Gabai, D.S and Sacks, R. 2020. "Optimized Installation Flow – A Strategy for Substantial Cycle Time Reduction." In: Tommelein, I.D. and Daniel, E. (eds.). *Proc. 28th Annual Conference of the International Group for Lean Construction (IGLC28),* Berkeley, California, USA, doi.org/10.24928/2020/0080, online at iglc.net.

OPTIMIZED INSTALLATION FLOW – A STRATEGY FOR SUBSTANTIAL CYCLE TIME REDUCTION

Doron S. Gabai[1] and Rafael Sacks[2]

ABSTRACT

Industrial system infrastructure installations, such as those in semiconductor fabrication plants, are complex, short-term and mission critical. They frequently encounter productivity, predictability and performance problems. We propose a strategic approach to manage such projects and substantially reduce their durations. The method, called Optimized Installation Flow (OIF), builds on lean and associated theories in the realm of production planning and control, synthesizing a method with seven principles. The results of implementation of OIF in 108 such projects show marked and consistent improvement in project duration when compared with the results of 91 other projects managed using the same company's previous best practice "Two-week buffer" approach. On average, cycle time durations for tool installation projects were reduced by 42%-48%, without any overtime on site. The method is gradually being adopted as new standard practice throughout the construction management portfolio of the case study company. OIF is an operating strategy that has demonstrated improvement, shifting mindsets, behaviours and organization's culture.

KEYWORDS

Action Research, High-Performance Teams, Last Planner® System, Optimized Installation Flow (OIF), Production Control.

INTRODUCTION

Many large industrial companies face growing complexity and change, leading them to continually seek new strategies to generate and sustain a competitive advantage. This often requires refurbishment and retooling of production plants. Investments in portfolios, construction programs, and specific projects must generate sustainable benefits. Yet according to a Project Management Institute survey (PMI 2019a p. 14-15), 'organizations wasted almost 12 percent of their investment in projects last year due to poor performance... Organizations [procuring projects] in the construction industry waste an average of $126 million for every $1 billion spent on projects and programs due to poor project performance'. The same source states that only 51% of projects are completed on time, suggesting poor predictability.

1 PMP, PgMP, LCI Israel Chairman, Senior PM Intel Construction, Israel, Doron.Gabai@LCI-Israel.org, https://www.leanconstruction.org/israel/, orcid.org/0000-0001-8297-2476

2 Professor, Virtual Construction Laboratory, Technion – Israel Institute of Technology, cvsacks@technion.ac.il, orcid.org/0000-0001-9427-5053

For companies such as the major semi-conductor manufacturer in which the research reported here was conducted, the challenges of productivity, predictability and performance that trouble the construction industry have a direct bearing on profitability, because production plants are frequently reconfigured as manufacturing methods evolve. In the semi-conductor industry, installation projects consist of installing and hooking-up tools to enable mass production. Projects are executed in a live manufacturing environment in which sophisticated, environmentally sensitive machines operate around the clock. Installation projects include ducting and piping to connect various chemicals, gases, ultra-pure water, exhausts, electrical power and other utilities to live production systems. A typical installation project consists of between 50-70 different utilities and services with orbital welds, and more than 100 connections. Most of the welded connections require high purity welds in a dense and congested space.

The Program manager and his project managers of the case study company continuously seek practical ways to reduce installation project durations. Lean thinking suggests taking a holistic approach, seeking a project operating strategy that addresses global optimization of cost, schedule, and predictability. In this paper, we report development of a project production system that significantly improves productivity, predictability and performance – a win-win method called ***Optimized Installation Flow*** (OIF). The company's construction management teams had already adopted the Last Planner® System (LPS) (Ballard 2000; Ballard and Tommelein 2016), but sought to improve on their achievements. Setting ambitious, aggressive goals for cycle time reduction, the first author proposed leveraging additional theoretical and practical notions of project control and production flow to improve performance, designed the OIF approach, tested and refined it through implementation in 108 installation projects. The goal set for OIF was to reduce construction duration by 50% on average without adding overtime and without adding more resources.

