Modelling Time Buffers in Repetitive Building Projects: a Case Study

Francisco Orozco[1], Vicente González[2], Eduardo Maravilla[3]

Abstract

Variability management in construction using buffering-driven production strategies is an emerging issue among researchers and practitioners alike. In the last two decades, construction researchers and practitioners have provided a number of buffering approaches for managing variability in construction projects. However, there is a lack of practical approaches, preventing a widespread adoption of buffering-driven production strategies in the construction industry. To overcome these limitations, this research proposes a practical approach to mitigate the impacts from the variability produced in the activities duration of repetitive building projects. A repetitive project of 50 houses was analysed as a case study over a 9 months-period, collecting production data from ten construction activities. By simulating the case study, a different schedule approach other than the traditional one was proposed, isolating the beginning of each activity in order to protect the downstream activities from the upstream activities variability. This research shows that a practical approach for allocating Time Buffers was effectively developed. Further research should consolidate the buffering framework.

Keywords: lean construction, risk management, scheduling, time buffers, variability.

1. Introduction

Construction Projects seldom happen as ideally as planned. Nature's uncertainty induces variability to spoil plans and becomes a major factor affecting project performance and productivity. Variability leads to ineffective production, increased cycle times, increased cost, and derailed plans. In fact, variability is a "common-place" in production systems (Hopp and Spearman, 2000). In construction projects, variability comes up as the fluctuating behaviour of factors such as production rate, labour productivity, and construction schedules. The use of buffers is one of the ways to protect the performance of construction projects against the negative impacts of variability (González et al, 2009). Buffers can prevent the loss of throughput, wasted capacity, inflated cycle times, larger inventory levels, long lead times, and poor customer service by shielding a production system against variability (Hopp and Spearman, 2000). Several types of buffers exist: inventory buffers (e.g., materials, work-in-process, and finished goods), capacity buffers (e.g., in-excess labour and equipment capacity), and time buffers (e.g., time contingencies and floats) (González et al., 2011).

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[1]Universidad Panamericana, México, forozco@up.edu.mx.
[2]University of Auckland, New Zealand, v.gonzalez@auckland.ac.nz
[3]Universidad Panamericana, México, eduardo.maravilla@up.edu.mx.

In construction, there are certain links between different buffers that allow them to be easily managed. For instance, the correspondence of work-in-progress (WIP) buffers and time buffers can be found between consecutive and dependent activities in repetitive projects (Figure 1). This correspondence allows these buffers to be explicitly considered in the construction schedule of these projects (González et al., 2010).
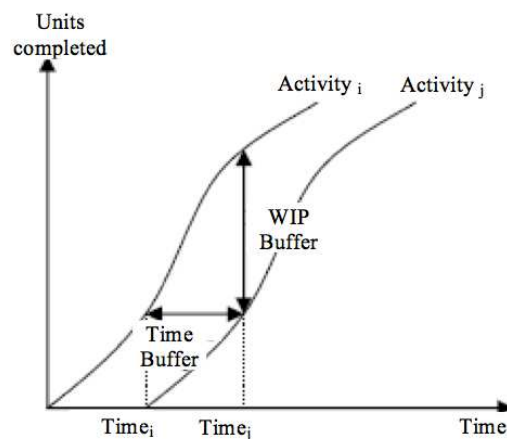
Figure 1. Types of buffers and their relationship (Adapted from González and Alarcón, 2003).

In the last two decades, construction researchers and practitioners have provided a number of buffering approaches for managing variability in construction projects, improving our understanding of the role of buffers as a production strategy in construction (Alarcón and Ashley, 1999; Goldratt, 1997; González et al. 2009, 2011 and 2012; Horman, 2000; Park and Peña-Mora, 2004; Tommelein et al. 1998; Walsh et al. 2007). These authors claim that a planned and deliberate use of buffers in construction has a positive impact on project performance. Buffering-driven production strategies can minimise the impacts of variability, thereby achieving significant reductions in lead times, waste and costs associated with projects. Horman (2000) suggests that when a buffer is used correctly, it not only provides a cushion or protection, but it also increases the ability to respond efficiently to changing conditions, and thus may be used to maintain or even increase system performance.

