RETURN ON INVESTMENT IN CONSTRUCTION INNOVATION—A LEAN CONSTRUCTION CASE STUDY

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ABSTRACT

The construction industry has frequently been criticized for not investing enough in innovation. This relates to both the managerial changes and technological developments required to support this innovation. Extending Lean Manufacturing techniques into the production based environment on one of Europe's largest and most complex construction projects, Strategic Project Solutions, Inc. (SPS) has worked in collaboration with the joint venture contracting group and the project client to establish new business processes and implement web-based tools which enable workflow control (SPS Production Manager) and management of materials (SPS Materials Manager) at the production level. Further, this process innovation has been coupled with product management in the form of 3D digital prototyping. The outcome of this effort has demonstrated significant tangible and intangible benefits, outweighing the initial investment and further establishing a movement toward innovation that can be extended to other projects across the continent.

This paper will act as a case study focusing first on the project challenges; physical, managerial, and contractual. It will then outline the success factors for the implementation of production control, illustrating the process undertaken. Unique case studies within the project will be used to reveal tangible results which exceed industry norms, and also to outline the intangible benefits that contribute to the overall results. These results will then be summarized into learning for the construction industry as a whole.

KEY WORDS

Innovation, Material management, Production control, Return on investment, Workflow.

INTRODUCTION

Even while the application of lean within the construction industry is gaining momentum, criticism still exists due to the fact that innovations within the construction industry cycle through slower than in other fields. If necessity is the mother of invention, then we should look to the extreme cases to see the future. Instead, the construction industry treats extreme cases as unique entities and instead focuses on benchmarking more traditional projects to identify areas for improvement.

Through the introduction of production control tools such as the SPS Production Manager and 3D digital prototyping, the Channel Tunnel Rail Link in London has seen groundbreaking returns that greatly exceed their investment in these tools. This paper describes the implementation of lean construction within this project through the application of innovative systems. A brief description of the project is provided, followed by a summary of improvements made to date, a few of which are described in detail.

CHANNEL TUNNEL RAIL LINK LONDON

The transformation of London's St. Pancras Station will complete The Channel Tunnel Rail Link (CTRL), Britain's first major new railway for over a century. CTRL Contract 105 consists of numerous inter-related portions of work focused around the refurbishment of the St. Pancras station. This work involves renovation of the existing Grade-1 listed Station (the 8th most

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significant historic site in the UK), constructing a 185m extension to the existing station providing 13 new platforms for domestic and international services, and a new underground Thameslink Station. These combined works will take place both inside and outside of the existing operational above ground rail and underground metro station. These works are heavily dependent upon one another and occur on a highly congested site in central London. Figure 1 shows an aerial view of the project site under construction.

Figure 1: Channel Tunnel Rail Link Contract 105 at St. Pancras Station

BACKGROUND

In June 2003, CORBER (a joint venture of Costain, Laing O'Rourke, Bachy, and EMCOR Rail) sought to incorporate many lean construction principles and began piloting the use of SPS Production Manager by Strategic Project Solutions (SPS) and 3D Digital Prototyping. Initial efforts were based around the Thameslink Box (TLB), an underground metro stop, to demonstrate the performance improvement it could deliver. Three key critical success factors were established prior to commencing the pilot:

- Ensure effective reliability of workflow
- Ensure that the best approach to product and process are developed prior to commencing fabrication and installation
- Ensure that the right material and plant, in the right quantity, get to the right place at the right time, every time
- In order to meet these critical success factors, it was agreed that SPS would provide and implement the following:
- SPS Production Manager (aka "ProjectFlow" on CTRL Project) enabling systematic scheduling, controlling, measuring and improving workflow throughout a project or production process in real time.
- Technical training and support in the use of SPS Production Manager, as needed until all designated team members were effectively using the system
- Facilitation for various team building and training sessions as needed to ensure that the CORBER team members working in the TLB become a high-performance team

Subsequently, CORBER instructed SPS to expand the pilot to the whole of the Contract 105 project.

