EMPIRICAL RESEARCH ON DEVIATIONS IN PRODUCTION AND CURRENT STATE OF PROJECT CONTROL

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ABSTRACT

Line-of-balance is a visual scheduling method which is suitable for construction projects because of their high degree of repetition. Line-of-balance allows the planner to explicitly account for flow of a project. To help effective project control line-of-balance enables drawing of actual lines next to the original plan. This allows for analysis of deviations during implementation. Forecasts can be made by continuing the actual lines with the same slope to show the total effect of deviations. If the forecast lines collide with each other, there will be problems as many crews will be working in the same physical space at the same time.

In this paper the main types of deviations and their effects are described with line-of-balance figures. Possible control actions and their effectiveness are examined. The prevalence of deviations and problems with production flow are shown by analysing the implementation on real projects which have the actual lines drawn next to the planned ones. The production rate deviations and interruptions of project flow were quantified. The main result of the research was that controlling of production and actively reacting to deviations is ineffective even if production start prerequisites exist. As a consequence, the production start prerequisites are lost for the succeeding tasks and the work flow is broken. The actual Line-of-Balance figures show graphically the resulting chaotic situation.

KEY WORDS

Line of balance, scheduling, schedule control, flow, control actions, deviations

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INTRODUCTION

The graphical line-of-balance scheduling method is a planning method for continuous flow of production. Advantages of line-of-balance scheduling for the General Contractor include less schedule risk because subcontractors can be kept on site, productivity benefits because the crews are less likely to interfere with each other and more realistic schedules as buffers can be easily planned and analysed (Kankainen & Seppänen 2003)

However, planning continuous flow doesn't guarantee that the project is implemented continuously. To achieve the benefits of flow, production must be controlled. With the Line-of-Balance method, it is possible to forecast when the space runs out for the following task and when control actions should be taken. The forecasts combined with actual and planned scheduling data provide the management powerful tool with which it is possible to detect critical deviations in order to plan a timely and optimal control action plan to preserve project flow.

Project control is both proactive and reactive. Proactive project control includes good preplanning of production, integrating procurement schedule with the master schedule and planning and achieving the prerequisites for starting work (making ready) (Kankainen & Sandvik 1993). The Last Planner System™ (Ballard 2000) concentrates on proactive control. It also has a reactive component: when weekly assignments are not realized, a root-cause analysis process is initiated to find the causes of planning failure. In addition reactive control should include estimating the total effect of deviation and taking control actions to minimize the effects of deviation on the flow of other tasks. Observations on site show that possible control actions include changing resources of a task, working overtime, changing sequence of task's locations or simultaneous production in multiple places (case schedules for this paper). All these control actions affect what CAN be done during the following weeks. If control actions are not taken, the Last Planners can achieve good PPC and at the same time destroy the prerequisites of continuing for the succeeding task. By taking control actions in time, it is possible to do more planned work, maintain good PPC and enable the following tasks to continue without disturbances.

This paper differs from other papers about LoB in its practical focus: this is an empirical study using actual data from projects which are using the LoB as the principal scheduling method. Earlier papers describe algorithms and heuristics to optimize continuity of resource use, to achieve duration cuts and to model learning curves (e.g Kang et al 2001, Arditi et al 2001, Harris & Ioannou 1998) While these papers give good theoretical foundation to the method, they don't describe utilization of these concepts in real projects.

In this paper typical deviations and their effects are illustrated with flow-line pictures. Possible control actions are shown and their effectiveness is analyzed. Finally, actual data gathered from a sample of six projects are analyzed. This is an ongoing study and the number of completed case projects is still small so the results are inconclusive and mainly descriptive. The final study will have 20 projects allowing more meaningful statistical analyses but most of the projects weren't yet completed.

DEVIATION TYPES

In the following figures, the basic types of deviations are shown with pictures. All deviation types are shown with two tasks in a project with five places. In one set of examples, the tasks have been synchronized (i.e. have the same durations, 25 shifts each). In another set of examples, the tasks aren't synchronized (duration of task 1 is 25 shifts, duration of task 2 is 19 shifts). In both sets of examples the start-up delay is ten days.

The first deviation type is that the preceding task starts late. (Fig 1) In the synchronized schedule this doesn't cause any immediate problems unless the delay is greater than the start-up delay. In unsynchronized schedule, there will be problems later and control actions are necessary. Deviation where the succeeding task starts early has the same results. This type of deviation can be prevented by good preplanning of procurement and by ensuring production start prerequisites through look-ahead planning and make-ready operations (Kankainen & Kolhonen 2004).

