Three steps forward, two steps back: managing information-driven design and engineering processes

John L Steele, Senior Vice President, Adept Management Ltd

Abstract

This paper introduces the issues associated with scheduling and managing complex, information-driven processes such as the design and engineering phases of a project. These phases are not linear (like manufacturing or production processes) but instead, require the project participants to share and develop information in iterative cycles, making assumptions in order to proceed with design and learn more about the problem before repeating the process with improved understanding. This is a challenging environment to manage, yet the management of the process is critical to the success of any project. This paper describes a methodology for capturing complex processes, integrating and streamlining the overall process, and managing / controlling the ultimate project using the detailed understanding of the information-driven process. The paper will be of interest to any organisation or PM professional that is faced with managing information intensive processes in any sector: construction, software development, marine, aerospace, discovery research, and so on.

Introduction

The separation of design and engineering from the rest of the project process has been consistently reported as a fundamental weakness in project delivery and project management generally. Steps have been taken by the PM profession to better integrate the design / engineering stages of projects within the broader project process. For example, in the construction sector many large contractors now have significant design management departments and on most projects they will manage the design team from at least the agreement of a scheme design. The need for improved management capability in the design / engineering stages has, in part, been driven by increased adoption of integrated contracts (including Design-Build, Integrated Project Delivery, and so on) – many of which are fast-track in nature and as such, require design, procurement and construction to be overlapped, thus forcing modifications to the intuitive / experience-driven sequence of work. Whilst this is generating an increased awareness of the criticality of seamless integration of design and construction for successful project results, figures published in the UK show that design still goes over budget in a third of projects and is delivered late over 40% of the time, with the knock-on effect that only 44% of project processes are delivered within budget and only 60% are on time (UK Department of Trade and Industry, 2007). Clearly there is more to do.

The ongoing failure to deliver the design and engineering stages of projects efficiently and effectively is in major part due to an inability to identify and plan the iteration which is inherent within the process – the reasoning: ‘you cannot manage what you cannot see’. Construction processes are, literally, straight forward whilst the design phase revolves (again, quite literally) around the project participants sharing and developing information in iterative cycles, making assumptions as they go in order to progress design and learn more about the problem before repeating the process with improved understanding. Many PMs see this as ‘re-work’ and as such, attempt to remove it from the process to ensure efficiency of delivery. Designers and engineers, however, recognize this as development and refinement - the life-blood of the design process. This difference in perspective can create major problems for the project delivery team but, whilst it is a challenging environment to understand, it is the management and control of this process that is critical to the success of the project as a whole.

The methodology

A methodology, comprising a number of well known and well utilized techniques, has been developed to enable all project participants to ‘see’ the design and engineering process – thus providing the team with a single representation of the overall project against which delivery can be synchronized, monitored, managed and controlled. This methodology comprises four distinct phases:

1. Create a dependency network - the scope of the design process is captured in terms of activities to be completed and their associated information dependencies;

Published as a part of 2010 PMI Global Congress Proceedings – National Harbor, Maryland

2. Optimize the sequence - the activities within the network are sequenced based on the flow of information between them to provide the optimum route through the process – this highlights where iteration exists and provides a means of optimizing the scale of iteration through focused decision-making;

3. Integrate with linear production sequence - the optimum sequence of activities is assimilated into a gantt chart and the interface (typically the procurement process) between design / engineering and production is reviewed to highlight, and enable resolution of, any clashes; and

4. Manage and control workflow - the flow of information is monitored and controlled using a variation on basic production control principles.

Defining the design process

To define the full scope of the design / engineering phase of a project in terms of the activities required and their dependencies can seem a daunting task. However, as long as the correct participants, representing the full expertise of the project team (or surrogate experts if specialists are not yet appointed to the team), are engaged the data is fairly simple to unearth and structure. It is essential that team-based workshops are utilized initially to ensure that representatives of each participating organization reach agreement on the structure and format of the design process. Furthermore, the PM should recognize the critical need for confident facilitation in applying this methodology (Jackson *et al*, 2008). Whether the PM undertakes this role themselves or appoints a professional facilitator, the individual will ideally have a balanced understanding of the project, the scheduling and design process generally, as well as the ability to foster positive and collaborative contributions from team members.

Generating the WBS

A Work Breakdown Structure (WBS) is best utilized to format and collate the project structure and activities. Although WBSs are common place in production / construction they are far less familiar to designers – particularly the non-engineering disciplines. As such, it is essential that the design / engineering team derive a WBS that works for them. If production-based personnel are involved they will typically propose a WBS based on the work packages that are to be produced. This fits with the way the built asset will be physically constructed, yet works contrary to the way in which the built asset is best designed. Rather than producing information by work package, designers prefer to produce information based on zone or area; all too often this is forgotten when developing the design / engineering schedule and designers end up being forced into assumption-making, which introduces significant risk or, as means of mitigation, overdesign, where none may have been necessary.