The project now has 38 active civils, building, and supplier teams, including 337 users who have entered over 55,000 tasks into SPS Production Manager. The project teams now have approximately 25 engineers trained for developing and using 3D prototyping. They are currently using both the SPS Production Manager and 3D modeling as tools to "engineer and plan their work".

OVERALL RESULTS / RETURN ON INVESTMENT

A list of improvements and the savings they have achieved is shown in Table 1. These results are largely due to the new approach to planning and executing work.

Measurable savings to date are calculated at \$3,509,971 against costs of \$947,105, for a current return of 3.7 times the investment. Total savings through the end of the project are estimated to be \$6,067,154 against costs of \$947,105, for a net savings of \$5,120,409, a 6.4% budget underrun, and a return of 6.4 times the investment. Additional savings are expected from initiatives still too new to evaluate, and indirect benefits in such areas as safety are also expected but not yet measured. Benefits beyond cost savings have been seen in stakeholder involvement, process transparency, collaborative planning, analysis and action on reasons for plan failures including links to the project's Six Sigma initiative, and integration of product and process design. These further unquantified benefits will be described later.

Table 1: Summary of Returns from ProjectFlow Implementation

Item	**Savings to Dec-2004**	**Future savings**	**Total savings**
Thameslink Box Productivity Improvements (Capping Beam Team)	$2,221,908	$0	$2,221,908
Thameslink Box Productivity Improvements (Fleet Sewer & East Central Concourse)	$378,842	$0	$378,842
Thameslink Box Fleet Sewer diversion & Orthotropic Deck installation	$378,842	$0	$378,842
West Deck – Buildability in 3D prototype	$94,710	$378,842	$473,553
West Deck – Improved productivity	$94,710	$852,394	$947,104
Site Stores – Satellite stores initiative	$151,537	$568,263	$719,800
Thameslink Base Slab – Labor saving	$0	$0	$0
Thameslink Base Slab – Schedule	$0	$284,132	$284,132
Concrete – reduced Ad Hoc orders, balance demand & supply	$189,421	$473,552	$662,974
Reinforcement	TBA	TBA	TBA
Self Certification	TBA	TBA	TBA
Intangible Effects	TBA	TBA	TBA
Total Savings	$3,509,971	$2,557,184	$6,067,154
Investment to date (SPS & CORBER staff)	($947,105)	$0	($947,105)
Net Savings	$2,562,866	$2,557,184	$5,120,049

IMPLEMENTATION & ASSESSMENT METHODOLOGY

The benefits described above were achieved through a continuous improvement strategy focused on improving work flow reliability[3], a fundamental concept of lean construction.

The SPS software, SPS Production Manager, is a production management tool that enables competitive advantage by improving quality, safety, time and cost. It accomplishes this through systematically scheduling, controlling, measuring and improving workflow throughout a project or production process. SPS Production Manager's single database aligns workflow from production to master level, eliminating the need for multiple schedules and related coordination problems. Its web-based user interface enables real-time updating of workflow status, ensuring that the schedule depicts the current situation. This allows users to make faster and better informed decisions, allowing coordination across all specialists, both on site and off site.

Enabling teams to successfully derive benefit from using the SPS Production Manager, requires intimate knowledge of how to implement tools or systems that require both process and behavioral changes within an organization.

SPS PRODUCTION MANAGER IMPLEMENTATION

Prior to implementing the SPS Production Manager, it is essential to have a clear idea of the approach or strategy to be followed, and the tools to support implementation. Without a detailed strategy or plan, the implementation effort will not progress, and the project team, as well as the implementation team, will quickly become frustrated. Similarly, each stage of the implementation process has a variety of support tools, techniques, and skills which must be common knowledge for the implementation team. Without this knowledge, the team will not be successful at guiding others through the implementation process.

Experience indicates that successful implementation of the SPS Production Manager requires the introduction of skills, techniques, and functionality in a specific sequence. It is essential for a pro-

3 "Work flow reliability", "production reliability", and "commitment reliability" are used interchangeably according to context

ject team to be fully competent in the use of the SPS Production Manager, and to have grasped the associated concepts, prior to moving on to additional modules such as the SPS Materials Manager. Typically, the implementation team will be responsible for determining when a team is ready to progress, however, all project stakeholders must be aware of the natural progression of activities, and understand that certain modules (such as the SPS Materials Manager) will not be implemented until a solid foundation is first established.

