Applications of Linear Scheduling Method for Nuclear Power Plant Construction

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ABSTRACT

According to a forecast, global energy demand is expected to increase by 44% from 2006 to 2030 (IEO 2009). The nuclear power plant construction market is also growing with sharper competition. In nuclear power plant construction, scheduling is one of the most important functions due to its mega size and heavy complexity. Therefore, it is crucial to incorporate the 'distinct characteristics of construction commodities' and the 'complex characteristics of scheduling techniques' when selecting appropriate schedule control methods for nuclear power plant construction. However, among various types of construction scheduling techniques, the traditional critical path method (CPM) has been used most often in real-world practice. In this context, the purpose of this paper is to examine the viability and effectiveness of linear scheduling method (LSM) applications for selective areas in nuclear power plant construction. First, in order to identify criteria for scheduling method selection, the characteristics of CPM and LSM were compared and analyzed through a literature review. Distinct characteristics of nuclear power plant construction were then explored through the use of a case project. Finally, promising areas for actual LSM application are suggested based on the proposed evaluation criteria and the case project. The findings and practical implications are discussed for further implementation.

Keywords: Nuclear Power Plant Construction, Scheduling, Linear Scheduling Method (LSM), Critical Path Method (CPM)

Global energy demand is expected to increase by 44% from 2006 to 2030 (IEO 2009). In developing countries, especially China and India, energy demand is expected to significantly increase. Due to the 2009 U.S. financial crisis, international crude oil prices surged to a slight slowdown. Another fact is the decreasing use of fossil fuels for energy due to environmental concerns. As a result, using oil for energy is expected to decrease to 32% by 2030. By contrast, the world's nuclear power generation was 2.7 trillion kWh in 2006 and is expected to increase to 3.0 trillion kWh by 2015 and 3.8 trillion kwh by 2030. Therefore, the nuclear power plant construction market is also growing with sharper competition. Under this intense competition, companies in the nuclear industry strive to enhance the quality, costs, and time for nuclear construction.

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In nuclear power plant construction, scheduling is one of the most important functions due to its mega size and heavy complexity. Therefore, it is crucial to incorporate the ‘distinct characteristics of construction commodities’ and the ‘complex characteristics of scheduling techniques’ when selecting appropriate schedule control methods for nuclear power plant construction. However, among the various types of construction scheduling techniques, the traditional critical path method (CPM) has been used most often in real-world practice. Using only one type of method may not be an effective way for these types of construction projects.

In this context, the purpose of this paper is to examine the viability and effectiveness of linear scheduling method (LSM) applications for selective areas in nuclear power plant construction. First, in order to identify criteria for scheduling method selection, the characteristics of CPM and LSM were compared and analyzed through a literature review. Distinct characteristics of nuclear power plant construction were then explored through the use of a case project. Finally, promising areas for LSM application are suggested based on the proposed evaluation criteria and the case project. The findings and practical implications are discussed for further implementation.

1. Breakdown structure for Nuclear power plant

Nuclear Plant Deployment Program Model (NPDPM 2008) provides a guideline for the entire process of nuclear power plant construction, including licensing procedures for construction companies in the U.S.A. The NPDPM defines hierarchical levels that can be used as construction activities. Depending on the complexity of management requirements, the level of work breakdown structure (WBS) is required to be determined. The WBS of NPDPM is analyzed in this study in order to develop evaluation criteria for the utilization of LSM in nuclear power plant construction.

Table 1. NPDPM Classifications (EPRI 2008)

NPDPM Level	Level I	Level II	Level III	Level IV
Classification Facet	Life Cycle (Phase)	Physical Break-down Structure (PBS)	Physical Break-down Structure (PBS)	Functional Breakdown Structure, or Commodity (FBS)

NPDPM (2008) Level I in Table 1 is a classification based on facility life cycle. This stage consists of seven phases that include “planning, design, procurement, construction, start-up, maintenance, and reload”. For the purpose of analyzing LSM application, the phase is limited within ‘construction phase’ in this paper. Level II conforms with the general form of physical breakdown structure (PBS) systems. Level II has “improvements, off-site improvement, nuclear island, auxiliary building, turbine island, rad waste building, control building”. Level III is a sub-level PBS, for example, consisting of “structural modules (below grade), structural modules (above grade), system modules, nuclear island construction testing” following each single facilities in Level II. In this study, the activities for LSM evaluation were selected based on Level III.

