USING BUFFERS TO MANAGE PRODUCTION: A CASE STUDY OF THE PENTAGON RENOVATION PROJECT

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ABSTRACT

In construction, it is not common to discuss the use of buffers to manage production. Some companies are clearly better at using these mechanisms than others, even if they do not explicitly discuss their buffer management practices. Certain projects and the way they are organized and managed are better suited for the use of buffer management techniques. This paper explores the implementation of buffer management techniques for the planning and execution of the renovation of the Pentagon. This case project provides a good example of the successful use of buffers.

The Pentagon Renovation Project (Wedge 2 to 5) is a $840 million, 10 year project with a high degree of repetition. The project is phased by wedge moving from Wedge 2 to Wedge 5. The work of the project was planned using a technique known as short interval production scheduling (SIPS). This schedule segmented the wedges into smaller work zones and sequenced a "parade of trades" through each zone. Each trade was provided a period of one week in each zone to complete their work. However, some parts of the project involved differing amounts of work for the trade contractor. This was particularly true of the mechanical contractor and it meant that resources could not be optimally balanced to avoid unproductive periods. This contractor used buffers to help smooth the varying levels of work between these zones. The methods used to plan their work are analyzed along with an analysis of the plan execution. Lessons and challenges to the use of buffers in this application are identified.

KEY WORDS

Buffers, Pentagon renovation, lean construction.

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INTRODUCTION

Planners in construction companies do not typically discuss the deliberate insertion of buffers in their schedules to manage their programs. Some companies are clearly better at using these mechanisms than others. Certain projects and the ways they are organized and managed are better suited for the use of buffer management techniques.

Buffers provide a method to accommodate uncertain and variable conditions and can take many forms. Buffers incur a cost, but when used properly can be effective at allowing work to be completed by increasing predictability in uncertain conditions. Because buffers do not directly contribute value, lean producers have in the past treated them as *muda*. However, there is a growing body of lean construction research that is seeing the worth of these methods to managing project production (Ballard & Howell 1995, Howell & Ballard 1994, Howell et al. 1993, Tommelein 1997 & 1998, Horman & Kenley 1998, Horman 2000, Sakamoto et al. 2002).

This paper describes the use of buffers in the sequence planning and scheduling of the Pentagon renovation. It is important to note that the Pentagon places great value on the predictability of the construction process and completion dates to allow for the coordination of the thousands of occupants in the Pentagon. As a result, the planning goal was to achieve a steady and predictable work rate as opposed to a steadily increasing production level as trades worked their way through the project.

To accomplish this, the design-build contractor used an innovative scheduling method called short interval production scheduling (SIPS) to organize the project construction work (Burkhart 1989). SIPS is a highly detailed planning tool that utilizes the personnel involved in the project as part of the plan development. The company has successfully used this method on other of their projects, particularly, prisons and high rise office towers. What is interesting about this particular plan is the use of buffers. The insertion of buffers in this production schedule is explicit and deliberate for maintaining the production schedule. However, a number of the subcontractors also used buffers to manage their workloads. This was especially the case for the mechanical contractor. This buffer provided a capability to the contractor to maintain their commitment to completing work as scheduled. It also provided a mechanism to smooth the varying levels of work between zones in the building.

The use of buffers in the Pentagon renovation provides an excellent example of how effective these methods can be at managing the conditions typically encountered on projects even in the best planned projects. Many of the features and principles discussed in lean construction, especially the pursuit of predictable work flow, are present in this case. However, other important issues are raised such as how to achieve productive operation when levels of work vary between work zones. This paper outlines these issues and provides some comment for learning and improved future application.

PENTAGON RENOVATION PROGRAM

The Pentagon renovation project (Wedge 2 to 5) is a $840 million, 10 year project with a high degree of repetition. There are a number of other projects that form the overall renovation program, but these are not addressed in this paper.

The Pentagon renovation (Wedge 2 to 5) was initially envisaged as four separately bid projects, but was bid out as a complete package to enhance buying power. Innovative acquisition features have been used for procuring this project, including the use of design-build, fixed price, award fee agreements, and performance based-specifications.

The Pentagon was initially constructed in 1941 as a barracks for troops heading to Europe as part of the US involvement in WWII. The project was built in 16 months so quality by today's standards is low. The building has a cast-in-place reinforced concrete structure. The walls, including the outer walls are brick masonry with a limestone panel façade. The Pentagon had never undergone a major renovation and has not complied with building codes since 1953.