Once a project team achieves a certain level of competence, they will be required to progress the implementation of the SPS Production Manager without the support of the implementation team. This requires the efficient transfer of skills over time from the implementation team to a self sustaining project team. It is this transfer of skills that enables implementation across an entire project, either large or small.

Progress against the implementation plan is measured through regular assessments with the project leadership and teams. The frequency of assessments at CTRL has been established on a fortnightly basis, with regular meetings held to review implementation progress, make transparent strategic & tactical issues, and mutually agree remedies to ensure successful implementation. The SPS Production Manager Implementation Assessment Form and SPS Production Manager performance reports are used for this purpose.

As outlined in the implementation sequence above, teams begin by holding daily production control meetings to review and commit to a production plan for the day and to record completions and non-completions for the previous day. The "work flow reliability" for the project, shown in Figure 2, has improved from 70% to 80% over an 18 month period. Notable also is the reduction in variation.

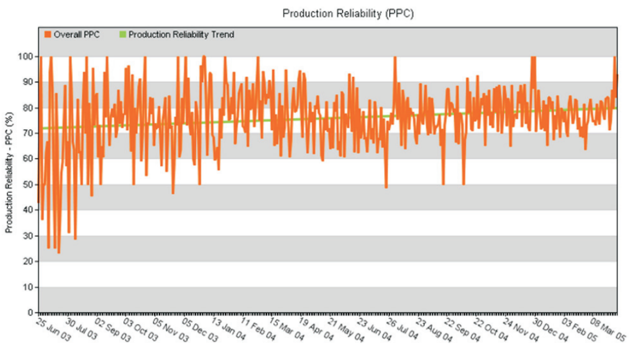

Figure 2: CTRL 105 Production Reliability Graph to 05 April 2005

In addition to measuring work flow reliability as shown in Figure 2, reasons for not achieving work as planned are collected and categorized. This data allows Six Sigma experts at CTRL to identify improvement areas that directly affect production activities. Figure 3 shows the Reasons Summary report.

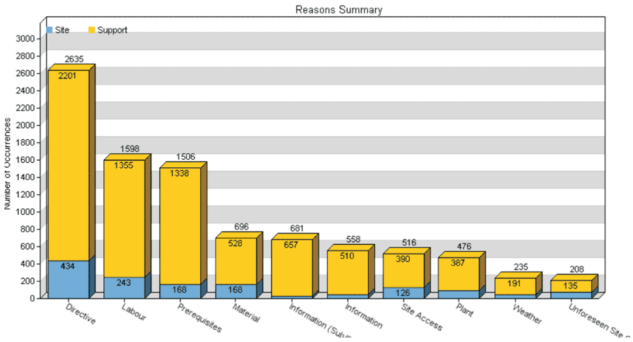

Figure 3: CTRL 105 Reasons Summary Graph to 05 April 2005

As a result of root cause analysis, teams undertook efforts to plan collaboratively with other teams, including the detailed planning of critical and repetitive operations using digital prototyping (3-D computer modeling) and process mapping. In addition, the SPS Materials Manager was implemented to control offsite supply and delivery. This will be discussed for the delivery of concrete later in this report.

RESULT EXAMPLES

Below are reports on performance improvement and return on investment for CORBER teams resulting from controlling production through SPS Production Manager and using 3D prototyping.

THAMESLINK BOX—CAPPING BEAM & EXIT STRUCTURES

Since April 2003, the SPS Production Manager Implementation team has supported the construction teams to improve the project delivery performance. Initially this work focused on the Thameslink Box.

The Thameslink Box Capping Beam work showed considerable productivity improvements. In April 2003, the productivity metrics were showing a serious potential overspend. These values were based on the production rates before the implementation of SPS Production Manager and 3D Digital Prototyping, but follow several months of work. Consequently, we assume that any learning curve improvements had already occurred.