The objectives of this study were to consolidate, evaluate and measure the performance of OIF in the context of complex, quick installation projects of the type described above. Action research led by the first author enabled acquisition of detailed outcome data from a very large sample of projects from different plants in different countries. In the following sections, we describe the theoretical basis for development of OIF and report on its implementation to date.

OIF DEVELOPMENT

At the outset, the project management team noted that despite using the LPS, subcontractors were moving between projects, from one location to another, and much time was wasted. Following this observation, they began systematically to develop reduced pull-plans with trades. Their goal was to reduce more than two weeks for typical projects by optimizing and eliminating waste from plans. For example, they analyzed the critical path and challenged both the traditional sequential construction logic, identifying activities that could be performed with overlap or in parallel. They challenged the stated durations of activities where those contradicted knowledge gathered of actual performance. They also worked with trades on design aspects, seeking opportunities to maximize prefabrication.

In their portfolio, the project team managed an average of 25 projects in parallel, across 75 unique locations in the plant (semi-conductor plants have three floors – the clean room floor and two floors below for MEP systems. Every project has part of its scope on each of the three floors, thus 75 locations for 25 projects). In a typical installation project four or more trades work in congested areas. Although they used LPS, some projects were late, some on track and some ahead, and all suffering high variability and limited predictability. Observations found several types of waste: crews were idle, crews were moving back and forth, rework, etc. Also, as is often seen in construction, subcontractors overbooked their resources – they committed to more work than could be performed, so that crews were often re-allocated from one location to another per urgency of installation (Sacks and Harel 2006).

The project management team suspected that the root cause of the variability in project durations was driven by an external element. They sought explanations from project and production management literature: Strategic Project Leadership (SPL) (Shenhar 2015), Factory Physics (Hopp and Spearman 2011), PMI Portfolio and Program Management and Benefits Realization Management Standards (PMI 2017a; b, 2019b), the Critical Chain and the Theory of Constraints (TOC) (Goldratt 1997), and the Portfolio, Process and Operations (PPO) model (Sacks 2016).

The PPO model (Sacks 2016) summarizes current understanding of production flow in construction. It proposes three levels to understand construction flow: flow of projects, flow of locations within a project, and flow of trade crews in and between the locations of projects. Consideration of the flow of trade crews across projects adds the relationship between the project and the operations flow, resulting in a cyclical model, as shown in Figure 1. This view of the flows has enabled statement of a set of ideal conditions for optimal flow.

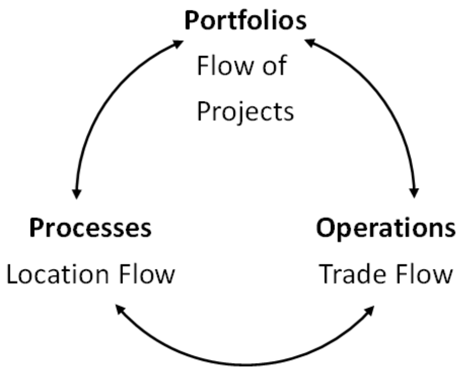

Figure 1: PPO Model - cyclical view of the relationship between project portfolios, processes and operations (Sacks 2016)

The project management team realized that new projects were being introduced into production without consideration of trades' capacities and other constraints - their projects were effectively in silos, not synced with one another. Flow was interrupted at all three levels: portfolio (flow of projects), process (location flow) and operations (trade flow). As more projects were executed, the project team realized that a global optimum solution was required rather than local optima. They decided to manage the new projects as a portfolio, with focus on throughput of projects as units of production in Little's Law (Little and Graves 2008), reducing the cycle time for project execution and controlling the work in process (WIP), i.e. controlling the number of projects operational at any given point in time. In addition, they levelled resources across subcontractor crews within the portfolio, requiring trades to work on projects in sequence and not simultaneously, eliminating unnecessary movement between project locations as far as possible.

Furthermore, the project team began to enforce start of installation projects only once all predecessors and constraints were resolved, which sometimes meant delaying start dates yet targeting shorter durations so as not to miss the customers' milestone dates. As preliminary results were positive, project team management worked in collaboration with customers to make sure that new projects were prioritized correctly and worked on continuously and without interruptions.