The Pentagon project is to provide renovated office space for approximately 25,000 workers. The construction work of the Pentagon renovation is segmented into core and shell work, which includes demolition and asbestos abatement, and then internal fit-out. Each wedge of the Pentagon is approximately 1 million square feet with 60% being office space and 40% taken up with general utility space (corridors, bathrooms, mechanical rooms, etc.).

As a result of the terrorist attack on September 11, 2001, the renovation of the remaining wedges was accelerated by four years at a cost of $225 million. Not surprisingly, this acceleration has elevated the pressure on the schedule to renovate the wedges.

OVERALL SEQUENCE

At the broadest level, the renovation of the Pentagon is phased by wedge moving from Wedge 2 through Wedge 5. This is shown in Figure 1. This means that only one wedge at any one time is under renovation allowing the remainder to be occupied and fully operational. Maintaining the full operation of the Pentagon throughout the extensive renovation was a key owner requirement and major project constraint. As discussed later, the sequence of space handover and the process for identifying the new tenants both had a major impact on the developed plan and the course of the project. The occupants of the first wedge were moved off site to "swing space" located in local office buildings. As each wedge is renovated the occupants of the next wedge move in and release their space for the next step of the renovation. Those in the first wedge, presently located in swing space, will move into Wedge 5 when this is completed.

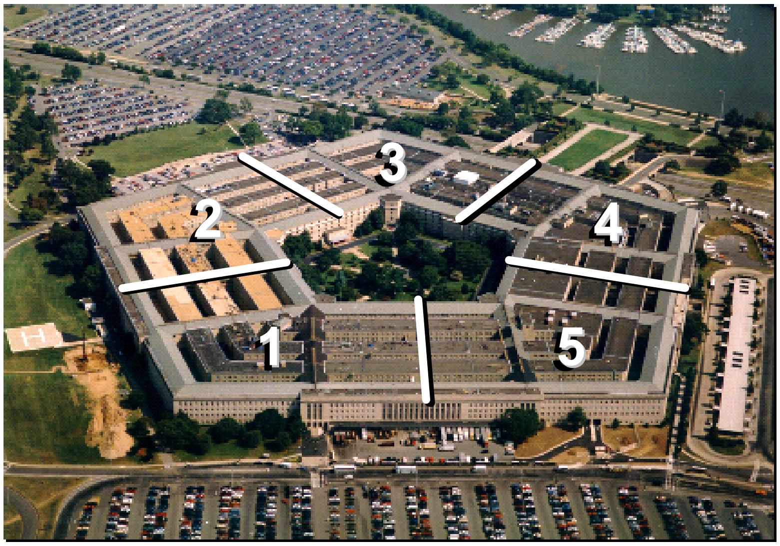

Figure 1: The overall sequence of construction for the Pentagon renovation. The exact delineations between wedges are more complex than shown.

DESIGN IMPACT ON CONSTRUCTION

One of the important requirements for the office space in the newly renovated Pentagon is its ability to meet the varied and constantly changing needs of the tenancies. There are approximately 200 hundred tenant groups in the Pentagon that range from the executive offices of the Secretary of Defense through the administrative division of Army Veteran Affairs and the Situation Center for the Marine Corps. These groups are transient in nature in this facility. Consequently, there is a high demand for flexible, high security office space that can be rapidly reconfigured. These operational requirements led to the design of the Universal Space Plan. An example of this is shown in Figure 2.

Figure 2: Example office layout within the Universal Space Plan.

The Universal Space Plan approach meant that a standardized layout was installed that would allow adaptation and reconfiguration to customize to the specific requirements of the tenant. Thus, a considerable amount of redundancy was built into the building. An example of this is the STC 45 sound attenuation system installed above the ceiling. This is installed to provide the required sound security (to guard against eavesdropping) regardless of whether a wall is located immediately below or not. However, by providing the system, the demountable office system can be reconfigured virtually overnight to the new tenant requirements. The other impact on construction was that the component, systems, and configuration of the office are repeated extensively throughout the building. This meant that it was very worthwhile to undertake detailed planning of construction in order to achieve a highly efficient schedule.

SHORT INTERVAL PRODUCTION SCHEDULE (SIPS) FOR THE PROJECT

Short interval production scheduling (SIPS) was used by the design-build contractor to plan the interior construction work. A SIPS differs from other scheduling methods in that:

- (Usually) only one specific operation is involved
- A much higher level of detail is developed in the construction plan
- Personnel involvement and commitment of everyone contributing to the operation is built into the process for developing a SIPS (Burkhart 1989).