In column D of Table 2, the actual hours per unit were significantly higher than estimated allowances. Based on a conservative estimate of labor rate including all costs of employment, overtime, management supervision, facilities and

Table 2 – Capping Beam Productivity Rates

	A	B	C	D	E	F
	Pre-SPS Production Manager & 3D Production Rate (to Apr-03)	Unit	Estimated Production Rate	Hours above Estimate	Potential Additional Hours	Post SPS Production Manager & 3D Production Rate (from Apr-03)
Concrete Placing	9.28	Hrs/m3	2.00	+ 7.28	41,986	1.76
Reinforcement Fixing	17.00	Hrs/ton	12.50	+ 4.50	10,919	12.48
Formwork fix & strike	5.22	Hrs/m2	4.00	+ 1.22	2,061	3.35

plant of $37.88/hour, the project was facing an overspend of $2,083,631 above the estimated cost representing a budget overrun of approximately 70%.

In December 2004, the Capping Beam team completed the works on time. The actual labor cost saving between the performance pre-SPS Production Manager to the completed work was approximately $2,221,908 (note that the total labor value for the capping beam works is $3,220,157). This is without apportioning the benefit from avoiding non-productive overtime, acceleration or damages from late completion of these critical works.

WEST DECK EXTENSION—COMPARISON TO EAST DECK (KPIS)

The West Deck team has a target production rate which is more aggressive than the completed symmetrical East Deck. It is difficult to compare because, while the structures are similar, differences exist in that the West Deck has the added complication of the critical Thameslink Box works beneath it.

In order to achieve these rates, the team is striving to understand their work better in advance of production on site to reduce the number of requests for information (RFI) raised on site, which could significantly delay the works. Using 3D prototyping, the engineers have identified 16 specific RFIs (Site Queries in the UK) that would have held up the works had the issue been left until the works had been constructed.

For instance: Site Query ref: 02553

> *"The reinforcement for the Long Beams are pre-fabricated in a yard and placed on table soffits for casting. Only after first stage of pour, (trackwell slab), are the platform starter bars fixed. In order for the position of these starter bars to be in accordance with the design requirements, the lap lengths of the top main beam bars in the beam cage need to be to the side. Standard fixing would lap these bars to the underside. This however, would prevent the correct fixing of platform starter bars. As a result of the modeling we were able to get the cages prefabricated correctly to suit the starter bar detail."*

From the team's experience on the East Deck, each Site Query raised on site would stop the work for an average of 4 days. The effects of this on production for a crew of approximately 8-12 are:

- Downtime to re-plan (estimated 2 hours per crew)
- Unplanned work (less productive, say 1/3 less productive)
- Potential non-productive overtime to repair (estimated 75% of unplanned work)
- Unplanned work for other teams
- Upstream / Downstream effects
- Material waste (estimated 50% of labor waste)
- Make do with materials to hand for new area
- Potentially less safe work, as it is unplanned
- Incorrect plant for new work
- Lower probability of "right-first-time" quality (estimated 10% labor for re-work)

Therefore each Site Query raised and solved in advance of the work results in a potential on-site saving of approximately $18,942. It is expected that 25 of these Site Queries will be raised therefore saving the Project $473,552.

On top of these individual items, by using SPS Production Manager & 3D prototyping to improve their control of the works and their short term planning on a daily basis, the West Deck team has targeted a 10% productivity improvement over the East Deck.

Based on a conservative estimate of labor rate including all costs of employment, overtime, management supervision, facilities and plant of $37.88/hour this equates to a productivity improvement of 25,000 hours or $947,000. This represents approximately 10% of the total labor budget for the West Deck Extension works.