Exhibit 1 - Collaborative development of WBS and definition of activities

Experience has shown that a function / discipline based hierarchy provides the best starting point – primarily owing to the fact that it provides focus for each discipline in relation to the scope of work on which they have been appointed (e.g., civil, structural, mechanical, and so on). However, it is important to recognize that other 'elements' are involved in the delivery of a project and these too must be included in the hierarchical breakdown. As such, the

Published as a part of 2010 PMI Global Congress Proceedings – National Harbor, Maryland

appropriate project stakeholders are also involved to create additional strands relating to ‘Management Activities’, ‘Owner Activities’, ‘Authorities Having Jurisdiction / permitting Activities’, and so on as required.

Another important consideration is the Procurement Strategy and accordingly, a further strand of the hierarchy is created that represents the Work Packages to be procured (i.e., the work package breakdown). Whilst creating a WBS by Work Package can prove counterproductive, the importance of defining the work packages that will be procured on the project cannot be underestimated (for reasons discussed later within this paper).

Once each discipline is focussing on their own scope of work they naturally tend to think in terms of the systems and sub-systems that make up the built asset; this generate a pseudo-Product Breakdown Structure (PBS) that again focuses in on the design that must take place to deliver each of the multiple elements. Once these systems and sub-systems have been identified to a level of detail with which each member of the team feels comfortable, the final step is to populate the deepest level of the hierarchy with ‘design activities’. Workshop participants are again encouraged to generate a level of detail with which they feel comfortable. However, as a rule of thumb participants are asked to decompose activities to a point that they are no longer than the ‘reporting period’ that will be used during the design / engineering delivery phase (this is discussed later but it should be determined and agreed by the PM as early as possible in the process).

Post-it™ notes are used to structure the WBS, with a different colour being used to represent each functional group involved (this is particularly useful when using a functional breakdown as the starting point for the WBS). The group is briefed on the scope and nature of the project in advance to ensure that there is alignment in understanding. Each participant is then asked to use a separate post-it note to describe the system / sub-system to be designed (this is then referenced back to their scope of work to ensure that there are no gaps or overlaps in responsibility). When the deepest level of the hierarchy is reached, each participant is asked to write each design task that is involved in designing each sub-system on a separate Post-it note. A verb-noun format is used for this to ensure that ‘what needs to be done’ is included along with what it is being done to i.e., ‘structural columns’ is insufficient and should be replaced with, for example, ‘layout structural column grid’. Once all activities are defined they are stuck to a large wall space and shared with the rest of the team (see exhibit 1 above). This enables team members to ask questions and gain additional clarity if required. The process of defining activities and then sharing them with the group always leads to the addition of further post-it notes and some redefinition of existing activities. Once complete, however, the resulting WBS is annotated with a unique numbering system (to ensure that each activity has a unique reference) and becomes the basis for determining the information required to deliver each activity – the platform for production of the process network.

Capturing information requirements

The WBS simply provides a hierarchical representation of the design / engineering activity. To define the process requires the introduction of flow. In production this flow represents the physical movement of resources (people, materials, money) between areas of the site / specific tasks; in design this flow represents information (which can comprise decisions, responses, comments, and so on) moving between design / engineering stakeholders: the former is tangible, the latter is intangible.

Exhibit 2 - Collaborative development of information requirements for an activity

In capturing the information flows as inputs to the activities within the WBS the team is enabling the flow of information between the designers to be 'seen' – it is in effect making the intangible, tangible. It is important to recognize that the stakeholders do not only include designers – owners, sub-contractors, authorities having jurisdiction, and so on also play a key role in integrated project delivery. As such, activities such as reviews, sign-off, and approvals also need to be included.

In order to identify the information inputs to each activity, the individuals responsible for each activity are asked to think in 'ideal world' terms. That is to say, do not consider the last project on which they worked and only reference the information that was available to them on that occasion; instead, think about all of the information that they would ideally have if they could have started and completed the activity in one go without having to assume any input. In using this approach the initial network will represent the 'ideal world' process and as such, will enable the optimum sequence to be derived without any embedded constraints or assumptions. Each design activity is considered in turn and the information inputs are listed under three categories: i) information that is produced by a design function other than the one being considered; ii) information that is produced by the same function as the one being considered; and iii) information that comes from an external source (e.g., a manufacturers catalogue). Designers are encouraged to think about each activity in complete isolation (see exhibit 2 above) to ensure that focus is not redirected to the overall process. Once the designers have become accustomed to this way of thinking, the information requirements for each activity can be generated fairly quickly. It is also interesting to note that on many occasions this process identifies further gaps within the WBS, enabling voids to be filled and the WBS to be enhanced accordingly. Once all information dependencies have been listed, the source activity (that which produces the information) can be identified – these linkages providing the logic required to create the network. This same approach to identifying information inputs to enable activities to be completed with certainty is also applied to the management, permitting, and procurement elements of the hierarchy – the only difference being, for example, that an individual would be defining the information needed to tender a particular procurement package as opposed to identifying the information required to undertake a particular design activity. It is a simple but effective approach to process definition.

To reiterate an earlier point: the development of a robust representation of a complex process can be daunting and, as has been stated above, takes time and effort. However, once the network is defined it provides a true representation of the design / engineering process, complex as it is (see Exhibit 3 below for a graphical – directed graph – representation of the design process of a major construction project), and as such, provides the basis for determining the optimum delivery sequence.