The result of the SIPS process is a detailed plan. Typically, SIPS are developed on self-perform operations where there is a significant degree of repetition. Successful applications have included the tunnel form operation used in prison and hotel construction projects as well as office tower construction. Developers of the process recommend that at least twenty repetitions be performed on the project for application of this scheduling approach. There are five distinct steps to the SIPS process as shown in Table 1.

Table 1: Steps for developing a SIPS. Source: Burkhart (1989).

SIPS Step	Explanation
1. Break the operation down into specific activities	Identify key steps and list these, e.g., prepare forms, place and align back, place rebar, close form, align, pour conc.
2. Quantify each activity	Identify physical quantities of work to be performed, e.g., c.y. of conc., s.f. of formwork
3. Assign production rates to each activity	Identify time to complete activity, e.g., 15 min. to set 120-lb rebar cage
4. Calculate extensions and set goals	Set crew size, compare to budget, and adjust as necessary
5. Develop a time-scaled, resource-loaded bar chart	Develop detailed schedule (typ. hourly), show crew sizes for each activity

The starting point for the Pentagon SIPS was to break down the wedge into smaller parcels. First, the building was segmented into “main bars” and “chevrons.” Figure 3 shows a section of the building broken down into main bars. Each parcel was approximately 6,000 s.f. in size. The work in these spaces broadly represented what could be done by a crew in one week. This approach of determining production time based on the volume of work to be executed is very similar to lean productions *takt* time (Womack & Jones 1996). In this case, the takt time would be one week. As it turned out, the work in these spaces was not always similar and required subcontractors to reconfigure their crews.

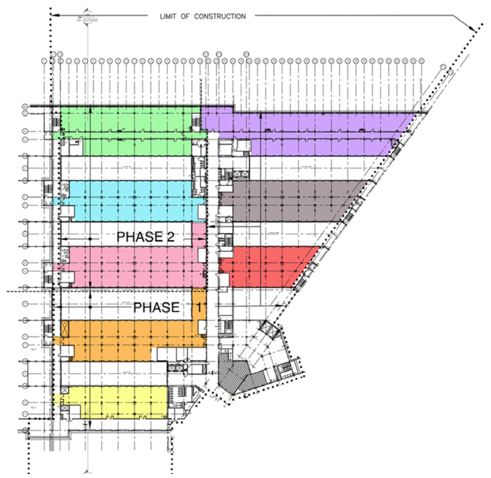

Figure 3: Space break down. Shown are the “main bars”. The other major space are “chevrons” in the corners of the wedge (not shown).

The second, third and fourth steps in the Pentagon SIPS were done together in an iterative manner. These determined the scope of work to be performed in the renovation and who was responsible for that work. Table 2 shows a preliminary breakdown and which contractors would perform the work. The 27 activities identified were established on the basis of each broadly representing a similar volume of work. Some negotiation occurred between specialty contractors and the design-build contractor over these breakdowns. The initial breakdown of activities led to a schedule of 45 weeks which did not allow them to reach the overall schedule dates. Through successive iterations they were able to get the schedule down to the required 27 weeks.

The fifth step of the SIPS process was to develop their schedule. This is shown in Figure 4. This simple schedule indicated clearly where each trade was located in the overall schedule and the path of work for the trades. An unintended, but quite useful benefit of the schedule was the transparency of the schedule as subcontractors gained a very clear understanding of their role in the entire project. The sequence of spaces throughout the wedge is shown in Figure 5. This sequence was determined by the riser work performed on the project (this was outside the SIPS train).

The Pentagon renovation is somewhat of a variation of a regular SIPS. The SIPS is applied to all of the interior office work being performed rather than just one specific operation. It is also used to schedule the work of subcontractors and there is only a very small amount of self-perform work (door carpentry) by the design-build contractor. Finally, the granularity of the Pentagon SIPS is much greater than typically found in other SIPS. For example, the SIPS for prison construction projects, schedules the workday into 30 minute periods. The scale of the Pentagon SIPS is weekly. However, given its size, it should be noted that the weekly interval SIPS represents a moderate level of detail for this project.