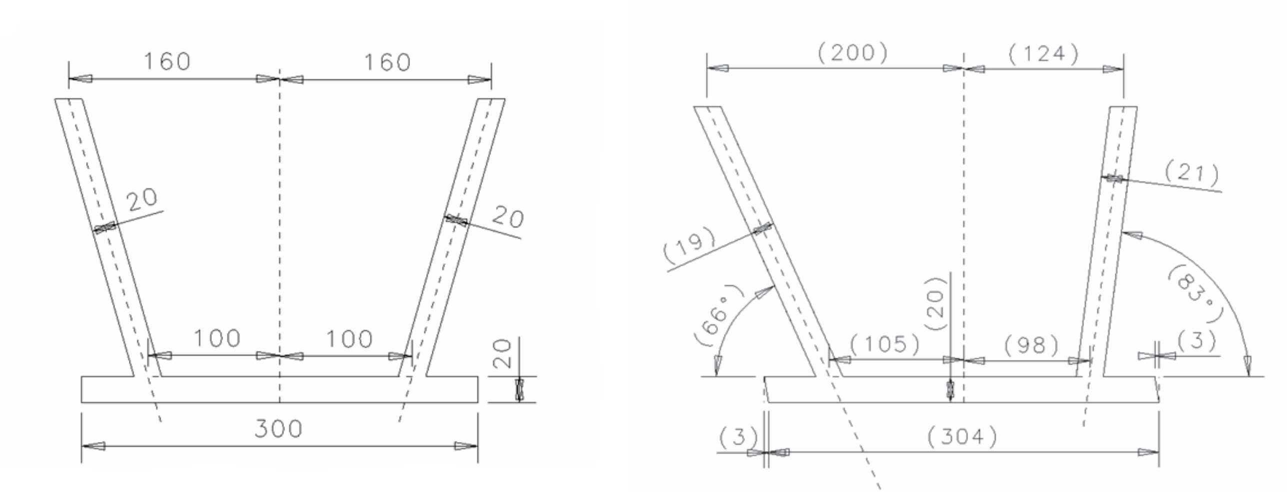

Figure 4: Section as detailed by designer (right) and after building digital prototype (left)

THAMESLINK BOX—FLEET SEWER & EAST CENTRAL CONCOURSE

The Fleet Sewer and East Central Concourse works were constructed using the same crews as the Capping Beam team. The Fleet Sewer team has used the SPS Production Manager to manage their processes and has achieved all their schedule milestones.

Without using the SPS Production Manager these structures could have reasonably assumed to have been delivered using the methods responsible for the "initial production rates" experienced by the Capping Beam team. Therefore, we conservatively estimate that the project has saved 10,000 man hours assuming that they are performing at similar productivity levels to the Capping Beam team. This is an approximate cost saving of $378,842.

In completing the Fleet Sewer diversion within the allocated rail possession times before the extended 35 week blockade period, the team ensured that this technically difficult work completed over a live railway was completed without any adverse effect to the schedule. This was only made possible by the team modeling in 3D detail the work which they were required to complete, and testing an installation sequence with the involvement of all the stakeholders including foremen, suppliers, client and third party representatives.

In the SPS Production Manager, the team used the date of the possession as the milestone and worked back to ensure sufficient time was allowed for all paperwork and approvals to be in place before the work started. Daily production plans were then created to monitor and control the works as they proceeded.

While checking the design for constructability in the 3D prototype, an inconsistency was found with the original design details. This is illustrated in Figure 4 above. The left figure shows a section through the steel orthotropic deck shown on the design drawings. The right figure is the same section taken from the 3D prototype and portrays what was actually fabricated.

Once the error was noticed, the fabrication was quickly amended and did not affect the construction schedule. Without using the 3D Prototype to identify this problem, the construction team may

