프로그램 공정계획을 위한 주기적 버퍼 설치에 관한 고찰

A Study on Periodic Buffer Allocation for Program Master Schedule

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Abstract

In a dynamically changing environment, the manager of a maintenance and remodeling (M/R) program is confronted with an increasing complexity of coordinating and cooperating multi-resource constrained multiple projects. The root causes of the complexity, uncertainty and interdependence, cause an internal disruption of an activity and chain reactions of disturbance propagation that deteriorate the stability and manageability of the program. This paper evaluates previous endeavors to apply production control and management techniques to the construction industry, and investigates the possibility of applying other management concepts and theories to organizational program management. In particular, this paper proposes a buffer allocation model by which periodic buffers are allocated in the flows of program constraint resources to stabilize a program master schedule instead of protecting individual activities. Comparative experiments by Monte Carlo simulations illustrate improved performance of the proposed model in terms of program's goals: productivity, flexibility, and long-term stability.

Keywords : program management, uncertainty, disturbance propagation, buffer allocation

1. Introduction

1.1 Program Management

Time and cost are two important performance measures of a maintenance and remodeling (M/R) program in a large owner organization. To a great extent, the costs of M/R projects depend on project durations, and project delays are becoming a major management issue in the program. When the program undertakes multiple projects under the capacity constraints of multiple trade shops, a projects coordinator is confronted with the following two objectives: (1) timely completion of current/future projects and (2) efficient and stable utilization of multi-trade technicians. The complexity of coordination in the projects is increased by the uncertainties of a dynamic M/R environment. In contrast to external uncertainty (an unknown stream of project requests), the projects coordinator needs to manage the impact of internal uncertainty (unexpected delays of activities) across interdependent projects. An activity delay of one project causes negative ripple effects to subsequent activities of that project. To make matters worse, disruption of the activity and/or the projects tends to trigger chain reactions of disturbance propagation throughout the whole program. Even though a rolling horizon approach proposed by Koo and Russell (2000) has the derivative effect of terminating the propagation at the end of a scheduling window, the stability of the M/R program is still unprotected within the window. Then the question is how to develop a protection mechanism inside the scheduling window, preventing the propagation of the internal disturbance across the highly-linked structure of a program master schedule.

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1.2 Problem Statement

Among studies in construction academia, Ballard and Howell (1998) introduced "shielding production" from workflow uncertainty through an individual buffer of each activity, and Tommelein et al. (1999) demonstrated the protection mechanism of individual buffers in a linear production process. In this individual buffering model, the schedule of each activity maintain an individual time buffer to the extent that all production units practice shielding and consequently become more reliable at keeping their near-term commitments (Ballard and Howell 1998, p. 16). If all production units practice shielding, however, total productivity of a program inevitably decreases and its duration increases. Moreover, the individual buffer is often exhausted by the disruption or delay of an activity, and a process containing sequential activities would not be protected from propagation of the disturbance. Since the buffering model focused on stabilization of a single-trade process or single-project, management of multi-resources constrained multiple projects was not considered from an organizational program view as much.

1.3 Objectives

Given the limitation of applying the individual buffering model to an M/R program, a way that makes the program master schedule of multiple projects predictable and manageable is allocating strategic time buffers in organizational resource flows. The predictability provides a mechanism of coordinating the overall progress of multi-projects, and gives opportunity to resolve problems with more confidence for further organization-wide management decisions. The objective of this paper, therefore, is to present a buffer allocation model that protects a program master schedule from the internal uncertainty of activity disturbance and its propagation. The buffering model enables program management to improve stability and predictability of the global progress rather than individual activities, while sustaining flexibility and productivity of the program.

2. Allocation of Time Buffer

According to the normal probability theorem, if the mean (μ_i) is used to represent the duration of activity i, the probability of activity completion less than μ_i is 50% (Moder, et al. 1983), that is, the possibility of delay is also 50%. To decrease the expected delay of the activity completion, if the estimate of the activity duration is increased up to ($\mu_i+\sigma_i$, where σ_i = standard deviation of the activity duration), the probability of activity completion within the increased estimate will be 84.13%. The individual buffering system explicitly allocates a time buffer (Δ_j) just after the schedule of an activity whose duration is μ_j.