SHORT INTERVAL PRODUCTION SCHEDULE (SIPS) FOR MECHANICAL WORK

Having established the project SIPS, the mechanical contractor then developed a SIPS for their work. The focus of their SIPS was the work that they performed in activities two through 5. This part of the project required the installation of the heating system and the HVAC system. The heating is a hot water baseboard system that has fin tubes located around the perimeter and is fed by hot water pipe. The HVAC is a ceiling mounted fan coil induction unit fed by chilled water pipe and small diameter circular ductwork. Most work is located in a central section of the space. The development of this SIPS followed closely the more usual SIPS process as this work was self-performed, planned to a high level of detail, and involved those actually executing the work. Figure 6 shows the SIPS table developed to determine volumes of work, production rates, crew sizes and activity durations. Figure 7 shows the resource loaded SIPS schedule for the period. This details the work in each of the main bars in Wedge 2 of the Pentagon.

ROLE OF BUFFERS

The SIPS schedules develop a production system where reliable and efficient flow rather than construction speed was achieved. The significant investment in this level of detailed construction planning was justified by the level of repetition in the project. Clearly understanding the project in production management terms helped to develop an effective construction schedule. However, despite these characterizations holding true, there were implemented mechanisms for addressing problems that could disrupt and significantly impact the SIPS schedule. The tight coupling of activities meant that problems encountered early in the project would impact many, if not all remaining activities. The variations in work between main bars and chevrons also had the potential to degrade the productive efficiency of the subcontractors. Four mechanisms were used to manage these issues:

1. Resource variation – At the instruction of the design-build contractor, subcontractors were expected to adjust (ramp up and down) their resources based on available work. The SIPS was able to achieve overall continuity, but the variations in the detailed work were left to the subcontractors to manage.
2. Progress management – The design-build contractor used a weekly progress review to sign-off the completion of work in each space.
3. SIPS time buffers – A time buffer was used by the design-build contractor in the form of weekend overtime to permit incomplete work to be made up. This buffer was strictly guarded.

Trade time buffers – The mechanical subcontractor also used a time buffer to help manage their workflow by scheduling to complete work in 19 days rather than the available 20 days.

Table 2: Break down of work to be performed.

Activities	Contractor
Fire Sprinkler Mains & Branches	Fire Sprinkler
HVAC System Induction Boxes & Ductwork Rough-In	Mechanical
Fintube (Heating) Piping	
Outside Air Branch Duct	
HVAC Piping Connections	
HVAC Piping Mains & Testing	
Pipe & Duct Insulation	
Frame Drywall, Bulkheads & Columns Zone B	Drywall Plasterer
Frame Drywall, Bulkheads & Columns Zone A	
Equipment Raceway Rough-In	Electrical
Overhead Electrical & Wall Rough-In	
Pull Electrical, Control Wiring	
Insulate Walls & Close-In	Drywall Plasterer
Hang Drywall	
Tape & Finish Walls & Soffits	
Paint Walls & Ceilings	Painter
Install Smart Walls	Furniture Installer
Pull Comm & Data Wire	OGC
Trim Smart Wall; HVAC Start-Up	
Install Grid & Window Trim	Drywall Plasterer
Mechanical Trim Work, Lights Hung, Security	Mechanical, Fire Sprinkler, Electrical
Ceiling Tiles, Doors & Hardware Installed	Drywall Plasterer, GC, Door Hardware Supplier
Security, Fire Protection, Electrical, HVAC, Security Trim	Fire Sprinkler, Electrical, Mechanical
Carpet Installed	Carpet Installer
Demountable Walls & Window Blinds Installed	Furniture Installer
Pre-Accreditation Walk-Through, Punchlist, Testing & Balancing	Mechanical and others
Furniture & Smart Wall Trim	Furniture Installer
Clean-Up & Commissioning	All