In summary, the team made the following changes as part of OIF: reducing the number of projects in parallel (flow of projects), starting a project only when it is 'sound' (location flow), managing the critical resource constraint (trade & project flows), assigning targets (flow of projects), developing pull plans derived by challenging targets (location & trade flows). PPO defines "what" construction flow is, while OIF provides the "how" with its seven principle actions.

SEVEN OIF PRINCIPLES

OIF is composed of seven principles which draw from several areas of knowledge: Portfolio, Process and Operations (PPO) (Sacks 2016), Strategic Project Leadership (Shenhar 2015); Lean construction (Koskela et al. 2007) and the Last Planner® System (LPS) (Ballard 2000); Theory of Constraints (Goldratt 1997; Goldratt et al. 2004); Benefit Realization Management (PMI 2019); Portfolio and Program management standards (PMI 2017a; b); and supply chain excellence (Koskela et al. 2007; Sacks 2008; Vrijhoef and Koskela 2000). The principles that underpin OIF are illustrated in Figure 2 and detailed in the following paragraphs.

Figure 2: Construction flow scheme relating PPO & OIF (*what* & *how*), also illustrating the seven OIF principles depicted as a flywheel

PRINCIPLE I: STRATEGIC INTEGRATION AND PLANNING

Strategic integration and planning is the development of a program plan with participation of the main stakeholders to achieve organizational strategic goals using minimum resources. This principle is based on Strategic Project Leadership (SPL) (Shenhar 2015), PMI Portfolio and Program Management and Benefits Realization Management Standards (PMI 2017a; b, 2019b) and the theory of constraints (Goldratt 1997).

SPL integrates business value, leadership, and innovation in a formal model, focusing on business outcomes rather than on traditional project deliverables. SPL focuses on dealing with uncertainty, complexity, and fast changes by developing a project strategy, as projects differ from each other and "one size does not fit all" (Shenhar 2015). Project strategy is defined as "the project perspective, position and guidelines on what to do and how to do it, to achieve the highest competitive advantage and the best value from the project outcome" (Shenhar 2015, p. 33). Therefore, a project strategy must both adapt to specific project requirements and simultaneously address the organization's goals and objectives to achieve best value according to the benefit realization plan. This view is supported by PMI's program management standard: 'the goal of linking the program to the organization's strategic plan is to plan and manage a program that will help the organization achieve its strategic goals and objectives and to balance its use of resources while maximizing value' (PMI 2017b, p. 35).

OIF adapts installation projects to the specific characteristics and contexts of each project's context, enabling reduction of construction durations, which serves the organization's goal of reducing time to market while still meeting cost constraints. The OIF method requires explicit identification and documentation of organizational benefits and details the expected outcomes at project, program, and portfolio levels. The program master schedule is developed and controlled as part of the strategy. The program milestones are derived from it, and each project is assigned a target reduction time.

The advantage of this principle is that it enables the senior management team to verify that available resources suffice to meet the strategic plan. This also enables them to identify overloading and mitigate it by schedule reduction. The main success criteria are: the strategic plan is developed and agreed to by all stakeholders; no acceleration[3] nor overtime is needed; no multitasking; any adjustments to plan may not require additional resources.

PRINCIPLE II: TARGET TACTICAL PLANNING

The outcome of Principle I is a target for each project aligned with the organization's strategic goals and its current portfolio. This schedule target is the governing constraint for the pull-plans that project teams develop collectively. Thus, optimizing and eliminating waste from the pull plans by focusing on the critical path and challenge its sequential construction logic and its durations striving to identify more parallel activities than before.

PRINCIPLE III: COLLABORATIVE PROCESS

Collaboration fuels OIF implementation, starting from the strategy initiation, through design planning, target planning and installation flow. Collaboration in implementing the LPS generates tasks with more value-added content (Ballard and Tommelein 2016). Coordinating and integrating owner, trades, construction management and other suppliers are critical for success. The team used unified, standard processes, and "one version of

[3] Acceleration is the addition of labor resources at an additional cost that exceeds the original budget.

the truth" software; to enhance collaboration. The added value is that effective collaborative planning and execution brings relevant experts together to rehearse the actual project and reduce durations and overall risk.