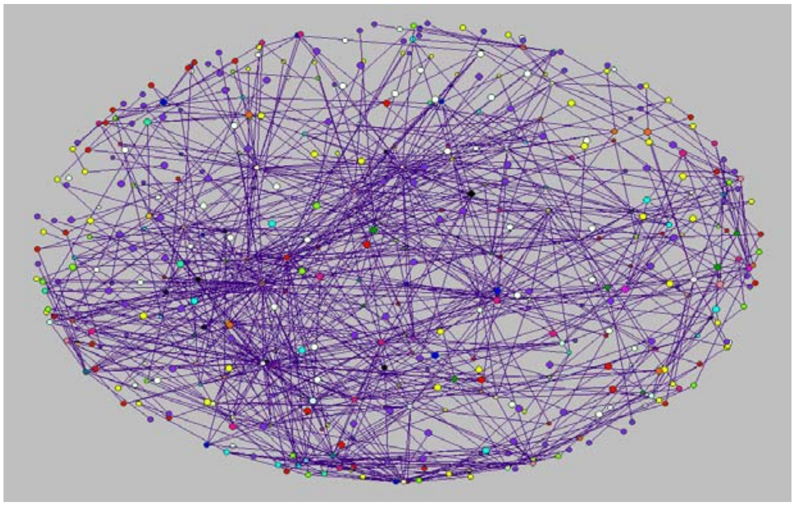

Exhibit 3 – The reality of the design / engineering process

It should also be noted that from as far back as the Egan report (1998) the design process has been identified as repeatable. Consequently, once a robust network of design / engineering activity has been defined it can be used as the starting point for any project thereafter - creating a data-library that can be both expanded and refined continuously as more projects are delivered. This significantly accelerates the network production process and supports continuous learning and process improvement at both a business and project level.

Process sequencing

Determining the optimum flow of information

Once the team has agreed the design / engineering network, the optimum sequence in which to undertake the work must be established. Many organizations apply a lean methodology known as 'reverse phase scheduling' or 'pull planning' (Ballard, 2000) to determine the optimum sequence of events that must be undertaken to achieve a pre-determined end goal. This involves identifying an end point (typically a milestone in scheduling terms) and then working backwards to determine what activities must be completed in what sequence to get there. Whilst this is a useful approach for optimizing linear processes, it can be problematic for design / engineering processes owing to their iterative nature. For example, teams can 'reverse phase schedule' through a series of design activities without realizing that they have pulled through an iterative loop and simply identified a single chain of events – in essence the approach can give highly iterative processes the appearance of being linear.

To overcome this, a different, yet complimentary, approach is utilized. The team is asked to initially identify those activities that have no predecessors (i.e., need no information in order to be progressed) and these become the anchors for the 'start' of the process. Owing to the fact that each of the activities within the network has its information requirements defined, along with the activity which produces each piece of information, the next step simply involves the team locating the activities that can be undertaken using only the information that has been produced by the preceding activities. As each activity is positioned relative to its information-producing predecessor, more information becomes available and activities can be located accordingly. This is a simple collaborative approach based on a detailed understanding of the ideal world sequence of events.

If this were a linear process this approach would continue until all activities were positioned (and it would provide the same sequence as if reverse phase scheduling were utilized). However, owing to the fact that the process is iterative, the team will quickly reach a point at which activities are interdependent (i.e., dependent upon information from one another) – this represents an iterative loop. The scale of these iterative loops can vary from two activities – which cause little problem for the team – to many hundreds of activities – which are far more difficult to reconcile in practice and can leave the team in a state of uncertainty over how to proceed (see exhibit 4 below).

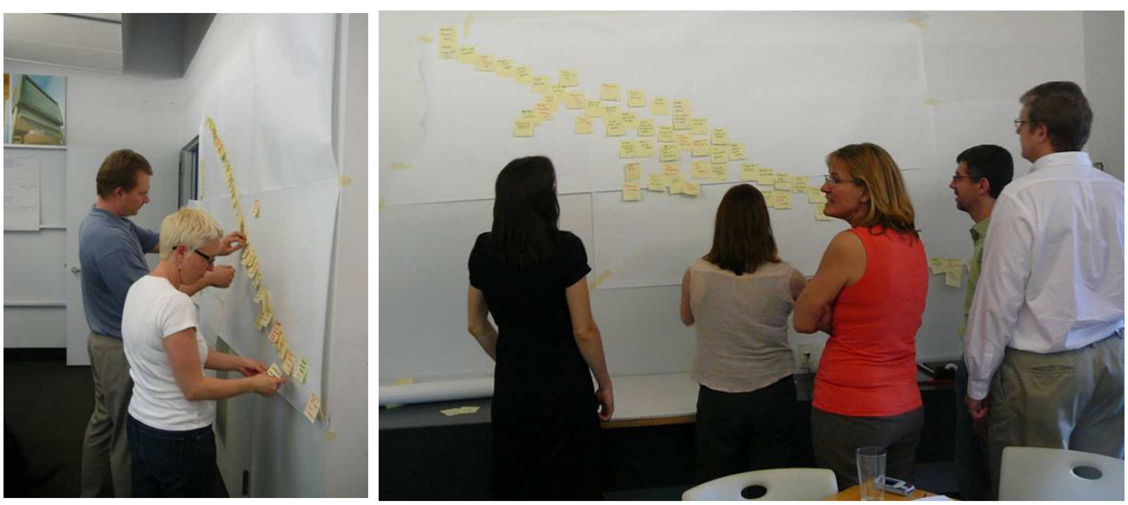

Exhibit 4 – Working collaboratively to sequence activity before finding an iterative loop