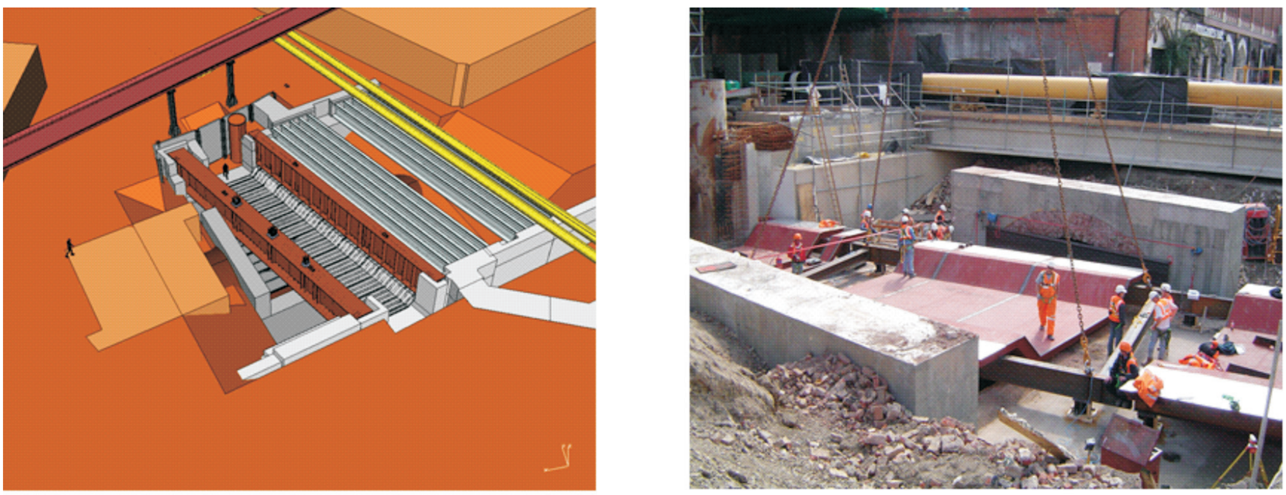

Figure 5 – Fleet Sewer Possession works in 3D (left) and during construction (right)

not have noticed it early enough and would have incurred the $378,842 cost for the 7 sections of the orthotropic deck twice. This is without factoring in the delay costs and the fact that this was the last possession available before the blockade. Performing this sensitive work during the blockade could have potentially delayed the entire CTRL schedule.

The 3D Prototype also highlighted a clash between the steel deck and the capping beam. The early identification of this clash enabled the team to carry out remedial works in advance of the possession, saving the potential calling off of the works. Figure 5 captures the 3D image alongside the actual construction works.

CONCRETE – REDUCED AD HOC ORDERS, BALANCED DEMAND & SUPPLY

There are a number of initiatives of which the benefits have not been fully measured. One example is concrete deliveries through the SPS Materials Manager. As workflow reliability at the production level increased, CORBER engaged SPS to help define and design the system and tools to enable concrete ordering through their production control tool, the SPS Production Manager. Communication between site and the supplier were better understood as a result of the site teams better planning and control. With a clearly defined planning process using the SPS Production Manager coupled with the integration of concrete ordering system through SPS Materials Manager, over time the project should see a reduction in the number of expensive overtime pours.

Initial estimates from the project indicate a significant reduction in man hours (see Table 3). This was measured over the 12 weeks from when the teams began entering concrete orders into SPS Materials Manager up until the holiday break in December 04. Based on a conservative estimate of labor rate including all costs of employment, overtime, management supervision, facilities and plant of $37.88/hour this equates to a productivity improvement of 5000 man hours or $189,400.

Assuming that the calculated average production rate will continue to be achieved over the remaining concrete forecast of 33,500 m3, this equates to an additional forecast productivity improvement of 12,600 man hours or $473,552.

Data will need to be continuously collected and used as verifiable evidence that this trend is being sustained.

Having the data on concrete orders and supply updated in real time has enabled the teams to review and analyze their improved ordering system and focus on continued improvements to the process. Figure 6 shows concrete supply, demand and overall reliability to take concrete orders per day.

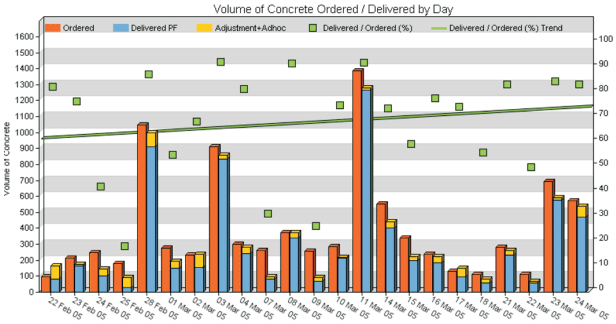

Figure 6: Concrete Reliability (Ordered/Delivered by Day)

INTANGIBLE BENEFITS

There were also intangible benefits from the lean construction initiative. These initiatives have not been quantified, but they have undoubtedly contributed to the overall return on investment yielded from the implementation of lean tools and concepts at CTRL.