PRINCIPLE IV: CONSTRAINT MANAGEMENT

A constraint is defined as something that stands in the way of a task being executable or sound Ballard and Tommelein (2016, p. 34). Constraints can be either physical (cable trays must be hung before pulling cables), or informational (design model must be approved before fabrication). As part of the LPS, the team standardized its constraint management process. They documented constraints in a designated information system from initiation, through planning, control and execution. Work was made ready through systematically investigating and addressing each of the constraints before performing an activity. In addition, the project team focused on cross project constraints such as trades' critical resources, overall critical materials, logistics and portfolio certainty.

PRINCIPLE V: MAXIMISE PREFABRICATION

Prefabrication is an "off-site" technique in which the manufacturing and packaging of elements and modules is done off site. This reduces delays on site, thus shortening construction duration and improving productivity. The advantages of pre-fabrication are reduced on-site work durations, reduced trade crew head count, and shifting skilled personnel (orbital welders, for example) to work at their facility where their productivity is higher than at the site itself. In installation projects pre-fabrication tasks are not on the critical path but performed in parallel with design development. This approach yields maximum schedule reduction. There are two success criteria for prefabrication: schedule reduction and minimisation of storage on site. We recommend tracking percentage of prefabrication over time and using it as a leading indicator.

PRINCIPLE VI: CONTROL INSTALLATION START

As the project team planned and executed installation projects in parallel, the timing for each project start was a critical determinant of project flow. The team optimized the projects' start date so that overall resources (mainly information, equipment, trade crews and customer engagement) fit the strategic goal and the target tactical plan for each project without constraints. In a manner similar to filtering 'sound' activities in LPS, the project team focused on making every project as a whole ready, or 'sound', at its start.

PRINCIPLE VII: ENSURE CONTINUOUS INSTALLATION

This is the process of ensuring that installation projects are continuous, i.e. installation activities are performed without interruption. This has a few advantages: increasing the predictability of project performance, so that the entire portfolio of projects can meet strategic organizational goals; it improves subcontractor trade crew productivity and profitability as waste is reduced substantially and less resources are required. As Ballard and Tommelein (2016 p. 11) suggested 'improve workflow reliability in order to improve operational performance'. Modig and Åhlström (2012) also discuss the value of improving the flow whilst managing the critical resources.

OIF APPLICATION TO AN INSTALLATION PROJECT

The tool installation project described here was performed in parallel with 25 other ongoing, similar projects. Figure 3 illustrates the kind of work and the working conditions. The organization's baseline duration was 37 working days. [Note: in the following text, the seven principles are highlighted in bold type]. The **strategic** target set for this specific project, devised in collaboration with the customer and the trades, was to reduce duration to three daytime shifts to enable early system acceptance that would maximize manufacturing throughput. This was done by setting a detailed **Target Tactical Plan** broken down into activities no longer than half a day each. This required **collaboration** with all trade partners – piping, electrical, mechanical and equipment suppliers – as work was conducted in a congested area on all three floors. The **Constraint Management** guided the **Pre-Fabrication stages.** For example, informed risks were taken, and long 8 inch and 6 inch diameter piping segments and electrical trunk cable segments were prefabricated in advance. **Installation start** timing was set only after all constraints were managed and resolved. For example: plan approved by all stakeholders; customer committed to be present in construction area during the full three days of installation; all prefabricated segments were ready and adjacent to gemba, all other standard equipment (pumps, power distribution units, etc.) were set in their final location ready to be connected. Removing all the constraints ensured keeping **Installation Flow** as planned to meet the three day target tactical pull-plan. Actual installation took 2½ days, thus removing 34½ days: a 93% schedule reduction without adding resources or overtime.