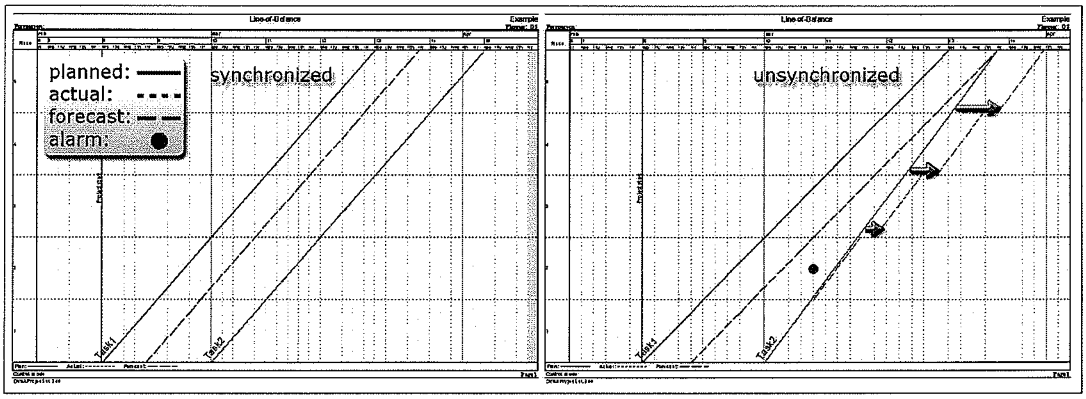

Figure 1: Effect of a start-up delay in synchronized and unsynchronized schedule

The second deviation type is the deviation in production rates. (Fig 2). Too slow production of the preceding task or too fast production of the succeeding task causes the succeeding task to lose its prerequisites of continuing in the future. The effect is more pronounced in the unsynchronized schedule. This type of deviation can be prevented by good preplanning of work based on quantities and labor consumptions in each place and controlling that enough men are available on site (Kankainen & Kolhonen 2004).

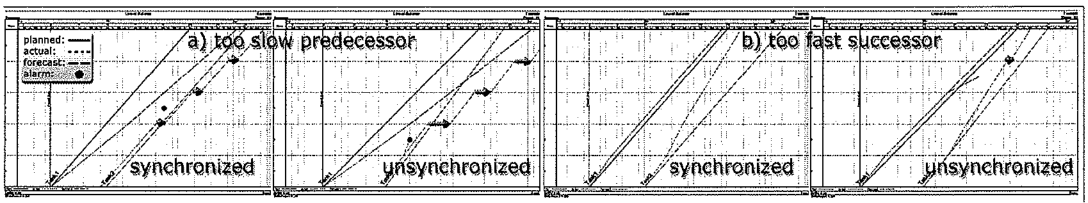

Figure 2: Effects of too slow predecessor (a) in synchronized and unsynchronized schedule and too fast successor (b) in synchronized and unsynchronized schedule

The third deviation type is the splitting of work to multiple locations at the same time (Fig 3). This results in locations being unfinished and the next trade can't begin work in the location. Finishing of work in locations slows down because resources are divided between places. This causes problems for the flow of succeeding tasks. This type of deviation can be prevented by good control of production flow and good contracts with subcontractors (Kankainen & Kolhonen 2004).

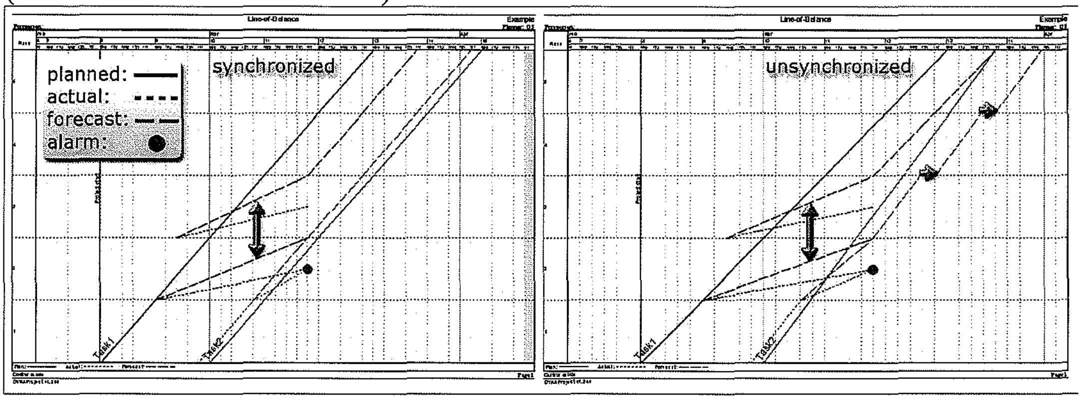

Figure 3: Effect of splitting work to multiple locations in synchronized and unsynchronized schedule

The fourth deviation type is wrong order of construction of places (Fig 4). This results in disruption of the next task's order of construction. This type of deviation can be prevented by effective control and tying payment schedule to completion of places instead of quantities (Kankainen & Kolhonen 2004).