Umble and Srikanth (1990) demonstrate that the individual buffering does not protect the whole process from a delay of a down-stream activity if the delay is larger than the capacity of an individual buffer. When the last activity of a five-activity project is delayed over the capacity of its buffer, as an example, the on-time commitment of project completion will not be accomplished despite protection premium of decreased productivity. To overcome the limited protection performance of the individual buffering, Goldratt (1997) proposed a process configuration with a project buffer. In the configuration, a mean value (μ) represents duration of each activity, and a pooled buffer ($\Sigma\Delta$) is allocated just before the delivery of a project. The project buffering focuses on improving possibility of timely project delivery, instead of directly protecting individual activities.

3. Rethinking the Project Buffer

The uncertainty and interdependence of the M/R program, however, makes it difficult to directly apply the single-process oriented project buffering to multiple projects. Even though allocating the entire buffer at the end of a project schedule assures the commitment date of each project, it may not terminate chain reactions of a disturbance that propagates beyond the project through resource sequences.

For easy description of the chain reactions, this section considers a sample program model of four

M/R projects and three trade shops. Figure 1 presents a *program Gantt chart* of the program model based on time-scaled activity-on-node scheme. The program master schedule of scheduling window $\overline{T_1T_3}$ was generated by the PCR scheduling algorithm, and the detailed description of the algorithm can be found in Koo (2000). Only for simplicity of the description, the trade shops are referred to as shops E (electric), M (mechanical), and C (carpenter). Also, it is assumed that there is one unit of technician available in each shop. If activity E1 of project 1 is delayed, for example, the delay will be propagated not only through the activity precedence of the project (i.e., E1>>M1>>C1>B1[2], where B1 is the project buffer of P1), but also through the resource sequence of trade shop E (e.g., E1>>E2).

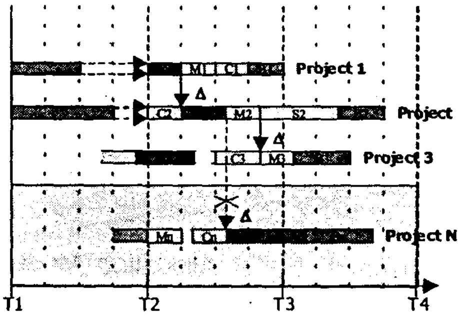

Figure 1. Propagation of Disturbance across M/R Projects (Koo and Russell 2000)

Subsequent delays through the dual passages of propagation, therefore, will delay all downstream activities of concurrent projects, and deteriorate the stability and predictability of the whole program. From an organizational view of coordinating multiple projects, if the disturbance propagation is not controlled by other stabilization mechanism (i.e., rescheduling the whole program or additional protection), the highly linked program may meet management chaos.

4. Periodic Buffer Allocation Model

4.1 Underlying Management Principles

The periodic buffer allocation (PBA) model that intends to overcome the limitation of the previous buffer allocation models, is facilitated by two principles: a period-based stabilization and "management by self-control"[3]. Since activities of current/future projects are executed by in-house technicians, stable and efficient management of resource sequences is the major interest of program management. In the PBA model, more emphasis is placed on long-term resource continuity in an M/R organization than ephemeral events of individual activities and projects. By periodically allocating time buffers in the flows of the resource sequences, any disturbance less than a capacity of a periodically pooled buffer wherever it was first activated, will only be propagated until the strategic buffer is reached. This termination mechanism will decrease the impact of the disturbance on the global program stability.