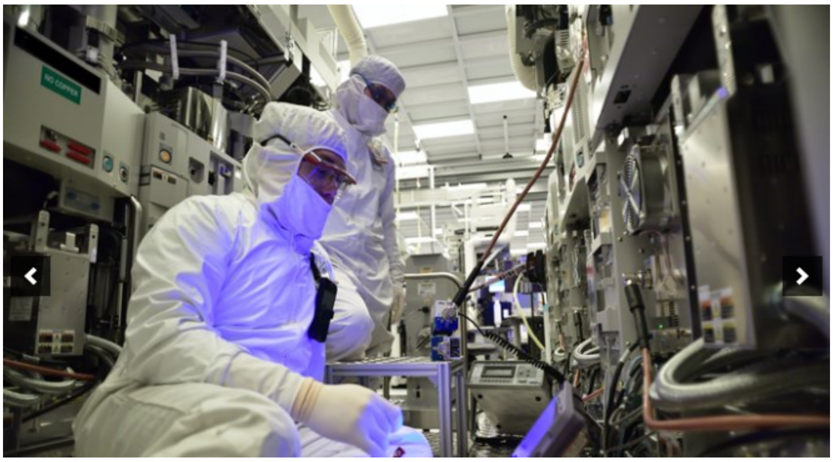

Figure 3: Typical installation project environment: production and cleanroom facilities at work in Hillsboro, Oregon (credit: Intel Corporation newsroom)

IMPLEMENTATION

OIF was developed and implemented in the context of construction and installation projects in three semi-conductor fabs starting in July 2018. In the first period we compared the schedule reduction of OIF to that of a control group. Over 13 months (July 2018 to July 2019), 166 installation projects were completed. The projects were in one of two groups, and both included projects with similar scope, physical locations and resources.

The two groups were:

1. **Control group –** this group of projects consisted of 91 projects managed using a two-week buffer implemented as a 'calculated end buffer' as described by Dlouhy et al. (2019). The approach is also based on LPS, with the reduction of two weeks from the critical path for each projects' pull-plan, as recommended by Ballard and Tommelein (2016 p. 9) that "Variation in production systems can be reduced but

never eliminated, so buffers are required to absorb that variation and protect targets".

2. **Experimental group #1 –** this group consisted of 75 projects that were conducted according to the OIF 7 principles approach. Project management team collaborated with their customers to identify business needs and options to reduce duration together by investing in optimizing their pull-plan templates.

To examine the added value of OIF, the project management team calculated a Schedule Performance Index (SPI), the schedule reduction percentage for each project. SPI was calculated as the difference between the organization's baseline planned duration and the actual execution duration, divided by the planned duration to obtain normalized percentage schedule reductions for each project. Positive values are schedule reductions, negative values are schedule extensions.

The results are provided in Table 1 and depicted graphically in whisker plots in Figure 4. The first approach, 'two-week buffer', yielded, on average, 8% schedule reduction. This means that the combination of the LPS with the two-week buffer is a good basic strategy for schedule reduction. Furthermore, as expected, the OIF approach proved highly beneficial, yielding an average schedule reduction of 48%.

Table 1: Schedule reduction statistics for the three different project groups

	Control group	**Experimental group #1**	**Experimental group #2**
Approach	Two-week buffer	OIF	OIF
# of projects	91	75	33
Period & duration	Period I 13 months Jul'18 - Jul'19	Period I 13 months Jul'18 - Jul'19	Period II 5 months Aug'19 - Dec'19
Average of schedule reduction	8%	48%	42%
Median	3%	45%	41%
Standard deviation	23%	23%	21%
Minimum	- 48%	11%	0%
Maximum	80%	94%	86%

However, a procedural question arises which casts doubt on the reliability of the results. The problem lies in the fact that the OIF projects were the subject of intense management focus during their target setting, pull planning and execution. It is quite possible that the Hawthorne effect, defined as 'an increase in worker productivity produced by the psychological stimulus of being singled out and made to feel important' (Adair 1984; Franke and Kaul 1978), is relevant. The downward trend of the schedule reduction values over time, which can be seen in the trend lines of the Control group and the Experimental group #1 shown in Figure 5, reinforce this doubt.

Therefore, in an effort to remove this potential bias, a second phase of experiments was conducted. In this second phase, all projects were managed using the OIF approach. This second phase was conducted over five months (August 2019 - December 2019). All 33 projects in the program were managed according to OIF principles. The projects in **Experimental group #2,** all managed using the OIF approach, were no different in scope, physical location or resources from those of the control group and experimental group #1. As can be seen in Figure 4 the projects in Experimental group #2 achieved average schedule reductions of 42%. This value is significantly different from the control group, but not significantly different from the result for experimental group #1. This result clearly illustrates the benefit of the OIF approach, underscoring the value of adopting the full set of OIF principles for all tool installation projects.