The value of the approach, however, is to find these iterations in the process as it is here that tactics can be applied to focus the collective understanding and expertise of the team on determining the scale of the iteration and how it can be worked through once the project proceeds. There are many tactics that can be applied to address, or further breakdown, an iterative cycle. Irrespective of the tactic that is applied (e.g., to create zoning strategies in the horizontal or vertical dimension to ensure that systems will never clash with one another as long as they are designed within the dimensions set by their zone), the agreement on, and commitment to, this decision by all parties is of paramount importance, as when the design process commences this decision will have to be adhered to by all members of the team if disruption is to be avoided. For this reason: the reasoning behind all 'process-based' decisions must be captured and maintained to ensure that rationale is available for reference when implementing the schedule once the process is in motion (these are sometime referred to as 'tear' registers and become the basis for the project 'Design / Engineering' risk register).

It is important to recognize that the aim of this approach is not to remove all of the iteration from the design / engineering process; to do this would reduce design to a linear production process. It is simply to reduce the volume of activities that are held within any single, iterative loop and instead, focus the iteration into smaller, manageable 'chunks'. Owing to the fact that information flow dictates the whereabouts of the iterative loops and informs decisions that will result in a focusing of design effort, the negative iteration (that typically results in wasteful re-work cycles) associated with out of sequence design / decision-making is already removed. The iterative loops that remain tend to represent highly integrated sets of systems / sub-systems – with the activities held within the loop (see exhibit 5 below) being owned by a number of functional groups and as such, requiring integrated collaborative design to ensure coordination, integration and to prevent clashes as the design / engineering solution evolves. Once an iterative loop has been identified and its boundaries have been determined, it can be treated as a single, collaborative design exercise (for the purposes of scheduling). The process of identifying the next activity in the sequence is then followed as described above - basically, identifying which activity can now proceed with certainty given the information that has been produced by preceding activities.

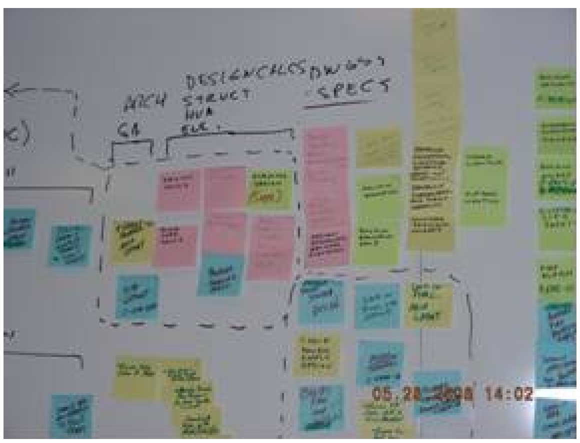

Exhibit 5 – An interdisciplinary iterative loop and working collaboratively to agree a tactical means of resolution

Avoiding unnecessary assumption-making

All too often, designers / engineers are forced to start and complete design without having all of the information that they need to do so with certainty. Unlike the construction process, where predecessor activities typically produce a tangible output, without which a successor activity cannot physically commence (e.g., two columns in place enable the placement of a beam), design is dependent upon information – which is intangible and thus, can be assumed if it is unavailable. A construction worker would not consider starting an activity if everything required to complete it was not available – doing so, if physically possible, would only serve to create delays and risk for the project. Conversely, designers are continuously pestered to produce 'documentation' to enable approvals to commence or work packages to be procured. As the drawing, as opposed to the information that it contains, is deemed to be the deliverable designers / engineers can be pressured into making 'guesses' about important pieces of design information in order for them to produce an output. In this respect, many designers believe that assumption-making 'comes with the territory' – whether it is a genuine necessity (i.e., the activity is part of an iterative loop) or just the result of poor planning (i.e., sub-optimal sequencing of work).

This type of ad hoc assumption making can have catastrophic effects on the overall project delivery process, particularly where fast-track delivery is utilized and design change can lead not only to re-worked design but also aborted manufacturing / construction. The primary reason for using information flow to drive the sequence of activities is to generate a process that ensures that the individual responsible for completing any activity has as much information as possible with which to complete their work – thus driving certainty into the design solution and reducing the risk of unnecessary re-working of the design / engineering process later in the project.

