, the Module "Planning" and "Actualization" is working since the beginning of the year 2014. Within the end of the year 2014 the concept for aligning demand with supply will be implemented and validated by the company F&R. Applying the methodology in a multi-project environment and in projects characterized by non-repetitive processes are the future research challenges presented in this paper.

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