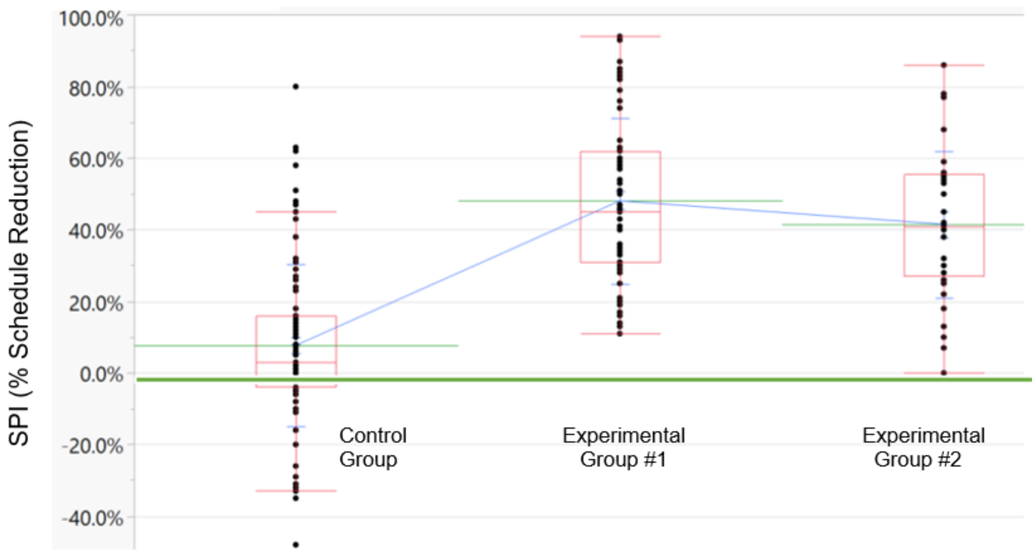

Figure 4: Schedule reduction statistics for the three different project groups

DISCUSSION

The mission set for OIF was to reduce installation duration by 50% on average without adding overtime and without adding resources. As results indicate (Table 2 and Figure 5), the overall average schedule reduction was 42-48 percent using the seven OIF principles. This is close to the target set and significantly better than the "two-week buffer" approach.

Before applying OIF, the project teams were using the basic LPS, but getting mixed results: some projects finished ahead of schedule, some late, and some on time. The production control element was missing. Ballard and Tommelein (2016 p. 4) state that: 'The initial equation of LPS with production control has changed over time... "partial" because pull planning may be used to detail plans at every level of task breakdown, but project cost and schedule targets (budgets and completion dates) are set outside the Last Planner system'. We propose that OIF's first principle of Strategic Integration and Planning and second principle of Target Tactical Planning fulfil the missing production control elements critical for substantial sustainable schedule reduction in portfolios.

Table 2: Average and Std. Dev. of schedule reduction for the different approaches. The groups were compared using a One-way ANOVA statistical test

Variable	Control group	Experimental group #1	Experimental group #2	$F_{(2,196)}$
% schedule reduction	8% a (23%)	48% b (23%)	42% b (21%)	72.86*** (***p < .001)