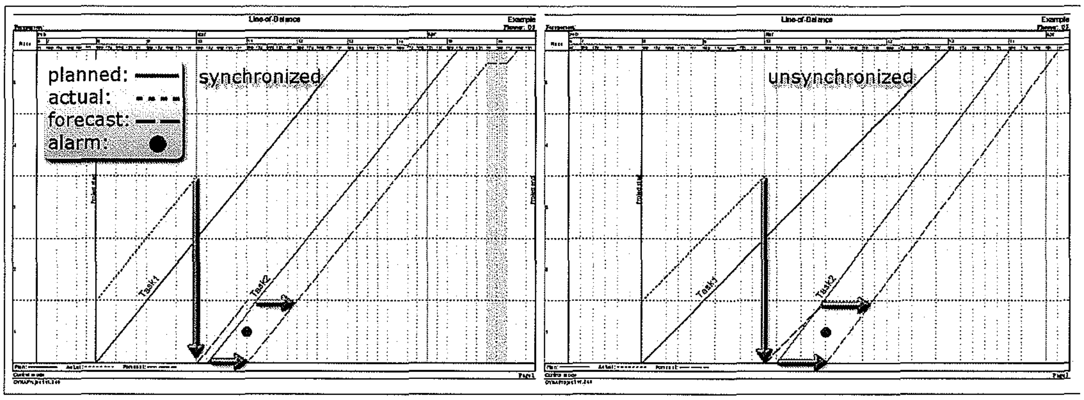

Figure 4: Effect of wrong order of completion of places in synchronized and unsynchronized schedule

CONTROL ACTION TYPES

In Line-of-Balance the effects of control actions can be analyzed by changing the slope of the forecast line. This enables preserving the original schedule and using it as the reporting tool of schedule while still facilitating control action optimization (Kankainen & Seppänen 2003). The possible control actions include working longer days, adding resources, changing the work content of the task, making task discontinuous, changing the construction order of the task and overlapping production in different locations.

Usually the best control actions are those which change the slope of the forecast line but preserve the continuity of the task. This is because the task remains continuous and is thus easier to control (Kiiras 1989) and the crews remain on site. This category of control actions includes adding resources (to the same location), working longer days or on weekends and decreasing the work content of the task. It is also possible to affect the slope by increasing productivity or by reducing non-value adding activities Figure 5 shows different control actions which affect the slope of the task.

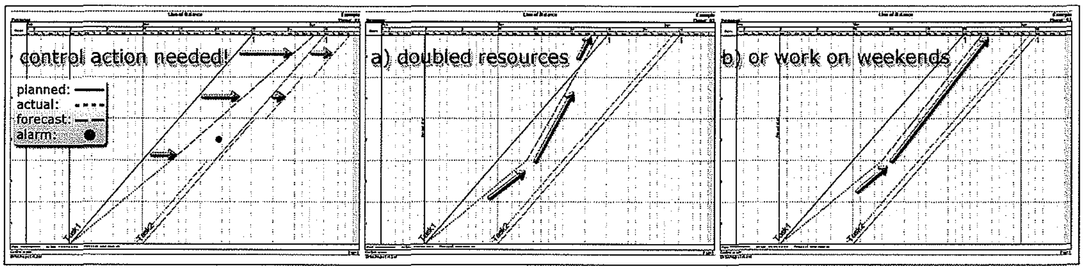

Figure 5: As a result of deviation control action is needed. In part a) the resources have been doubled in part b) work is done on weekends. Both control actions prevent the breaking of flow of succeeding task

Control actions which make tasks discontinuous, change the construction order of the task or increase resources so that work overlaps in different locations, tend to increase schedule risk of the project. Discontinous tasks are more difficult to control and the crews may not come back or the crew composition may change. Changing construction order often causes deviations in other tasks. Overlapping production in different locations makes it more difficult to control the progress and often increases chaos in the project. Figure 6 shows graphically examples of these.