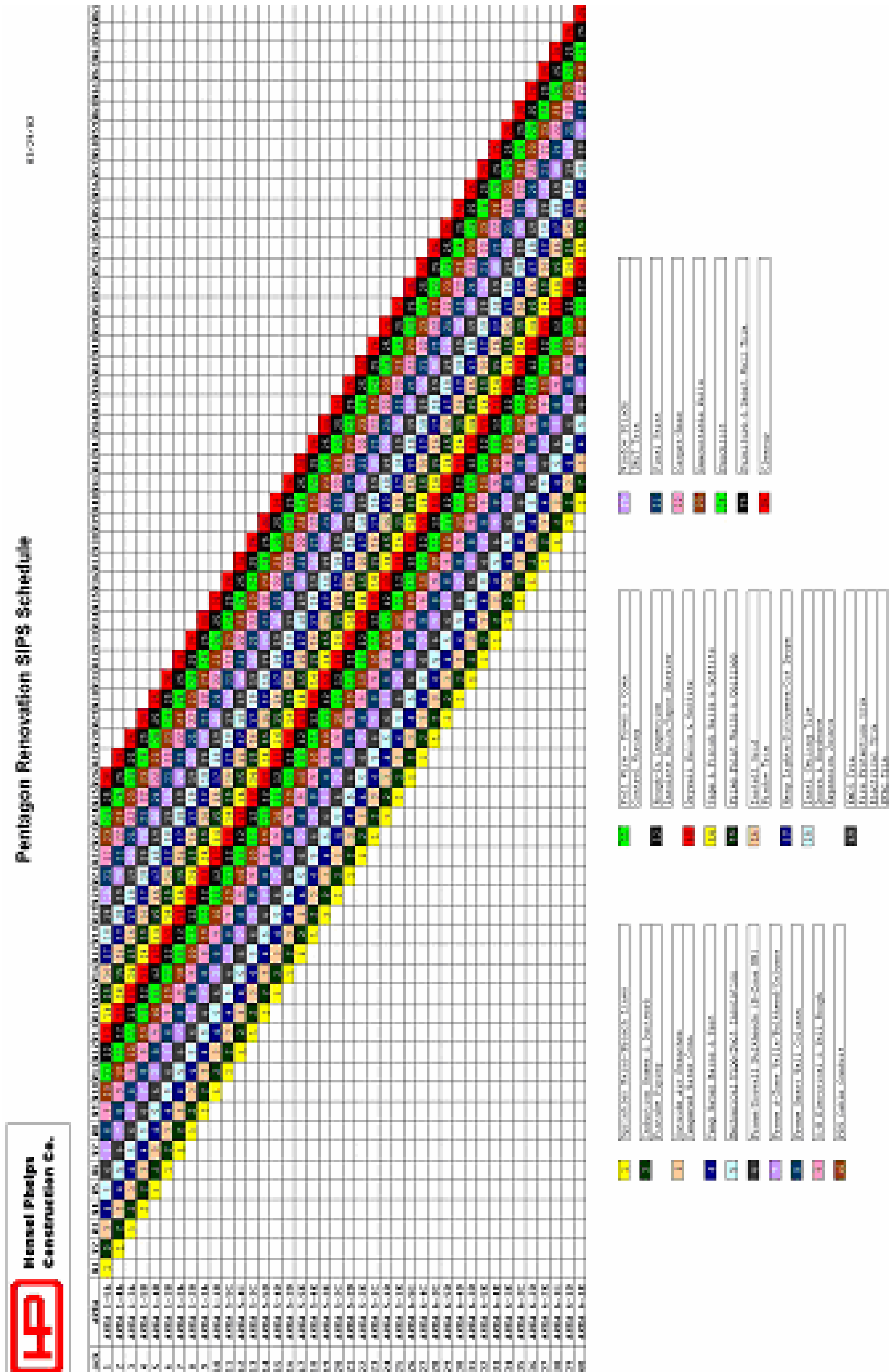

Figure 4: SIPS train for the Pentagon renovation Wedge 2.

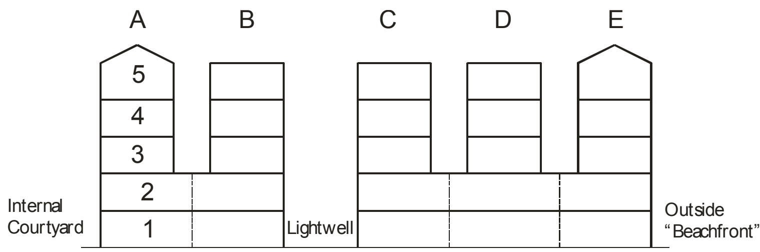

Figure 5: Section through the Pentagon showing construction sequence. These references match up with those in Figure 4.