All the 38 teams using ProjectFlow are involving the relevant stakeholders in the short term planning processes and regularly collaborate to agree on workstreams and processes. This involvement has been critically important at CTRL due to the complexity of the project and the number of people involved in the work.

Other stakeholders benefiting from the tools are the client, and our suppliers. For instance, Figure 7 is a detail of a structural connection. The model gives a far better representation of the space and requirements of the connection, enabling faster and better informed decision making.

Table 3: Concrete Productivity Rates – Mid-September 2004 to Mid-December 2004

	A	B	C	D
	Rates	Unit	Quantity Placed (m3)	Total Hours per Rate (Hrs)
Concrete Placing Tender Production Rate	2.00	Hrs/m3	13,352	26,704
Concrete Placing Calculated Average Production Rate	1.62	Hrs/m3	13,352	21,664

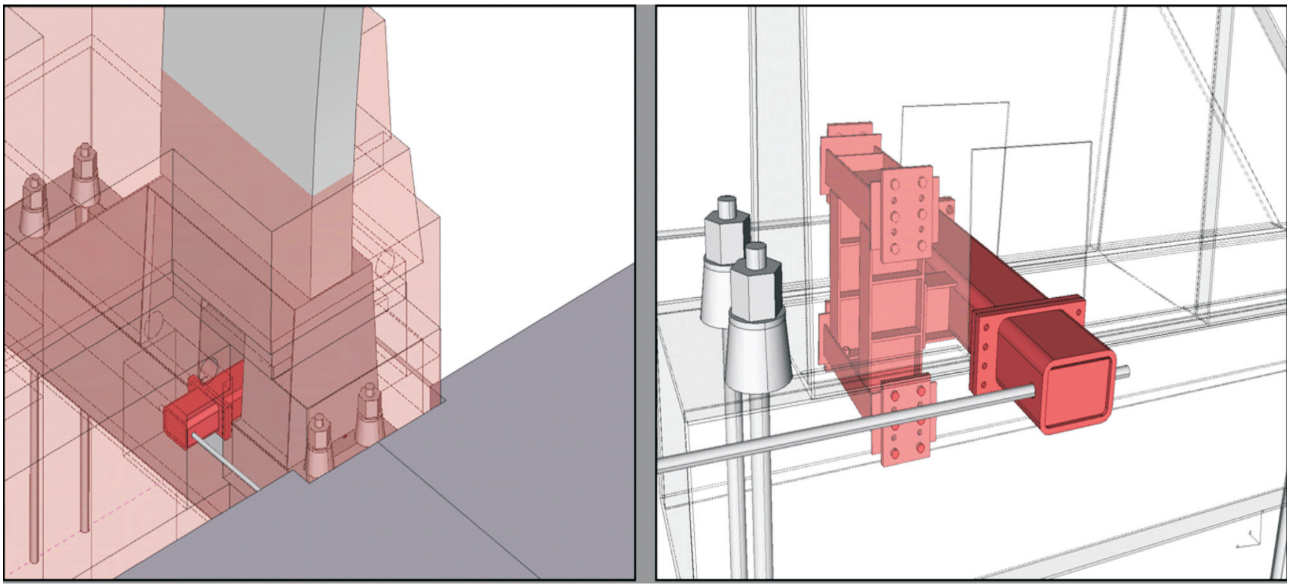

Figure 7: Boot Permanent Tie Detail (roof arch—wall connection)

CONCLUSION

Concepts and techniques of lean construction have been explained and an implementation strategy based on the application of production control (through SPS Production Manager and SPS Materials Manager) to construction has been presented. The CTRL case study illustrates the benefits and the quick and attainable return on investment from application of these concepts, strategies and tools to construction projects. These benefits are not only being achieved on CTRL but across the globe for many clients.

Further development and application of innovative tools, such as those presented will aid to embed Lean Project Delivery as standard practice. The authors expect future implementations to generate even greater value for customers and stakeholders.

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