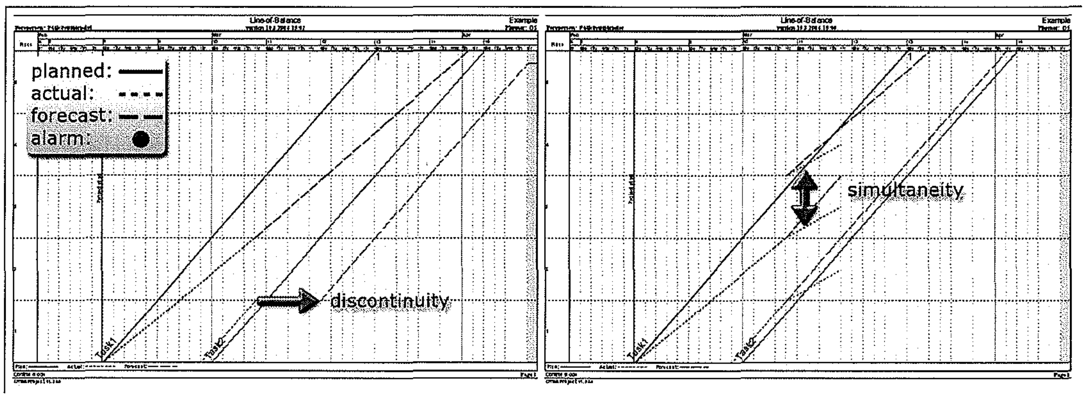

Figure 6: Disturbance caused by preceding task can be prevented by making succeeding task discontinuous or splitting the preceding task to proceed simultaneously in multiple locations. However, these control actions tend to increase project risk and to cause further disturbances.

In Figure 7, an actual project is shown. Left side of the figure shows the planned schedule for a few select tasks. Right side of the figure shows how the project was implemented. In the planned schedule there is a lot of overlapping work in sections, discontinuities of work, many tasks planned to be done at the same time in the same location and wrong implementation order between plasterwork and board walls in one location. Poor control and preplanning result in slowdowns and discontinuities. Plasterwork, which had been planned to be done simultaneously in many locations, is actually done continuously, which results in slowdowns of painting work and lots of wasted time between board walls and plasterwork.

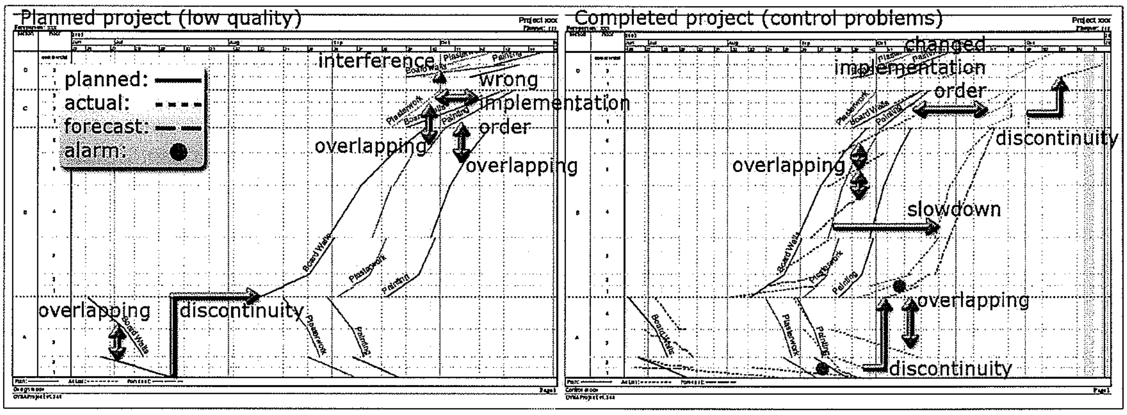

Figure 8: Problems in preplanning of flow (left) result in actual problems during implementation

METHODS

The data of this study was gathered from 6 real projects. The projects included 4 residential construction projects, a business park and a school building. The size of the projects varied from 3000 m2 to 24 500 m2.

The data gathering and analysis tool was DYNAProject™, a commercial line-of-balance based schedule planning and control system. The system was used by the site personnel to schedule and control the project. The schedules were planned based on quantities and resource use and controlled using the control chart (features of the software have been described in Kankainen & Seppänen 2003). DYNAProject automatically draws actual lines aside the planned ones, which makes it possible to localize deviations and infer control actions. The system also tracks the actual production rates compared to the planned production rates. The site entered start and finish date, actual quantities and actual resources used for every location.

The data was analyzed in three ways: using numerical information about actual production rates and quantities, by examining the deviations shown by the actual completion lines and by jumping backwards in time and examining the forecast lines as they appeared to the user. This was done by using DYNAProject's history feature, which has been implemented to facilitate this kind of research.

To be able to compare different projects a set of tasks which had similar work contents and schedule dependencies in every project were analyzed. The work content of tasks is explicitly planned in DYNAProject which enable comparisons across projects. The tasks included erection of the precast concrete framework, roofing work, concrete floor finishing work, board walls, wall and floor tiling, plasterwork, painting, floor covering work and furniture installation.