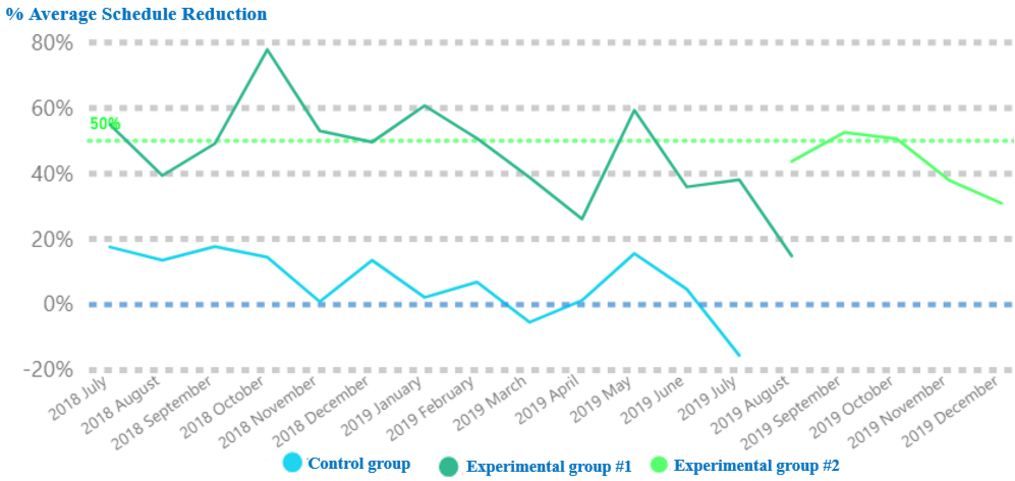

Figure 5: Average percentage schedule reduction trend for the three project groups

Each of the areas of project management knowledge discussed in the introduction, which underpinned development of the OIF approach, has been shown to yield benefits when applied on its own. By adding the strategic and tactical planning layers to the basic LPS methods, and adopting a portfolio-project-operations viewpoint, we were able to exceed the performance of LPS implemented alone. Thus, the whole is greater than the sum of the parts. Indeed, Ballard alluded to the possible benefits of applying workflow principles across project portfolios in 2005: "This completed the shift in focus from productivity and resource utilization to work flow as the instrumental cause for performance improvement, and the shift from the operation or crew to the project (or even multiple projects) as the ultimate object of improvement efforts" (Ballard 2005).

Experience has shown that OIF can succeed as a win-win approach to maximize the benefits for all partners: trades, design, construction management, and customers. The primary benefit of OIF is substantial construction schedule reduction. However, as more OIF projects were accomplished, we learned of additional benefits:

- Since OIF is a standardised approach, it also has the benefit of being a basis for continuous improvement.
- OIF addresses the need for both the owner and trades to manage and balance the allocation of their resources across projects and locations.
- OIF provides comparable as-planned and as-built data that are the basis for development of quantitative measures of workflow quality, needed to support practitioners' efforts to improve workflow
- OIF balances the construction delivery, removing waste and increasing opportunities for prefabrication. It therefore yielded thousands fewer person-days working in gemba, thus reducing likelihood to safety hazards.

The most significant barrier to OIF implementation was the need to introduce a new method to multi-disciplinary, high performance teams composed of people from independent contractors. The willingness to collaboratively plan and execute differently is a journey the client organization is committed to; active listening to all stakeholders generated more commitment and innovation in implementation, which led to substantial schedule reduction without overtime and strengthened overall team cohesiveness.

The limitations of this research include the fact that it was restricted to a single major client organization. Nevertheless, the total number of projects included in the study (199) is very large. OIF is currently planned for rollout at more of the client's manufacturing facilities. A second issue is that data collection could be automated using lean project control tools such as Visilean (2018), which would yield better quality and richer data.

CONCLUSION

The project management team of a semi-conductor manufacturer identified the need for an integrated operating strategy to that would enable it to improve predictability, productivity, and performance by coordinating company strategic level project targets across its portfolio of projects. Based on the PPO model and other theories, the team proposed a method called Optimized Installation Flow, which integrates two project management principles (**strategic integration and planning** and **target tactical planning),** two LPS steps (**collaborative planning** and **constraint management)**, two measures designed to ensure project flow at the portfolio level (**control installation start** and **ensure continuous installation**) and an emphasis on **prefabrication**.

Analysis of data from 199 installation projects in semi-conductor fabs shows that the use of OIF is effective in strategically reducing project cycle times. It also increases the predictability of projects, by integrating the complex network of handoffs, and teams can shorten construction project schedules without adding resources or acceleration.

This work demonstrated the suitability of OIF for reducing cycle times substantially in portfolios of complex industrial installation projects. As such, we suggest that it is appropriate for construction in industrial and other process plants, or any situation where clients have portfolios of projects. It may also be applicable for general construction, when one views a local industry as a network of interdependent projects that share resources (Bertelsen and Sacks 2007; Korb and Sacks 2020).