Between buffer points in the program master schedule, the technicians of multiple trades adjust and control detailed progress of M/R projects, when unexpected delays of activities and projects develop. PBA consists of a dual level management structure: (1) sequences and speed of major resource flows in the program are determined by top-down management decision at the time of scheduling, (2) detailed decisions are postponed as late as possible and made by actual players at the time of realization, based on the principle of management by self-control. The principles provide a program manager stable but flexible management of the program based on a mechanism of coordination and cooperation.

4.2 General Description of PBA Model

This section provides an overview of the rhythmical organization of the periodic buffers. Given the program master schedule in Figure 2, if

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[2] Giffler and Thompson (1960) introduced next-follows (<<) relations to describe active chain (p. 488, p. 493).

[3] Drucker (1954) defined management by self-control as the second principle of a philosophy of management with the management by objectives as the other principle (p. 136).

there is a delay at activity E of project 3 (P_3) or project 1 (P_1), disturbance from the delay will be propagated to activity E of P_4 through the resource sequence of electric shop (E). And this propagation will be continued to other activities of future projects that will be scheduled in period $\overline{T_2T_3}$. In Figure 2, a time buffer is allocated in the resource flow of the shop E that is the program resource with largest utilization demand against shop capacity within the given scheduling window. The time buffer in activity E of P_2, as a stabilizer, will prevent the *chain reactions* to subsequent activities of the electric shop (E) and the other shops' activities that have technical precedence relations. Allocation of the buffer *right-shifts* the schedule of activity M in P3, because it has a resource relation with activity M of P_2.

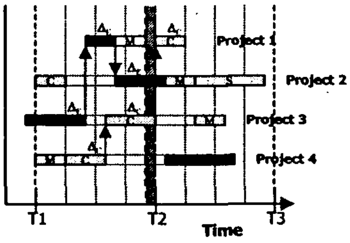
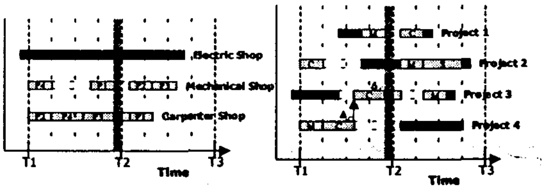


Figure 2. Periodic Buffer in Resource E: Program Gantt Chart

When activity C of P_4 is delayed, however, its disturbance propagates to P_3 and P_1. Since there is no buffer within the resource flow of carpenter shop (C), the chain reactions will propagate to downstream activities and projects. Another protection buffer is needed at the resource sequence of shop C, which is shown in Figure 3. The time buffers in the flows of resources E and C may be interpreted as a buffer zone around time T_2. The interval between adjacent buffer zones is set to two-weeks (King and Wilson 1967, p. 309) that is two times as that of weekly meetings among shop supervisors and a program manager.

There are two issues to be commented on in detail. First, no buffer is directly provided into the resource flow of shop M. Its schedule is subordinated to the schedules of shops E and C. The periodic buffers in the resource flows of shop E and C dichotomize the progress of the program at that point, and right-shift the program schedule as much as the size of the buffer zone. All resource flows of the schedules in a scheduling window, therefore, are consequently protected by the periodic buffers. Second, each project has a *delivery buffer* whose size is smaller than that of the project buffer. The delivery buffer copes with disturbances occurred only between the last buffer zone (e.g., T2) and the completion date of a project, and its size is smaller than or equal to the size of the buffer zone. One additional comment on the described buffering model is that the time scale of an actual activity is usually smaller than those of Figure 3. The above figures are only for a conceptual description of the developed buffer allocation model.