The use of contingencies or time buffers is a key issue when scheduling construction projects. Normally the scheduling techniques along with the management heuristics used to plan projects under or overestimate the size of the time buffers. For instance, the most typical scheduling technique is the Critical Path Method (CPM), which is deterministic in nature and neglects the variable nature of the construction activity durations. Otherwise, there are scheduling techniques that try to introduce uncertainty in the duration estimates such as the Program Evaluation and Review Technique (PERT), which represents a variation of the CPM networks. However, PERT is - to a certain extent – a "deterministic" technique because the same distribution of durations will be produced every time given the same input project data, so it is difficult to generate different production scenarios (Lu, 2002; Lu and AbouRizk, 2000; Barraza et al, 2000). As a result, it is hard to accurately estimate the

size of time buffers using deterministic approaches, when the production scenarios that are analysed are variable or "stochastic" in nature.

In the other hand, the traditional management heuristics in construction to manage buffers have been based mainly on intuition and experience of the decision-makers. This follows the typical management pattern in the construction industry, in which there is not record of successfully applying decision-making support methods (McGray, 2002). Therefore, construction practitioners still work with optimistic projections and use poor buffer mechanisms to protect construction processes from the negative impacts of variability (Gonzalez, 2009). In addition, there is a lack of practical methods to determine the size of buffers in construction, which prevents the application of buffering strategies in projects, negatively impacting project performance (Gonzalez et al, 2011; Park and Peña-Mora, 2004).

To overcome these limitations, this research proposes a practical approach to mitigate the impacts from the variability produced in the activities duration of repetitive building projects. This paper analyses, as a case study, a real repetitive project of 50 houses over a 9 months-period in Guadalajara-Mexico, collecting production data from ten construction activities. By simulating the case study, a different schedule approach other than the traditional one was proposed, isolating the beginning of each activity in order to protect the downstream activities from the upstream activities variability. This research shows that a practical approach for allocating Time Buffers can be effectively developed.

2. Research Methodology

Current studies shows that the construction industry is still affected by delays and cost overruns due to the difficulty of controlling variability in the processes. Although there have been efforts to control variability in construction, this has not been reduced enough in order to make projects more predictable (González and Alarcón, 2010). Reducing variability in construction activities is a complex task that can take a considerable time.

Commonly it is assumed that each activity begins when the previous one ends up. The typical approach is focused on reducing the variability at the end of the activities where variability is noticeable. However, this paper addresses a different perspective: to control the beginning of the activities instead of the end of them. If the beginnings of the activities are controlled, which is seemingly feasible, the variability of activities duration, which is visible at the end of the activities, will become much more manageable and estimates will be more reliable. It does not imply that the variability at the end of the activities will not be controlled, but this approach can produce a smoother and reliable progress of the activities.

The proposed approach in this paper is based on practical experience and observation of horizontal housing projects, and implies to control the start dates of the activities, which can be established by the general contractor, in order to manage the impact from variability. A time buffer between consecutive and interdependent activities (similar to that shown in Figure 1) has to be estimated in order to isolate them. Thus, the probability that a delay in an activity can affect the start of the next one is reduced.

A number of steps were followed to undertake this research:

1) The behaviour of each activity needs to be represented with a probability distribution. It is assumed that companies are able to fit the probability distributions for their own activities with their historic data.

2) The required time buffer between activities to provide a certain confidence level (e.g., 95%) that the activity "n" is not going to affect the activity "n+1" needs to be determined.

3) Repetitive projects can be easily scheduled using the "line-of-balance" method. However, this chart shows the progress of the activities assuming that the "units" (e.g. houses) are performed sequentially. The proposed approach suggests that the beginnings of the activities have to continue even if a previous unit has not been finished. Thus, two lines for each activity have to be plotted; one for the pace of its beginnings (completely straight with the speed determined by the management) and another for its finishes.

4) The amount of resources that would be demanded by this approach is going to be variable. So the proposed approach assumes to have all the necessary crews at any time over the execution of the project. Its effects will be explained in detail in the case study.

5) Finally, the amount of human resources demanded by the system is calculated in order to check the feasibility of the proposed approach.