Activities by Zone

Job Name: Pentagon - Wedge 2-5 Renovation *Zone:* Main Bar

ID	Trade	Activity	Quanity	Unit	Budget Production (Units / MHR)	Total Budget Time (MHR)	Crew Size (People)	Activity Duration (HR)	Activity Duration (Days)	Resources Needed	Notes
10	SM	Layout/Install Duct Hangers	1	total	0.03	32	2	16.0	2.0		
20	PF	Layout/Install Pipe Hangers	1	total	0.02	48	2	24.0	3.0		
50	SM	Hang Induction Units	20	ea	0.25	80	2	40.0	5.0		
60	PF	Chilled Water Mains (S&R)	290	lf	7.50	39	2	19.3	2.4		
70	SM	Install Duct Mains (OA)	490	lf	7.00	70	2	35.0	4.4		
80	PF	Install Branch CHW Lines	20	ea	1.00	20	2	10.0	1.3		
90	PF	CHW Coil Connections	20	ea	0.50	40	2	20.0	2.5		
100	SM	Supply OA Connection	20	ea	0.50	40	2	20.0	2.5		
110	SM	Install Flex Duct from Units	37	ea	2.00	19	2	9.3	1.2		2 connections/unit.
120	PF	Install Baseboard Carriers	1	total	0.03	32	2	16.0	2.0		Metal clips for unit.
130	PF	Install Baseboard Units	30	ea	0.50	60	2	30.0	3.8		
140	PF	Test CHW Lines	1	total	0.06	16	2	8.0	1.0		
150	SUB	Insulate CHW Lines	1	total	0.01	160	4	40.0	5.0		
160	SUB	Install Control Wiring	1	total	0.01	120	3	40.0	5.0		
170	SM	Air Pressure Test	1	total	0.06	16	2	8.0	1.0		
180	Comp	Area Clean-up	1	total	1/8	8	2	4.0	0.5		

Figure 6: SIPS table developed for the mechanical work in weeks 2 through 5.

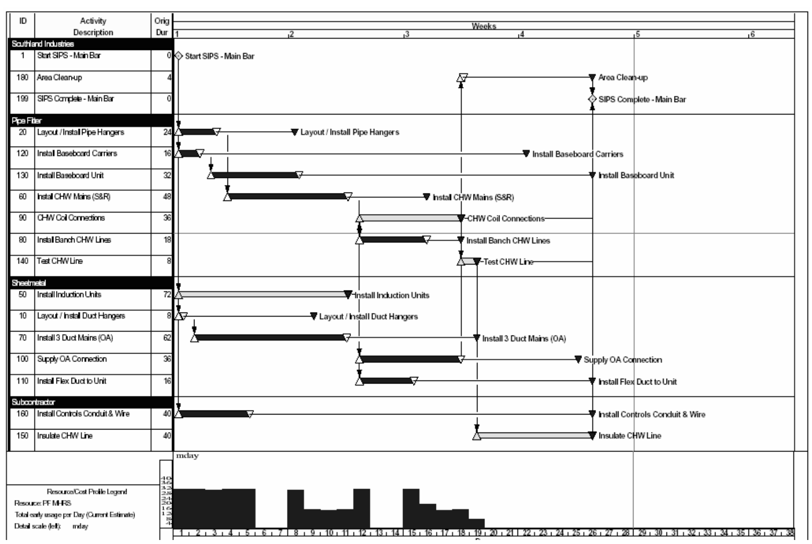

Figure 7: Resource loaded SIPS schedule for the mechanical work in weeks 2 through 5.

These mechanisms were not explicitly discussed by the responsible planners as buffers, but clearly there is a detailed understanding of production management, the weaknesses of the system, and forethought being given to address problems that arise. These mechanisms were important for maintaining production performance on the project although they did not manage all problems encountered, as will be discussed later. These mechanisms worked in unison in the production system, but it makes sense to discuss their operation and impact at the project level and then at the trade contractor level.

AT THE PROJECT LEVEL

The project level was where the design-builder's SIPS operated. This SIPS provided the direction as to where, when, and by whom work was to be performed. The detail of execution was left to the trade contractors. Crucial to the execution of this SIPS was that all involved completed their allotted work in the allotted time. To ensure this, the design-build contractor insisted that the trade contractors schedule their work to be completed in a five day week. It was up to the trade contractor to manage this in the best way possible. It was understood that this was likely to mean labor resources would not always be used in the most efficient manner possible. On Friday afternoon, the design-build contractor superintendent walked through the job to assess progress and sign-off on work in spaces. Where work was not completed satisfactorily, the trade contractor would be instructed to complete the work over the weekend. It was paramount that the space be available for the next trade at the start of the next week.