(a) Resource Schedule Chart (b) Program Gantt Chart

Figure 3. Periodic Buffers in E and C

4. Comparison of Buffer Allocation Models

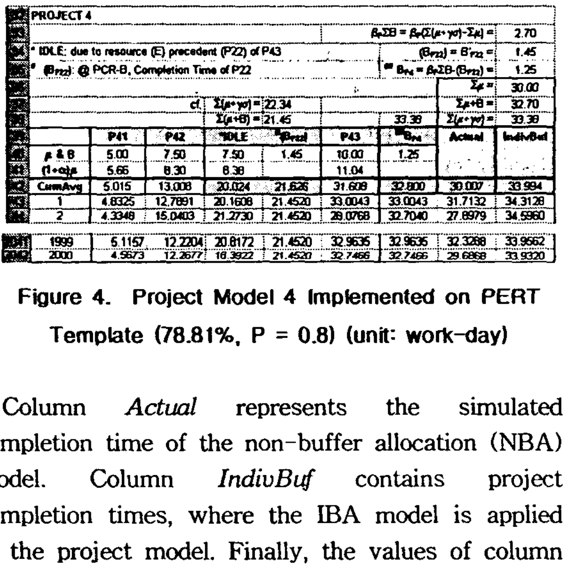
4.1 Monte Carlo Simulation For Stochastic Network Analysis

This study adopts Monte Carlo simulations to compare the performances of three buffer management models: (1) individual buffer allocation (IBA) model, (2) periodic buffer allocation (PBA) model, and (3) non-buffer allocation (NBA) model as the benchmark. In the Monte Carlo simulations, modeling stochastic distributions of the activity durations is essential to represent uncertainty of the durations (Aboukizk et al. 1991). Four types of distributions are used to generate random values for the activity durations: (1) PERT, (2) triangular, (3) uniform, and (4) normal distributions. The purpose of considering distribution types is to see their effects on the performance of the buffer allocation models.

4.2 Implementation of Program Model

A sample program model in Figure 3 is implemented in a common spreadsheet package, Microsoft Excel, for simulation experiments. While four delivery buffers of the M/R projects are shown in a project Gantt chart, both charts of Figure 3 contain the same size of two periodic buffers (B2 in the resource flow of trade shop E and B3 in the resource flow of trade shop C).

Figure 4 shows the simulation template of project 4 whose row represents each run for the experiment. The project template is constructed based on activity information of a PERT template. Row 40 (μ&B) contains average activity durations (μ), and row 41 (μ+νσ) has buffered activity durations. The values for PBA buffers are also put into the row 40.



PROJECT 4

$\beta_P\Sigma B = \beta_P(\Sigma(\mu+\gamma\sigma)-\Sigma\mu) =$ 2.70

* IDLE: due to resource (E) precedent (P22) of P43

$(B_{P22}) = B'_{P22} =$ 1.45

** (B_{P22}): @ PCR-B, Completion Time of P22

*** $B_{P4} = \beta_P\Sigma B-(B_{P22}) =$ 1.25

$\Sigma\mu =$ 30.00

cf. $\Sigma(\mu+\gamma\sigma) =$ 22.34

$\Sigma\mu+B =$ 32.70

$\Sigma(\mu+B) =$ 21.45

33.38

$\Sigma(\mu+\gamma\sigma) =$ 33.38

	P41	P42	*IDLE	**B_{P22}	P43	***B_{P4}	Actual	IndivBuf
μ & B	5.00	7.50	7.50	1.45	10.00	1.25		
$(1+\alpha)\mu$	5.66	8.30	8.38		11.04			
CumAvg	5.015	13.008	20.024	21.626	31.608	32.800	30.007	33.994
1	4.8325	12.7891	20.1608	21.4520	33.0043	33.0043	31.7132	34.3128
2	4.3348	15.0403	21.2730	21.4520	28.0768	32.7040	27.8979	34.5960
1999	5.1157	12.2204	20.8172	21.4520	32.9635	32.9635	32.3288	33.9562
2000	4.5673	12.2677	16.3922	21.4520	32.7466	32.7466	29.6868	33.9320

Figure 4. Project Model 4 Implemented on PERT Template (78.81%, P = 0.8) (unit: work-day)

Column *Actual* represents the simulated completion time of the non-buffer allocation (NBA) model. Column *IndivBuf* contains project completion times, where the IBA model is applied to the project model. Finally, the values of column BP4 represent the project completion times of the PBA model. The number of iterations is set to 2000 based on the study of Crandall (1977)[4], and the results of the iterations are presented from row 43 to row 2042. The average value of each column is included in row 42, *CumAvg*.