Converting the optimum sequence into a schedule

Introducing time

In order to convert the optimized sequence into a schedule, each activity must be allocated a duration and, if resource loading, an effort level. This is a fairly straight-forward process that can be undertaken prior to the sequencing of the activities i.e., within the WBS. Each function / owner is tasked with providing durations for the activities that they own. PMs should be aware that typical responses tend to suggest longer durations than necessary to complete a task – simply because: i) many designers are used to starting activities without sufficient information only to come back and complete them at a later time – thus allowance is made for this experience; and ii) designers may include time for re-working activities owing to the fact that historically re-working has been a standard practice. In practice, additional time allowance also reduces the pressure on the designer completing the work and as such, the addition of contingency is a tactic for reducing stress. An open and honest approach facilitated by a knowledgeable PM or facilitator can cut through this obfuscation and a realistic timeline can be developed within a standard scheduling tool (such as MSProject or Primavera P6) quickly and simply. These standard critical path based tools, however, are not capable of analyzing the true complexity of the design process as they do not enable backward flows of logic (i.e., the iteration within the process) to be represented. To accommodate the iterative loops within the CPM schedule each of the iterations must be scheduled and managed as a single phase of work (through the introduction of a hammock in effect) – these hammocks are renamed as ‘interdisciplinary coordination’ events / exercises and treated as such during the delivery process. This approach basically involves grouping activities together in the programme and running them concurrently over a window of time deemed sufficient to develop a co-ordinated design solution. Each group then represents a collaborative, cross-disciplinary period of work that is focused on developing a co-ordinated design solution.

The more significant challenge (and opportunity) lies in defining tactics to manage the design team as they work collaboratively on an interdependent design problem. There is no single solution as the number of activities to be completed, number of team members involved, and time required to develop the design will dictate the most suitable approach. What is important is that all of these issues are considered in determining and agreeing the most effective design approach. To reiterate an earlier point: recording the rationale and agreement using a standard procedure or method statement focuses the design team on these iterative co-ordination problems and provides rationale for how and why each period of concurrent working will be undertaken. Finally, owing to the flow of design information being the only logic driving the sequence, the start and end date for each activity is determined by the duration of each activity and only one other key constraint - the project start date. This is an important point to recognize given the large number of Requests for Proposal (RFPs) that now demand that schedules are provided in native file format – thus enabling owners to analyze the sequence and identify any constraints that may have been embedded to ‘force’ the schedule to fit the desired timescales.

Integrating design with construction

The approach to generating the design sequence provides the optimum means of completing the design process based on as much certain design information, and thus as few assumptions, as possible. However, whilst this does represent an inter-disciplinary design process and thus, is an ‘ideal world’ representation from a design perspective, it is not constrained by the realities of the construction sequence. Traditionally, the construction / build sequence is created using the reverse phase scheduling approach – which enables the key dates for work packages to start on site to be determined and creates the ‘critical’ start on site date for the project. Many PMs / planners simply apply the same approach to determining the design sequence, working backward from each work package’s ‘start on site’ date, assuming a lead time, and defining the design activity that needs to be completed to enable procurement – this gives a ‘start design’ date (which is often many months prior to the current date!). The problem with this approach is that it generates a linear stream of events that assumes design is unique to each work package. This is far from being the case, of course, as design information feeds multiple streams of work and thus, impacts many different design chains (Austin *et al*, 2001) throughout the project process. Accordingly, reverse phase scheduling from a single procurement point does not capture the true interrelatedness of design nor does it represent the wider-use of the information to progress multiple chains of events in the design and procurement process – the complexity of which was illustrated in Exhibit 3 previously.

As the design process is optimized for design and does not consider construction / build, it will be ideal for a traditional design-bid-build type contract (where design is complete before the build commences). However, it will be unrealistic for alternative delivery methods that require design and construction to be overlapped – creating a fast-track delivery process. In this instance, the design process cannot be optimized independent of the construction process; either one or both must be sub-optimized in order that they can be integrated to optimize the overall project delivery process – the goal being to always optimize the whole. Taking a building project as an example; the optimum means of designing the building is to work from the top down, working from the roof, through the structure, and ultimately sizing the foundations (so that they are sized as accurately as possible). However, buildings are built from the bottom up; with the placement of foundations being the starting point for erection of the frame. Consequently, if the design and construction processes are overlapped they do not naturally dovetail – in fact, far from it. The key to integrating design / engineering with build / construction lies in determining where the two phases clash (which is simply a result of how overlapped they are) and then resolving these clashes to create a streamlined flow of work through the project whilst recording, managing and mitigating any risk associated with necessary modifications to the delivery sequence.