RESULTS

Implementation of the plan was analyzed by examining start-up delays (delta from plan), production rate deviations (number under 1 means slower than planned), actual interruptions of work (shifts of interrupted days) and actual delays (how much the task finished early or late). Table 1 below shows the variables grouped by the work type.

			Start-up delay				Production rate deviation				Interruptions				Final delay			
Task	Task ID	N	MIN	AVG	MAX	STD.	MIN	AVG	MAX	STD	MIN	AVG	MAX	STD	MIN	AVG	MAX	STD
PPC Framework	21	5	-1	0.6	2	1.34	0.92	1.02	1.13	0.08	0	1.2	3	1.6	0	2	7	3.08
Roofing	22	5	-3	1.6	7	4.16	0.65	1.2	1.63	0.42	0	20	42	20	-6	2.6	10	6.8
Concrete floor finishing work	30	3	3	7	14	6.09	0.71	0.73	0.75	0.02	13	31	47	17	13	21	29	8.02
Masonry	31	6	-4	3.7	16	7.4	0.28	0.89	1.46	0.4	0	5.2	13	6.1	3	19	32	12.1
Board walls	32	6	-29	-1.5	10	13.9	0.46	1.06	1.58	0.46	0	4.3	15	6	-6	11.2	11	10.3
Plasterwork	33	6	-10	2.3	10	7.2	0.81	1.02	1.5	0.26	0	4.7	14	6	2	15.3	40	13.4
Painting	34	6	-16	-5.8	4	7.6	0.76	0.89	1.14	0.17	0	8	26	9.5	-6	17.5	55	20.5
Tiling - Walls	35	4	-20	-3.5	11	13.2	0.39	0.69	1.01	0.26	0	8.5	30	15	10	27.3	60	22.3
Tiling - Floors	36	3	-24	-0.7	20	22.1	0.48	0.86	1.17	0.35	14	27	44	15	10	19.7	35	13.4
Floor covering work	37	6	-12	-1.5	8	8.4	0.66	1.09	1.94	0.45	0	12	27	10	5	14.8	30	10
Furniture installation	38	5	-4	0	2	2.4	0.69	0.79	1.05	0.15	0	4	10	4	0	20.6	40	15.2

Table 1: Start-up delay, production rate deviation, interruptions and final delay grouped by work type (average of all projects)

On average the start-up delays weren't a problem except for concrete floor finishing work. This is usually a result of erroneous scheduling because the dependency between roof work and concrete floor finishing work hasn't been taken into account which results in a start-up delay. To be noted is the fact that many tasks tended to begin on average before schedule (painting, tiling). However, the same tasks usually had lower production rate than planned and on average finished late which implies that crew size was smaller than planned or there were disturbances during work. Erection of building framework is well controlled in all of the projects with no notable deviations in start-up, production rates or interruptions in flow. Interior works were badly controlled. Even the first tasks (concrete floor finishing, masonry and board walls) tended to be late two to four weeks and the last tasks were on average four weeks late. The reason of finishing late was either production rate deviation (working with slower pace than planned), typical in painting and tiling work, or interruptions of flow, typical in painting and floor covering work.

In table 2 the same results are grouped by project taking an average over all tasks.

Project	Size	N	Start-up delay MIN	Start-up delay AVG	Start-up delay MAX	Start-up delay STD.	Production rate deviation MIN	Production rate deviation AVG	Production rate deviation MAX	Production rate deviation STD	Interruptions MIN	Interruptions AVG	Interruptions MAX	Interruptions STD	Final delay MIN	Final delay AVG	Final delay MAX	Final delay STD
Residential 1	4194	8	-11	3.75	10	6.96	0.65	1	1.58	0.32	0	0.88	3	1.25	-6	6.25	18	7.09
Residential 2	4742	8	-4	1.5	16	6.55	0.61	0.95	1.52	0.25	3	10.88	23	6.49	3	17	31	10.8
Residential 3	7687	11	-13	4.8	20	8.81	0.75	1.01	1.63	0.28	0	14.5	47	17	0	30	60	19.3
Residential 4	3000	11	-2	1.38	4	1.57	0.28	0.83	1.6	0.42	0	5.18	14	5.17	0	10.1	19	6.89
Business Park 1	24384	10	-29	-10.2	3	10.3	0.62	0.96	1.46	0.24	0	21.8	44	15.4	-6	11.7	20	8.9
School 1	7980	7	-20	-1.3	8	9.3	0.39	1.01	1.94	0.48	0	1.43	5	2.1	-6	10.7	32	12.6

Table 2: Start-up delay, production rate deviation, interruptions and final delay grouped by project (average of all work types)

Projects had differences in their strengths and weaknesses in terms of control. More complex projects (business park and school) have more room for workers, so it was more likely that production start prerequisites would exist in one or more locations which led to low probability of start-up delays (on average tasks started early). Most projects had average production rates on average similar to planned. Number of interruptions varied wildly between projects. This doesn't seem to be a factor of project complexity because some of the residential construction projects had on average two or three weeks of interruptions in each task! Tasks were on average late one to three weeks in every project, with notable exception of a residential construction project which had on average 6 weeks of finishing delays.