2. LSM adaptability for construction projects

LSM technique is effective for repeated and successive construction activities. (Yamin and Harmelink 2001; Soini et al. 2004, Kallantzis et al. 2007; Lucko 2008; Hegazy and Kamarah 2008) By contrast, critical path method (CPM) is apt to analyze a variety of complex occurrences of construction activities. As such, including scheduling methods, management techniques for each business functions each have their own distinct characteristics. Based on extensive research literature, this study identified 'process characteristics', 'spatial characteristics' and 'resource allocation' as three LSM assessment variables and detailed requirements were defined as six items. (Table 2)

Table 2 Assessment Measures for LSM Application

Variable	Measure	Definition
Process characteristic	Repetition of the same work types	Suitable if same processes is repeating
	Occurrence of concurrent works	Advantage by interference check for concurrent works
Spatial characteristic	Vertically or Horizontally continuous operation	Effectiveness by visualizing spatially continuous operations
	Density of work space	Suitable if workspace is not dense
Resource allocation	Equal distribution of resources	Suitable if productivity is stable
	Continuity of resources	Suitable if resources are required constantly

'Process characteristic' has two measures; 'repetition of same work types' and 'occurrence of concurrent works'. Clearly, LSM is effective for repetition of the same types of works (Yamin and Harmelink 2001). A good example is the construction of a skyscraper where same works are repeated vertically. The 'Occurrence of concurrent works' is an important feature for interference check process, and LSM is utilized more effectively for this feature. 'Space characteristic' is another effective perspective for LSM application as LSM itself clearly shows an inter-relationship between space and time. Using LSM for 'resource allocation' brings about the effects of shortening the construction period by maintaining the same productivity with an even distribution of labor, materials, and equipment. (Hsie et al. 2009)

3. LSM Assessment for nuclear power plant construction

A two-step assessment methodology for identifying appropriate activities for LSM application is developed in this study. The proposed methodology uses the two dimensions previously discussed in this paper. One dimension is the WBS of nuclear power plant construction in Table 1, the other dimension is LSM assessment measure as shown in Table 2. In order to effectively identify promising LSM areas, the first step examines an appropriate facility (e.g. reactor container building). The second step evaluates LSM suitable work sections (e.g. concrete work) by scheduling activity level.

3.1 Step 1: Appropriate facilities for LSM application in nuclear power plant

Nuclear power plant facilities are composed of “site improvements (SITE), nuclear island (RCB), auxiliary building (AUX), turbine island (TUB), rad waste building (RWB), control building (COB), yard structure (YARD)”. Work-sections were defined into six categories including ‘common temporary work, civil, architectural, mechanical, electrical, and piping’. Based on these six work sections, a total of 26 detailed commodities were defined, and these commodities were reviewed and confirmed by experts in this area.

Table 3. Assessment of Facility for LSM Application

Work-section	Commodity	Facility						
		SITE	RCB	AUX	TUB	RWB	COB	YARD
Common Temporary work	Crane installation	0	0	0	0	0	0	
	Foundation excavation	0	0	0	0	0	0	
Civil	Concrete foundation	0	0	0	0	0	0	
	Outdoor utilities							0
Architectural	Structural steel plate		@					
	Structural steel (Tendon)		@					
	Steel frame		@	0	0	0	0	
	Metals		@	0	0	0	0	
	Concrete pouring		@	0	0	0	0	
	Case work		@	0	0	0	0	
	Painting/Coating		@	0	0	0	0	
	Finishing		0	0	0	0	0	
Mechanical	General equipment		0	0	0	0	0	
	Steam condenser				0			
	Turbine generator				0			
	HAVC		0	0	0	0	0	
	NSSS		0					
	Tank							0
	Fuel rail		0	0		0		
Electrical	Electrical instrument		0	0	0	0	0	
	Electrical wire		0	0	0	0	0	
	Outdoor switching station							
	Security/communication							
	Instrumentation/Equipments							
Piping	Piping		@	0	0	0	0	
	Insulation		0	0	0	0	0	
Total		3	19	16	17	16	15	2

LEGEND: O: Commodities included in each facility.
@: Highly repetitive commodities in schedule.

A matrix for assessing facilities was developed as shown in Table 3 by using the 'facility' (e.g. SITE, RCB in Table 3) and 'commodity' (e.g. concrete pouring) dimensions. An initial trial evaluation was performed to see whether each facility has the same redundant activities based on 'process characteristics' in Table 2. Namely, a facility was reviewed for its number of subordinate commodities and the frequency of repeat activities for each commodity. For example, a nuclear island (RCB) as in Table 3 has 19 commodities as schedule activities. Among these 19 activities, eight activities marked with an @ have highly repetitive work processes. It should be noted that a nuclear power plant expert performed this evaluation.

Another issue is that the construction period of a RCB on the critical path has significant impact on the entire nuclear power plant construction schedule. Moreover, a RCB is the most important building for safety constructed under intensive management throughout the project. Therefore, a shortened construction period of a RCB can contribute positive results for the entire schedule. RCB was selected as the most promising LSM application area in this study.