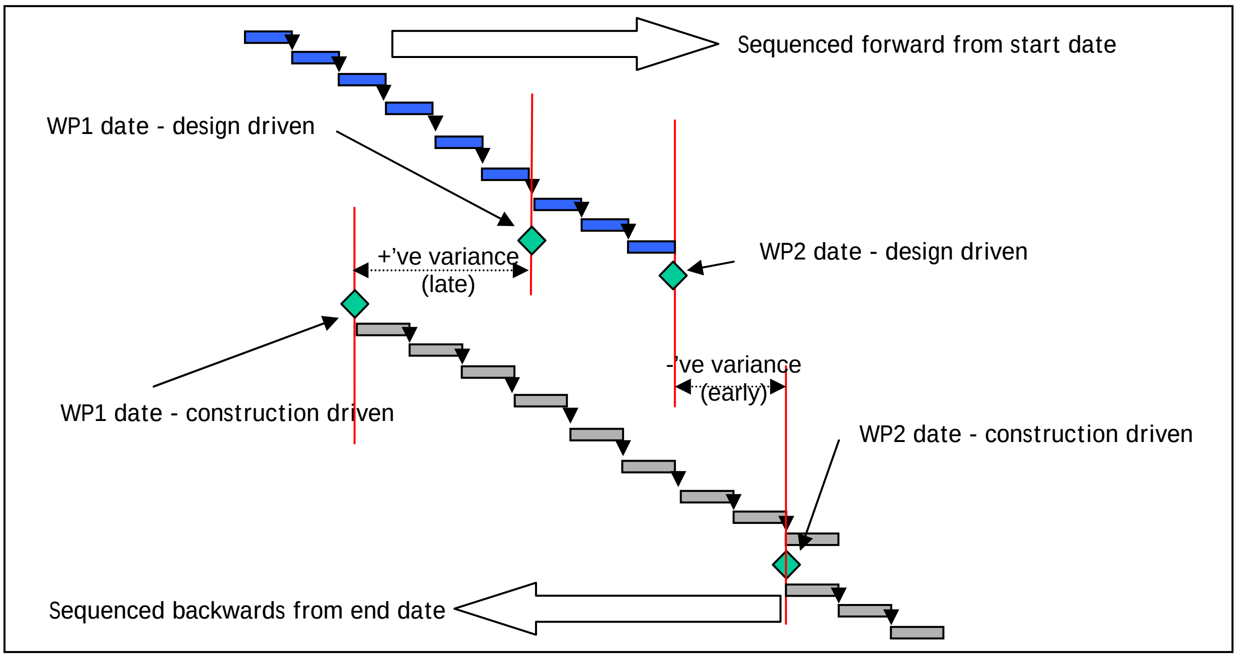

Exhibit 6 – Understanding the clashes between design and construction sequence

The procurement process represents the linkage between the two discrete phases of work and as such, provides the pivot through which integration is enabled. As each work package (WP) has been represented in the WBS and its information requirements were captured, it is simply represented as a milestone and sequenced along with all of the other activities. This sequence is driven by the flow of information and as such, each WP procurement milestone is dispersed throughout the programme at dates relative to the overall design activity – this creates a set of design-driven WP procurement dates. As has been described previously; the construction sequence has been determined using reverse phase scheduling so the flow of construction activity determines a start on site date for each work package – the construction-driven WP procurement dates. As the time taken for tender, selection, ordering and delivery for each work package is understood, the alignment between the design phases and the construction phase is basically determined by comparing the design-driven procurement dates with the construction-driven procurement dates – as shown in exhibit 6 above. There can be only 3-outcomes from this analysis: i) the dates align; ii) the design-driven date is earlier than the construction date; or iii) the design-driven date is later than the construction-driven date. Exhibit 7 provides an illustration of this analysis in practice. Each horizontal bar on the chart represents a WP with the vertical line against which they are placed representing the point of alignment between the design driven date and the construction driven date (outcome i. as described above). Where the bar is to the right of the vertical line the design-driven date is later than the construction driven date i.e., the design will be complete prior to the date that it is required for construction – there is no problem. Where the bar is to the left of the vertical line the design-driven date is later than the construction driven date i.e., the design cannot be completed in time to procure the WP with certainty – they are misaligned and there is a problem.

The project team can now focus their collective efforts on agreeing how to resolve the clash points. Typically, this is a case of identifying where information can be assumed without risk, or decisions can be made with certainty, to ensure that WPs can be procured and construction work can be commenced without risk of failure or re-work being required. As these decisions are agreed by the team, activities can be moved earlier in time (as the information that would be required has now been replaced with a decision on how to proceed without risk) and thus, brought into alignment