The results of descriptive data presented show that task start dates were on average well controlled. Interruptions in work flow were the biggest problem. However, there are great differences between projects.

Line-of-Balance scheduling aims at planning continuous work flow for crews. In table three the planned continuity and actual continuity are compared. Most of the works were planned to be continuous. Exception was roofing work because if there were many sections in the building, roofing would start immediately after the framework of a section was completed. Concrete floor finishing work was another understandable exception because concrete pouring is a very short duration activity in each location and the projects were big enough so that all concrete couldn't be poured in one day.

Task	Task ID	N	Planned continuity	Actual continuity
PPC Framework	21	5	100 %	66%
Roofing	22	5	40 %	40%
Concrete floor finishing work	30	3	33 %	0 %
Masonry	31	6	67 %	17 %
Board walls	32	6	83 %	50 %
Plasterwork	33	6	83 %	50 %
Painting	34	6	100 %	33 %
Tiling – Walls	35	4	50 %	50 %
Tiling – Floors	36	3	0 %	0 %
Floor covering work	37	6	83 %	17 %
Furniture installation	38	5	80 %	20 %
All tasks			71 %	33 %

Table 3: Planned and actual continuity grouped by work type as percentage of case projects

There are striking differences between projects (table 4). One residential construction project and school construction project were planned to be totally continuous. In these projects over 50 % of tasks in the study achieved work flow. Two of the residential construction projects had planned for work flow but implementation was poor (0 % and 27 %). In the business park and one of the residential construction projects work flow was planned on only 50 % or less of the tasks. It is interesting that in residential project 3, more tasks actually achieved work flow than were planned to have work flow. Overall, many benefits of planning continuous work weren't realized in the projects.

Project	Size	N	Planned continuity	Actual continuity
Residential 1	4194	8	100 %	63 %
Residential 2	4742	8	87,5%	0 %
Residential 3	7687	11	36 %	45 %
Residential 4	3000	11	73 %	27 %
Business Park	12438	410	50 %	10 %
School 1	7980	7	100 %	57 %
All projects			**71 %**	**33 %**

Table 4: Planned and actual continuity as percentage of tasks in the project

The second research question was which factors explain best the poor implementation of schedules. Interruptions of flow were identified to be very common so their causes were researched. Regression analysis using minimum buffer size[3], maximum buffer size, planned start-up delay and project size was run. The regression model explained 30 % of the variance.

[3] Minimum buffer size means number of days between predecessor and successor in a location where the tasks are nearest to each other

Maximum buffer sizes[4] and start-up delays didn't have significant effect. When minimum buffer sizes increase the interruptions decrease. When project size increases the amount of interruptions increase. Correlation between minimum buffer size to predecessor and interruptions was –0.391**, significant at 0.01 level. Planned start-up delays and maximum buffer size didn't significantly correlate with interruptions. These results show that it doesn't matter what the maximum buffer size is, because the optimum schedule of a task has the same amount of buffer in every location, i.e the schedule is synchronized.

In this study disturbances were divided into slowdowns, start-up delays and discontinuities. Disturbance is defined as a deviation which is caused by preceding task. In tables 5 and 6 the quantities of disturbances of each kind are shown grouped by task (table 5) and by project (table 6).

Task	Task ID	N	Start-up delay	Slowdown	Discontinuity
PPC Framework	21	5	40 %	0 %	0 %
Roofing	22	5	80 %	0 %	0 %
Concrete floor finishing work	30	3	33 %	33 %	33 %
Masonry	31	6	0	0 %	0 %
Board walls	32	6	33 %	17 %	17 %
Plasterwork	33	6	33 %	33 %	0 %
Painting	34	6	0 %	67 %	67 %
Tiling – Walls	35	4	50 %	75 %	25 %
Tiling – Floors	36	3	67 %	67 %	67 %
Floor covering work	37	6	33 %	50 %	67 %
Furniture installation	38	5	20 %	20 %	40 %
All tasks		**54**	**33 %**	**31 %**	**28 %**

Table 5: Percentage of projects which had disturbances in each task type.