In conclusion, it appears that LPS must be complemented by organizational strategy and portfolio approaches. Portfolio wide levelling of WIP and resources holds the key to reduce production waste further than can be achieved by project-centric production planning and control alone. For manufacturing and other process plants where time to market is a priority, project performance can be improved by pro-actively shortening construction duration (i.e. cycle time), reducing the number of projects in progress, thus reducing the waste of transport and loss of focus caused by overloading trades' capacity or that of critical capital equipment.

REFERENCES

Adair, J. G. (1984). "The Hawthorne effect: A reconsideration of the methodological artifact." *J. of Applied Psychology*, 69(2), 334–345.

Ballard, G. (2000). "The Last Planner System of Production Control." PhD Dissertation, University of Birmingham, UK.

Ballard, G. (2005). "Construction: One Type of Project Production System." *13th Annual Conference of the International Group for Lean Construction*, University of New South Wales, Sydney, 29–35.

Ballard, G., and Tommelein, I. (2016). *Current Process Benchmark for the Last Planner System*. P2SL, Berkeley, CA, 42.

Bertelsen, S., and Sacks, R. (2007). "Towards a new Understanding of the Construction Industry and the Nature of its Production." *15th Conference of the International*

Group for Lean Construction, C. Pasquire and P. Tzortzopoulous, eds., Michigan State University, East Lansing, Michigan, 46–56.

Dlouhy, J., Binninger, M., and Haghsheno, S. (2019). "Buffer Management in Takt Planning – An Overview of Buffers in Takt Systems." Dublin, Ireland, 429–440.

Franke, R. H., and Kaul, J. D. (1978). "The Hawthorne Experiments: First Statistical Interpretation." *American Sociological Review*, 43(5), 623.

Goldratt, E. M. (1997). *Critical Chain*. North River Press, Great Barrington, MA.

Goldratt, E. M., Cox, J., and Whitford, D. (2004). *The goal: a process of ongoing improvement*. Gower.

Hopp, W. J. and Spearman, M. L. (2011). *Factory Physics*. 3rd ed. Waveland Press.

Korb, S., and Sacks, R. (2020). "General Contractor-Subcontractor Interactions in a Multi-Project Environment. I: Agent-Based Simulation." *Journal of Construction Engineering and Management*, under review.

Koskela, L. J., Howell, G. A., Ballard, G., and Tommelein, I. D. (2007). "The Foundations of Lean Construction." *Design and Construction*, R. Best and G. de Valence, eds., Taylor & Francis, Oxford, UK, 211–226.

Little, J. D. C., and Graves, S. C. (2008). "Little's Law." *Building Intuition*, D. Chhajed and T. J. Lowe, eds., Springer US, Boston, MA, 81–100.

Modig, N., and Åhlström, P. (2012). *This is Lean: Resolving the Efficiency Paradox*. Rheologica Publishing.

PMI (2017a). *The Standard for Portfolio Management*. Project Management Institute, Newtown Square, PA.

PMI (2017b). *The Standard for Program Management*. Project Management Institute, Newtown Square, PA.

PMI (2019a). *Pulse of the Profession: Research Highlights by Industry and Region*. Project Management Institute, 43.

PMI (2019b). *Benefits Realization Management*. Project Management Institute, Newtown Square, PA.

Sacks, R. (2008). "Production System Instability and Subcontracted Labor." *Construction Supply Chain Management Handbook*, W. O'Brien, C. Formoso, K. London, and R. Vrijhoef, eds., CRC Press/Taylor and Francis, Boca Raton & London.

Sacks, R. (2016). "What constitutes good production flow in construction?" *Construction Management & Economics*, 34(9), 641–656.

Sacks, R., and Harel, M. (2006). "An economic game theory model of subcontractor resource allocation behavior." *Construction Management & Economics*, 24, 869-881.

Shenhar, A. (2015). "What is Strategic Project Leadership?" *Open Economics and Management Journal*, 2 (Suppl 1: M5), 29–37.

Visilean, . (2018). "Visilean." <http://visilean.com/about/> (Mar. 4, 2017).

Vrijhoef, R., and Koskela, L. (2000). "The four roles of supply chain management in construction." *European J. of Purchasing & Supply Management*, 6(3–4), 169–178.