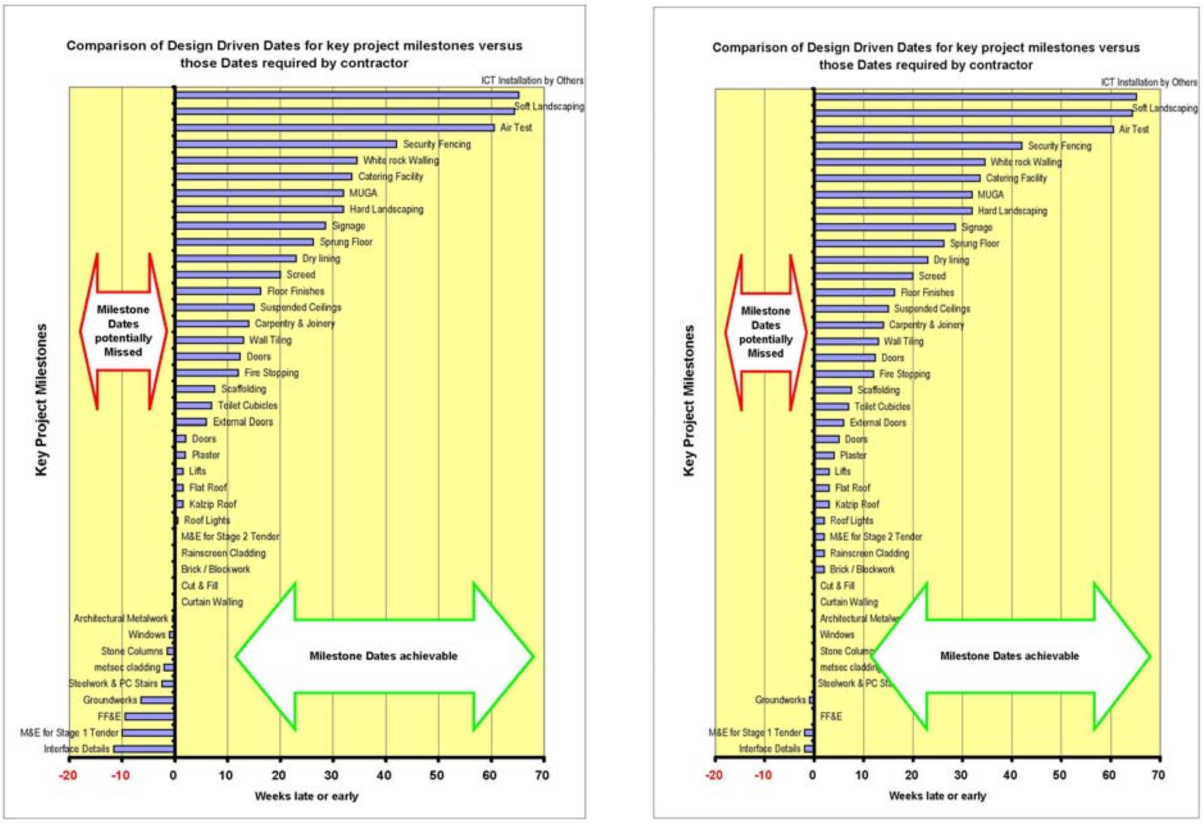

Exhibit 7 – Comparison of WP procurement clashes before streamlining and after re-sequencing

The illustration on the right of Exhibit 7 demonstrates the enhanced alignment that results from this process. As can be seen, it is not always possible to bring the design and construction sequences into perfect alignment but effort can be focused on those few WPs that are not aligned and appropriate tactics can be employed (e.g., negotiation of shorter lead times). Once this process is complete, the project team has an integrated project schedule which can be utilized to monitor, manage and control the delivery process.

Managing, monitoring and controlling the project delivery process

In utilizing a collaborative approach to defining the project delivery process it would be anticipated that the team will be far more focused on working to the integrated process than if they were simply handed a schedule to follow. Whilst this process does create a lot more affinity with the schedule, it is interesting to note that if engineers / designers are not guided and managed they tend to disregard the optimum process in favour of selecting activities to undertake based on preference, experience and in many cases 'gut feel'. All too often this type of deviation from the integrated schedule by one individual engineer / designer results in other's using incorrect information (as many information requirements may have been assumed by the person undertaking the prior task) and being forced to undertake their design in a sub-optimal manner. Once this is allowed to occur, it become almost impossible to implement action to get the process back to the target schedule and the deviation increases to the point where the ongoing process is unworkable. Experience has shown that many conventionally planned projects suffer from this problem. Therefore, having produced a target design schedule, the process needs to be managed, controlled, and monitored if the project is to be delivered to it successfully.

Owing to the definition achieved in the design and procurement phases of the schedule, as well as the construction phase, when determining the integrated project process, management and control approaches that have been commonplace in other industries (including construction), yet are, traditionally, perceived as being unusable in design / engineering, can be implemented during the entire project delivery process. Production control principles, such as Last Planner™ (Ballard, 2001), dictate that an activity should not be undertaken until everything that is needed to complete it is available – closing out activities being the primary driver here. Yet in engineering / design those activities that fall within an iterative loop (i.e., are interdependent) do not have all of the information needed to start and complete them and as such, they will never be made ready – thus, the need to make assumptions or work collaboratively with others in order to proceed. As these iterative loops have been identified, the activities within them are known, and they have been scheduled accordingly, production control principles can be applied.

The schedule is split into a number of equal work periods – the duration of the work period being agreed between the members of the project team earlier in the process – as the WBS is developed ideally. The overall schedule is then simply divided into a number of equal work periods, resulting in each work period containing a piece of the overall work plan. To initiate the delivery of the schedule, the designers that own activities within the first work period are asked to proceed with design and feedback their level of completion by the start of the next work period. In this way the team members focus their effort on a small piece of the overall schedule, completing the activities in the sequence and timescales defined by the schedule as opposed to looking ahead and undertaking activities that they would like to do. In this way, the ongoing rate of production of all stakeholders / team members is dictated by the integrated schedule – allowing their performance against schedule to be monitored and reported to ensure their rate of production is synchronized and controlled throughout. All too often, individual designers believe that they are adding-value by getting ahead of schedule (i.e., increasing their rate of production to do more design than planned). However, when the work of the team is integrated into a single, integrated process, the only way that an individual can accelerate their work independent of their team mates is by making assumptions about the information produced by others. As stated before, this creates risk and can lead to re-work and abortive work – in effect, the individual is compromising the design process rather than helping it. The focus of the team must be always to maintain their collective rate of production in line with the schedule and focus on optimizing the whole over and above the individual parts. This approach is applied throughout the project (during design, procurement and construction) to monitor and report Percentage Plan complete (PPC) and Work in Progress (WIP).