Project	Size	N	Start-up delay	Slowdown	Discontinuity
Residential 1	4194	8	25 %	13 %	0 %
Residential 2	4742	8	25 %	13 %	25 %
Residential 3	7687	11	55 %	36 %	55 %
Residential 4	3000	11	64 %	36 %	45 %
Business Park 1	24384	10	0 %	70 %	20 %
School 1	7980	7	17 %	0 %	0 %
All projects		**54**	**33 %**	**31 %**	**28 %**

Table 6: Percentage of tasks which had disturbances in each project

Masonry walls was the only work which didn't have any disturbances caused by other tasks. The projects had significant differences. Residential construction projects 3 and 4 had high

[4] Maximum buffer size means number of days between predecessor and successor in a location where the tasks are farthers from each other

amounts of all disturbance types. The business park had a high amount of slowdowns but no start-up delays. School project was well in control and didn't have any slowdowns or discontinuities caused by other tasks.

A correlation analysis was run between disturbance types and the final delay. Starting tasks late correlated negatively with having slow-down disturbances (correlation –0.442**) which shows that starting as soon as possible can lead to slow-downs in the future. Of the disturbance types slowdowns and discontinuities affected tasks' end dates (correlations 0.357** and 0.383**), start-up delays didn't have statistically significant effects.

To assess the need for control two measures were used: forecast maximum delay and forecast disturbances on other tasks. DYNAProject™ calculates forecasts based on actual production rates. Dependencies between tasks shift the forecasts if predecessor is late. This causes alarms (or forecast disturbances) if the disturbance is forecast to happen in the near future. For each task the whole task history was checked and the worst possible forecast was recorded. Tables 7 and 8 show the results by task type and by project.

			Forecast max delay				Actual delay				Forecasted disturbances				Actual disturbances			
Task	**Task ID**	N	**MIN**	**AVG**	**MAX**	**STD.**	**MIN**	**AVG**	**MAX**	**STD**	**MIN**	**AVG**	**MAX**	**STD**	**MIN**	**AVG**	**MAX**	
PPC Framework	21	5	7	23	36	10.7	0	2	7	3.08	1	1.8	3	1.1	1	1	1	0
Roofing	22	5	4	26.6	70	25.4	-6	2.6	10	6.8	0	0.8	2	0.84	0	0.6	2	0.89
Concrete floor finishing work	30	3	14	27	37	11.8	13	21	29	8.02	0	1.3	3	1.53	0	1	2	1
Masonry	31	6	4	25.5	36	13.3	3	19	32	12.08	0	0.83	1	0.41	0	0.5	1	0.55
Board walls	32	6	8	21.8	44	13	-6	10.5	20	10.3	0	0.67	2	0.82	0	0.67	2	0.82
Plasterwork	33	6	6	47.3	93	31	2	15.3	40	13.4	0	1	2	0.63	0	0.5	1	0.55
Painting	34	6	16	50	96	30.3	-6	17.5	55	20.5	0	0.67	1	0.52	0	0.67	1	0.52
Tiling - Walls	35	4	19	60	100	33.07	10	27.3	60	22.3	0	2	3	1.4	0	2	3	1.4
Tiling - Floors	36	3	14	46.3	90	39.2	10	19.7	35	13.4	0	0.67	1	0.58	0	0.67	1	0.58
Floor covering work	37	6	12	46.7	96	32.9	5	14.8	30	10	0	0	0	0	0	0	0	0
Furniture installation	38	5	24	41.8	75	20.7	0	20.6	40	15.2	0	0.8	1	0.45	0	0.8	1	0.45

Table 7: Effectiveness of control by task type

All tasks were late in some part of their progress because minimum forecasted delay was over zero for all tasks. Comparison between forecast maximum delay and actual delay shows that some control actions were taken to catch up with the planned schedule, however the whole delay wasn't on average caught up. Control in terms of disturbances prevented was worse. Average actualized disturbances have very similar means with forecast disturbances which shows that control wasn't very effective.