6. Discssion of Simulation Results

Due to the uncertainty and interdependency of the M/R program, a projects coordinator has experienced unexpected delay of an activity and disturbance propagation from the delay. The paper provided a framework of a coordination and cooperation mechanism for organizational goals: productivity, flexibility, and long-term stability. The periodic buffer allocation (PBA) model provided a control mechanism for the projects coordinator and the shop supervisors to adjust the progress of M/R projects within the buffer periods, when the internal uncertainty developed. Therefore, this rhythm-based flow management of PBA could stabilize the program master schedule by terminating propagation of an internal disturbance at safety zones of periodic buffers. The PBA model aims to improve the flexibility and practicality of the program master schedule based on technicians' *self-adjustment* and *self-control*, while preserving the productivity of the M/R program at smaller protection premium of the periodic buffers than individual activity buffers.

Monte Carlo experiments were simulated to compare the performance of the developed PBA model with the IBA model. A sample program model of four M/R projects constrained by the resource capacities of three trade shops was considered. The simulation variables of the experiments were: (1) stochastic distribution types of activity duration (normal, PERT, triangular, and uniform distribution), and (2) the size of allocated buffers (duration safety factor (γ) and periodic buffer ratio (β_P).

The simulation results on buffer allocation models are analyzed in terms of two major evaluation criteria: (1) average completion days, and (2) completion lateness. The first criterion represents the throughput performance of a buffer allocation model, and the second criterion evaluates protection performance and predictability of the model. The completion lateness was further divided to two sub-criteria: percentage late completion and average percentage lateness. Regardless of which distribution type of activity duration was applied to the experiments, PBA produced a smaller value of the average completion days than IBA proportionate to the periodic buffer ratio (β_P). The most interesting result of these experiments was

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[4] The study asserted that "the majority of information required by network analysis is available with sufficient accuracy with 1,000 iterations" (p. 393).

that PBA significantly improved the performance in terms of completion lateness criteria. Even though the total size of allocated periodic buffers was smaller than that of individual buffers ($\beta_P = 0.8$), for example, PBA significantly decreased percentage late completion and average percentage lateness in all experiments. In summary, the periodic buffer allocation model improved the productivity and predictability of the program schedule comparing to IBA.

The size of the periodic buffers, however, was not fully addressed in this paper. The buffer sizes were determined by a factorial design of two values (1.0 and 0.8) for simulation variables, duration safety factor (γ) and periodic buffer ratio (β_P). Since the main objective of the experiments was to evaluate the relative performance of the two buffer allocation strategies, the absolute sizes of the buffers were not studied as much. While the determination of actual buffer sizes depends on the experience and intuition of a program scheduler as well as historical data of similar activities and projects, a formal procedure for sizing the buffer needs further research.

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요 약

동적 변화가 상존하는 건설환경에서, 보수・리모델링 프로그램의 관리자는 자원하의 복수 프로젝트를 조정・관리하는데 어려움을 겪게 된다. 프로그램에 내재하는 불확실성과 상호종속성으로 인해, 단위작업의 지연과 그로 인한 연쇄적인 공정계획의 동요는 프로그램 전체의 안정성과 관리가능성을 저해한다. 본 논문은 먼저 건설관리에 적용되었던 생산관리기법들이 프로그램관리에 적용될 수 있는가를 살펴본 후, 프로그램 내부의 자원유동의 흐름에 주기적으로 버퍼를 설치하는 공정 안정화 모델을 제안하고자 한다. 몬테-칼로 시뮬레이션에 의한 비교실험으로 제안된 버퍼 관리모델의 성능을 프로그램의 생산성, 유연성, 그리고 안정성의 관점에서 분석하였다.

키워드: 프로그램관리, 불확실성, 공기지연, 연쇄적 파급, 버퍼설치