Exhibit 8 – Project delivery performance dashboards

If, due to poor performance or unforeseen circumstance, work is not completed to plan in the work period, root cause analysis is undertaken and 'reasons for failure' are captured and logged. If an unforeseen circumstance occurs, the detailed understanding within the integrated project schedule allows the impact on future activity and key milestones to be quickly analysed and understood. Only once the true impact is understood is it possible to work collaboratively with all project participants to agree strategy and actions for bringing the schedule back into alignment with the key program milestones – this level of control is critical to the successful delivery of complex projects. Whilst this may be nothing new for the construction phase (the Lean Construction Institute has been promoting Last Planner™ for a decade now), it is highly innovative for the non-construction phases.

It is also important to augment the 'lagging measures' of how the team has done (PPC and WIP), with a lookahead planning approach – basically, working with the project team to look ahead into the schedule and identify any potential constraints that may stop them delivering in line with the integrated project schedule. To enable this: engineers / designers that are allocated activities to complete or progress in the current 'work period' are also asked to look ahead at the next 'work period' to identify any forthcoming activities that they believe cannot be completed and if so, the reasons why this is the case. In this way the team is managed to be proactive; to identify and share potential concerns that could result in schedule impacts so that actions can be taken in advance of the problem occurring (thus, moving the team's delivery and management focus from being reactive to being proactive). The process is then monitored on an incremental basis (the period between monitoring and reporting being determined by the scale, complexity and timescale of the project) with all performance data made transparent and communicated using visual 'performance Dashboards' – example data is illustrated in exhibit 8 above.

This ensures that the entire team knows 'where the project is' at any given time and that trends in performance are readily apparent. This workflow management and control approach is maintained throughout the delivery process. It provides key management data that helps predict future project team performance and allows the Project Manager to take appropriate action to maintain performance to schedule whilst reviewing and ensuring the quality of the asset being designed.

Practical Implementation & benefits

Although the methodology can be applied in the form describe herein, it can prove time consuming and inefficient – with much development, revision and issuing of hand-written notes prior to replication and reproduction in electronic format. Accordingly, software applications have been developed, ADePT *Design Builder*™ and ADePT *Design Manager*™, to enable the implementation of the methodology in practice and, through the use of matrix analysis, eradicate the need for the time consuming process of manual optimization whilst avoiding double handling of data.

This methodology and the associated software has been applied on many projects and data has been generated to demonstrate how the delivery schedules for projects using this approach have achieved and bettered project delivery timescales when compared with earlier projects that applied more 'traditional' approaches to scheduling and project management (Capita Symonds, 2007). This demonstrates the power of the approach and also provides invaluable insights into its value to one-off projects as well as enabling continuous process / performance improvement over multi-project programs of work. Independent assessment of benefits has identified largely common areas of impact, including:

- Identifies and removes "turbulence" from the project process
- Provides greater certainty of design co-ordination;
- Offers an ability to better prioritise design work;
- Integrates sub-contractor design with consultant design in an effective way;
- Management of design change is more effective than is typically the case;
- Collaboration between design team members is improved;
- Workflow control focuses the team on task completion;
- Fosters a 'self-policing' design team; and
- The relationship between delivery of design and the design fee is made clear.

Three examples of these impacts which were quantified:

- Design co-ordination: 32 week saving on achieving co-ordinated design in one complex work package;

- Change management: at least 5 man-weeks saved in avoiding the knock-on effect of a single change; and
- Design outputs: approximately $150K saving where design fees were linked to achievement of design outputs.

It is clear from these examples that there are significant benefits to be derived from the implementation of the approach. Of course, these benefits are not derived without the essential input and buy-in of the project team; the team must be prepared to invest in the adoption of the new approach. This means staff time contributing to the design scheduling process and the costs of expert facilitation, training and, when utilizing technology, the supporting tools to deploy the technique. Nevertheless, a mounting body of evidence from diverse sectors such as construction, marine and 'Fast Moving Consumer Goods' suggests that this approach provides an opportunity to significantly enhance project delivery performance, management capability, and overall control in processes that necessarily combine iterative and linear phases of work.

References

Austin S.A, Baldwin A, Hammond J, Murray M, Root D, Thomson D, Thorpe A (2001). *Design Chains: A handbook for integrated collaborative design.* Thomas Telford Publishing.

DTI: Construction statistics annual report - 2007. (2007) UK Department of Trade and Industry.

Jackson B, Steele J.L, Waskett P.R (2008). *Managing design in Design-Build.* In DBIA Dateline, Journal of the Design Build Institute of America. September, 2008.

Egan J (2008). *Rethinking Construction*. UK Department of the Environment, Transport and the Regions, ISBN 1 85112 094 7 (1998).

Capita Symonds (2007). *Impact of ADePT*, Independent report produced for Adept Management Ltd, (2007).

Egan J (1998). *Rethinking Construction*. UK Department of the Environment, Transport and the Regions, ISBN 1 85112 094 7 (1998).

Ballard, G (2001). *Lean construction white paper: reverse phase scheduling*. Lean Construction Institute.

Ballard G, Nickerson R, Hammond J (2009). *Production Control Principles.* Proceedings of International Group for Lean Construction (IGLC) International conference. 2009.