			Forecast max delay				Actual delay				Forecasted disturbances				Actual disturbances			
Project	Size	N	MIN	AVG	MAX	STD.	MIN	AVG	MAX	STD	MIN	AVG	MAX	STD	MIN	AVG	MAX	
Residential 1	4194	8	10	17.8	25	4.9	-6	6.25	18	7.09	0	0.375	1	0.52	0	0.25	1	0.46
Residential 2	4742	8	20	38.75	55	13.5	3	17	31	10.8	0	0.5	1	0.53	0	0.5	1	0.53
Residential 3	7687	11	25	41.4	70	14.4	0	30	60	19.3	0	1.36	3	0.92	0	1.18	3	0.75
Residential 4	3000	11	4	12.6	24	6.7	0	10	19	6.9	0	1	3	0.89	0	0.9	3	0.94
Business Park 1	24384	10	24	63.8	100	33.5	-6	11.7	20	8.9	0	1.3	3	1.06	0	0.9	2	0.74
School 1	7980	7	8	54	75	24.3	-6	10.7	32	12.6	0	0.57	2	0.79	0	0.14	1	0.38

Table 8: Effectiveness of control by project

Projects had dramatic differences in effectiveness of control. The smallest project had small forecast maximum delays but the actual delays were almost the same, i.e. there was no catching up. The biggest project had large forecast maximum delays but was able to catch up very much of the delay. The school project was well controlled both in terms of final delay and in terms of disturbances.

Which factors affect the effectiveness of control? Effectiveness of control in terms of delay was calculated by subtracting the final delay from maximum forecast delay and dividing by maximum forecast delay. The effectiveness of control was negatively correlated with having discontinuities in the task (correlation –0.381**) and positively with project size (correlation 0.373**). Discontinuities seemed to be harder to recover from than from the other disturbance types. Effectiveness of control in terms of disturbances prevented was calculated similarly (percentage of forecast disturbances prevented). Here the correlations were smaller and less significant. There was a negative correlation with planned overlap (correlation –0.293*) and a positive one with planned minimum buffer size (correlation 0.271*). If the works were planned to be done in more than one location at the same time, the control was more difficult. Planning overlapping work is against the Line-of-Balance scheduling principles. (Kankainen & Sandvik 1993)

The case schedules revealed an interesting phenomenon: splitting of work to multiple locations. This has never been observed in such a large scale in Finnish studies, which possibly is caused by stronger schedule control focus of earlier studies (researcher was always on site and tried to optimize control). Significant correlations were found with start-up delay (-0.409**), actual implementation order (0 = not planned / 1 = planned, -0.482**), having to change implementation order because earlier task had changed implementation order (0.299*), forecast maximum delay (0.588**), project size (0.717**) and the number of actualized disturbances in the succeeding tasks (correlation 0.330*). Overlapping of production increased the number of actually occurring disturbances. By examining the schedules it was determined that most of the tasks with lots of overlapping had started as early as possible in the first available location. This control strategy caused disturbances in other tasks.

DISCUSSION

To writers' knowledge this is the first study where actual data has been systematically gathered and compared to the original plan using the Line-of-Balance method as the underlying model. The following interesting results were found:

- it is not enough to plan continuous work because without good control on site the work won't be implemented continuously
- starting as soon as possible results in slow-downs
- it is hardest to recover from discontinuities
- splitting work to multiple locations as a control action causes delays and disturbances in following tasks
- planning overlapping work in locations makes project control more difficult

The results support the aims of Lean Construction by giving supportive evidence to the need to control workflow reliability and the need for pull scheduling. They suggest that CPM is a flawed approach to schedule construction projects because it promotes starting as early as possible, it makes work discontinuous, it usually causes splitting work to multiple locations and the resulting problems. By using Line-of-Balance as a scheduling tool, it is possible to prevent all of the identified problems.

Because of the small amount of data and nonrepresentative sample at this stage, the results are mainly descriptive and can't be generalized to all projects. Cause – effect relationships can't be shown with the small sample. In the study the sites entered actual data for location start and end dates and actual quantities very well. However, no site entered the actual resources or actual lengths of work shifts. This makes it impossible to analyze productivity effects of disturbances. Taken control actions could have been entered to the system but they weren't, so researchers had to assume control actions from actual lines. The real reasons of interruptions are not known, only the deviations are known numerically. These issues decrease the validity of results.

In the future more data will be gathered. Finnish contractors are committed to supporting this research and will provide data when their current projects run with DYNAProject are finished. The aim is to get a representative sample of projects to be able to reach generalizable conclusions. From new projects, also resource data, cost data, quality data and client satisfaction data will be gathered. With more complete data it is possible to show cost and quality effects of schedule control.

CONCLUSION

A major problem in case projects was poor control, which is seen as disturbances of flow and splitting of production to multiple locations at the same time. Realization of start-up prerequisites doesn't seem to be a big problem. Securing work continuity is much more urgent. As a conclusion, it can be said that in addition to a proactive control mechanism, a reactive control action mechanism which forecasts disturbances and prompts for control actions is needed. Line-of-Balance based production control mechanisms provide such a tool.

The results of this paper support the writers' belief that Line-of-Balance should be adopted as the Lean planning method.

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