In the SIPS schedule, the weekend was used as a buffer to absorb problems and permit efficient production flow. This proved to be an effective method of accommodating the day to day problems on the project that typically extend and delay construction schedules. It was clearly necessary that all trade contractors understood and bought into this schedule for it to work. At times, it also required strong and forceful management.

AT THE TRADE CONTRACTOR LEVEL

Work at the trade contractor level is different to the project level in that the work of the project is executed at this level. Problems had to be addressed here by the foremen because they would directly impact the work and could not be deferred to any other entity. Not all trade contractors developed a formal SIPS for their work in the project. However, the mechanical contractor felt it would benefit their operations if they did. Scheduling their work so it was complete with one day to spare was the way the mechanical contractor used a buffer to ensure production was maintained despite potential problems that were likely to arise. For all trades, there were many challenges on this project ranging from high security screening of material deliveries and labor personnel to significant variations in work volume in some areas. These would make the achievement of a consistent work schedule difficult and the time buffer gave some room.

The mechanical contractor was in an interesting position on this project. Being the second trade into the spaces proved to be a real advantage as trades in the middle and end of the SIPS train were often caught in difficult circumstances where delays in prerequisite work sometimes delayed their start, but they were expected to make up the delay and this meant accelerated work. Their early involvement meant they were not impacted by many of these challenges.

The other aspect to the position of the mechanical contractor in the project was that their work differed significantly between the main bars and the chevron spaces. Typically the chevron spaces required less mechanical construction. This meant that the labor demands almost halved in these spaces and the mechanical contractor was left with a dilemma: Complete the work with a suboptimal crew and incur additional labor costs, or redistribute the crews in some fashion. There were no projects nearby where labor could be shared, but there was riser mechanical work that they could share labor with. This was still less than optimal. As it turned out, being involved early in the project gave the mechanical contractor a solution that later contractors did not have. The mechanical contractor was able to commence their work in the next space ahead of their scheduled time because they were not constrained at the front end as other trade contractors were. This gave the mechanical contractor another opportunity that other trade contractors did not have to redistribute their labor resources.

INSIGHTS AND CONCLUSIONS

The approach to planning the production of the Pentagon renovation clearly reveals that buffers go hand in hand with efforts to achieve smooth workflow. While it is not common to discuss the mechanisms we use to manage construction schedules in terms of buffers, it is clear they are used. Construction often needs buffers because workflow is subject to many influences that obstruct and delay, even in detailed construction plans like the Pentagon SIPS.

Different types of buffers were available and used by participants in the production system. Time buffers were used in the form of deliberate spaces between steps in the construction schedule. These spaces, in the form of weekend work, were available only if needed. Time buffers were also used by the mechanical contractor by deliberately scheduling their work to complete ahead of the expected date. While deliberate, this additional time was obscured from the design-build contractor so that they could be sure that it was available if needed. The third type of buffer used was resources. Resource buffers were essentially used by the design-build contractor when minor variations in work had to be accommodated by flexible capacity strategies (Horman 2000). High levels of resource utilization were sacrificed in their planning criteria and focused on executing fluctuating amounts of work in their schedule. It was fortunate that the mechanical contractor was early in the project because they could rapidly redistribute their resources to other tasks they had on the project and were able to start upcoming work ahead of schedule. Other contractors were not so fortunate and they had to sacrifice labor performance to meet their schedule objectives.

It was also interesting that the SIPS schedule derailed part way through the sequence. Activity 23 was the installation of the demountable wall furniture and the schedule was significantly delayed by this activity. This activity required information from the owner concerning the tenant requirements for the space. While the Universal Space Plan was used to provide space flexibility, individual tenants had very specific requirements for their space. Information about these requirements was not obtained early enough so furniture fabrication and installation was delayed. This was clearly a breakdown of the system to alert management sufficiently early of this need. A critical milestone date at the required point in the SIPS would have helped trap this problem, as would have a more robust lookahead component planning system (Howell and Ballard 1994). This problem delayed the SIPS by three weeks and meant that the remaining four activities were derailed. This work was rescheduled as a caboose to the SIPS train as a consequence.

Despite the extensive planning performed on this project, it was still subject to problems and challenges that required the effective use of buffers and some major challenges that significantly upset the schedule. The Pentagon renovation shows that buffer management goes hand in hand with efforts to achieve smooth workflow in construction projects.

ACKNOWLEDGEMENTS

We wish to thank the Pentagon Renovation Team, Hensel Phelps Construction Company, and Southland Industries, Inc. for their support and cooperation throughout this study.

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