Table 4 Assessment of Commodity for LSM Application

	Process characteristic		Spatial characteristic		Resource allocation	
Measure	Repetition of the same work types	Occurrence of concurrent works	Vertically/ horizontally continuous operation	Density of work space	Equal distribution of resources	Continuity of resources
Method	Times of repetition	Y/N	Y/N	Relative volume	Same labor	Buffering time
Score	None : 0 Under 10 times : 5 Over 10 times : 10	No : 0 Yes : 5	No : 0 Yes : 5	High : 0 Middle : 5 Low : 10	No : 0 Yes : 5	No : 0 Yes : 5

3.2 Step 2: Appropriate worksections for LSM application in Nuclear Power Plant

In the first step, a RCB was chosen as being the first priority. In the second step, for RCB, a subordinate 19 commodities were evaluated by using six measures as defined in Table 2. For each measure, measurement methods and units are defined as shown in Table 4. For the process characteristic variable, a measure of 'repetition of the same work types' was scored by the 'times of repetition' of each commodity in a facility. Scores for no repeat, under 10 times, over 10 times are 0, 5, and 10 respectively.

In 'spatial characteristic', 'vertically or horizontally continuous operation' is judged by yes or no. Comparing to the CPM technique, activities that have characteristics of continuous operation is more efficient by adopting LSM control. 'Density of work space' approaches the topic in terms of space management. In a congested space, many activities being performed at the same time may cause interference or decreased productivity. It is also an important issue to consider for the buffering of time and delays together. The measurement method for ‘density of work space’ is to evaluate the relative scope of work to the volume of workspace.

‘Equal distribution of resources’ are well addressed in relevant research titled “choosing a proper combination of production rates can effectively shorten the project duration” by Hsie et al. (2009). This paper focuses on the utilization of the same labor group as suggested by Hsie et al. (2009). ‘Continuity of resources’ evaluates the availability of buffering time. Due to the complexity of nuclear power plant construction, numerous stakeholders generate much construction and interference. Therefore, wait time process that occurs during construction should be managed within the planned construction period.

Table 5 LSM Assessment for RCB Scheduling Activities

Work-section	Commodity	Scores
Common temporary work	Crane installation	5
Civil	Foundation excavation	5
	Concrete foundation	15
	Outdoor utilities	10
Architectural	Structural steel plate	40
	Structural steel (Tendon)	40
	Steel frame	35
	Metals	35
	Concrete pouring	40
	Case work	40
	Painting/coating	25
	Finishing	0
Mechanical	General equipment	0
	Steam condenser	0
	Turbine generator	0
	HAVC	0
	NSSS	0
	Tank	0
	Fuel rail	0
Electrical/ Instrumentation	Electrical instrument	0
	Electrical wire	0
	Outdoor switching station	0
	Security/Communication	0
	Instrumentation/Equipment	0
Piping	Piping	25
	Heat insulation work	5

In a case-study with expert participation, nineteen commodities categorized into six work-sections for RCB were evaluated by using the assessment method shown in Table 4. Final scores for these commodities are summarized and listed in Table 5. For the measure of ‘repetition of same work types’, structural steel plate, structural steel (tendon), steel frame, metals, concrete pouring, case work, painting/coating, and piping were evaluated as high scores. In ‘occurrences concurrent work type’, six commodities obtained a high score including structural steel plate, structural steel (tendon), steel frame, concrete pouring, case work, and painting/coating. The result of ‘vertically or horizontally continuous operation’ is the same as the results for ‘repetition of same work types’. As for ‘density of work space’, the commodity of concrete (civil, architectural) were also evaluated with high scores. This means that a large volume required a relatively small working space during concrete works. ‘Equal distribution of resources’ appeared to be confined within the ‘architectural’ work-section. For the ‘continuity of resources’ measure, almost all commodities except for mechanical and electrical / instrumentation scored similarly. It is found that there is much interference between such activities.

4. Conclusion

The distinct characteristics of each project and its commodities should be thoroughly considered when selecting the most appropriate and effective management techniques. The unique characteristics of a nuclear power plant construction project include its mega size and heavy complexity. In this context, the purpose of this paper is to develop a methodology for selecting appropriate areas to apply LSM techniques in nuclear power plant construction

The proposed methodology has two major dimensions for assessment; one is the WBS of a nuclear power plant, and the other is LSM assessment measure identified in this study. Based on these two dimensions, detailed assessment methods and scales are developed. A two-step evaluation of LSM applicability for nuclear power plant construction was conducted as a case-study. Eight commodities in a nuclear island (RCB) that included structural steel plate, structural steel (tendon), steel frame, metals, concrete pouring, case work, painting/coating, and piping were selected as promising areas for LSM application.

This study is currently on-going, and further case studies will compare the CPM and LSM schedules for the chosen eight commodities. This would validate the proposed methodology. It is expected that the methodology and measures developed in this study can facilitate to increase efficiency and to reduce the project schedule for nuclear power plant construction projects.

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