3. Case Study

The proposed approach was tested with real data from a housing project composed by 50 houses, executed in the metropolitan area of Guadalajara, Mexico. Ten activities were chosen to be analysed. Their actual cumulative progress was measured and plotted on the line-of-balance chart shown in Figure 2, which presents in the horizontal axis the dates in which the different activities started and in the vertical axis the cumulative progress represented for the number of completed houses by each activity.
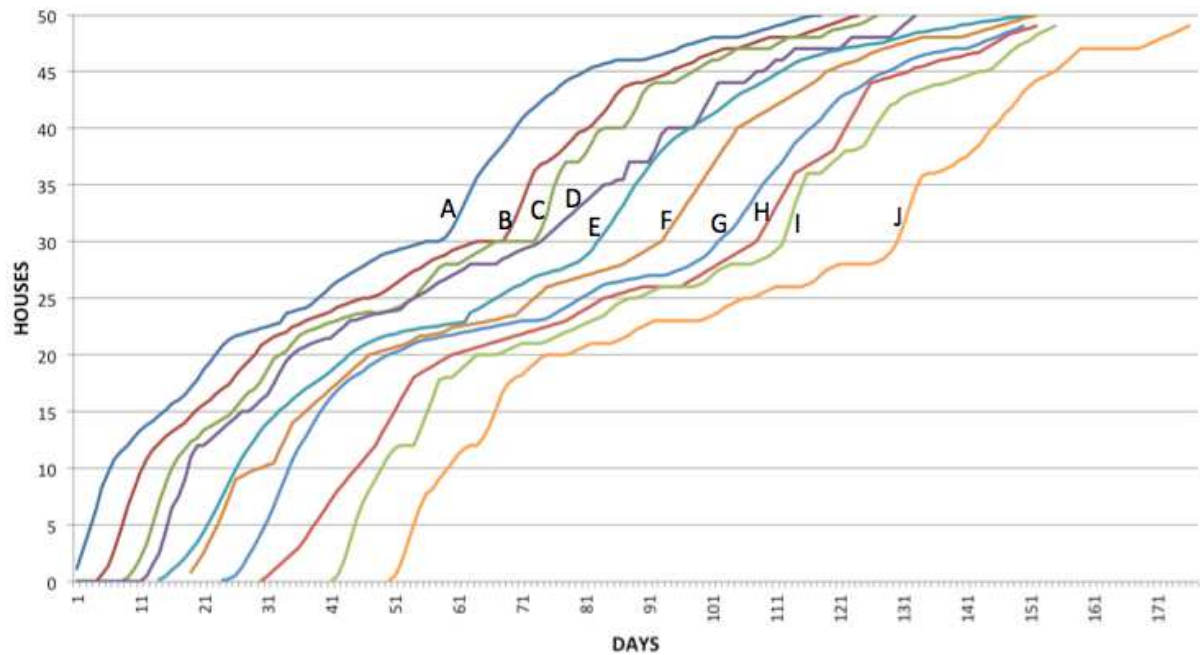
Figure 2. Line-of-balance chart shows the actual cumulative progress for ten activities.

The activities measured were (Figure 2):

A. Excavation and foundation
B. Levelling, strap footing beams and reinforced columns
C. Drainage system
D. Backfilling and compaction
E. First floor brick walls
F. First level roof pouring
G. Second floor brick walls
H. Second level roof pouring
I. Roof parapets
J. Roof waterproofing

Based on an unrealistic construction schedule with zero variability, it was plotted a line-of-balance chart that met the goals of the project developers, producing a progress pace of two houses a week for each activity (see Figure 3). As a result, an expectable term of 215 days was produced for the ten activities analysed. This "ideal" construction schedule provides a point of comparison in relation to the data collected and the further analysis to find out an "optimum" time buffer size. In practice, it is impossible to deliver a project with no variability. Thus, the ideal construction schedule also helps to understand how much the project analysed was disrupted because of the influence of the variability in the activities duration.
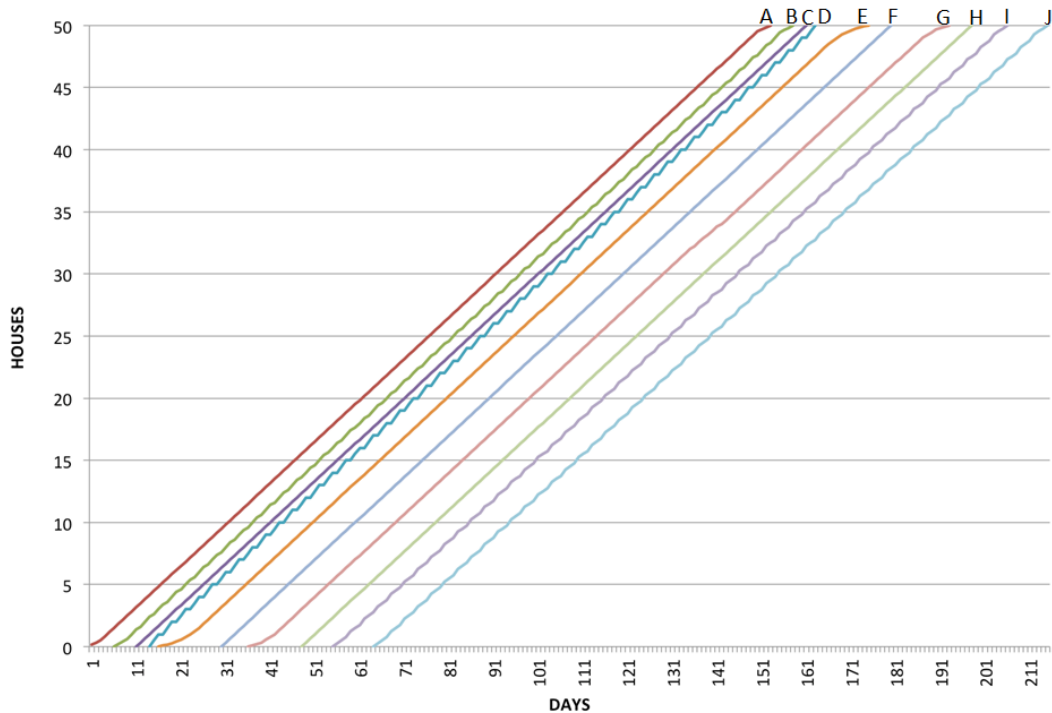
Figure 3. The unrealistic cumulative progress for ten activities in a line-of-balance chart.

Note that the separation observed between each activity depends on the duration of the activity itself and the required time buffer to assure that a minimum space is available for the next activity (i.e. to avoid congestion between the crews).

There were analysed only ten activities that were under the control of the managers and subcontractors performed the rest of activities. Those ten activities were performed by the same type of labour, which means that the crews were interchangeable.

Probabilistic distributions for the activities duration were fitted. First, the standard deviation for each activity was determined. Then, normal distributions for durations were tested using goodness-of-fit tests (chi-square test). In general, poor results assuming normal distributions were obtained. Beta distributions were also tested obtaining much better results for a couple of activities. However, the time buffer for both normal and beta distribution were nearly the same in this case study. For example, assuming beta distribution the activity will last a maximum of nine days, and with normal distribution the result is 9.50 days.

Even though the beta distribution provided better results for goodness-of-fit, the normal distribution was used as this distribution can be fitted in simpler fashion than the Beta distribution (Gonzalez and Alarcon, 2010), and accordingly, the assessment of the Normal properties is much simpler than Beta distributions. This study pays attention in the maximum values that the activities duration can reach, which are very similar, in order to determine the size of the time buffers.

The time buffer required between activities is determined bearing in mind the degree of risk that the manager is willing to accept. To calculate the size of the time buffer, a certain

number of standard deviations or sigmas is added to the mean of the activity duration according to the desired confidence interval. For instance, to calculate the time buffer between the activities A and B, considering a one-sided confidence interval of 97.5%, it is necessary to add 1.96 standard deviations to the mean of the activity A duration. The calculation is shown as follows:

Time Buffer$_{A-B}$ = Mean of activity A duration (6.34 days) + 1.96 standard deviations (s.d.=1.45) = 9.18 days to start the activity B

The same procedure was repeated for all the activities obtaining the results shown in table 1:

***Table 1. Calculation of the time buffer $_{i-j}$ for the activities in Figure 2.***

ACTIVITY	Mean of duration	Std. dev.	Time Buffer	Next higher whole number	Start date
A. Excavation and foundation	6.34	1.45	9.18	10	1
B. Levelling, strap footing beams and reinforced columns	4.58	1.33	7.19	8	11
C. Drainage system	3.16	0.84	4.81	5	19
D. Backfilling and compaction	2.00	1.47	4.88	5	24
E. First floor brick walls	11.94	2.24	16.33	17	29
F. First level roof pouring	5.82	0.75	7.29	8	46
G. Second floor brick walls	8.94	2.70	14.23	15	54
H. Second level roof pouring	5.86	0.50	6.84	7	69
I. Roof parapets	4.20	0.93	6.02	7	76
J. Roof waterproofing	4.08	0.73	5.51	6	83

According to the time buffers calculated in Table 1 a manual simulation in Microsoft Excel was performed to create a different scenario and show how the project would perform under the proposed conditions: controlling the beginnings of the activities, applying the time buffers calculated, and leaving the durations unrestricted. The result for the ten analysed activities is shown in the Figure 4.
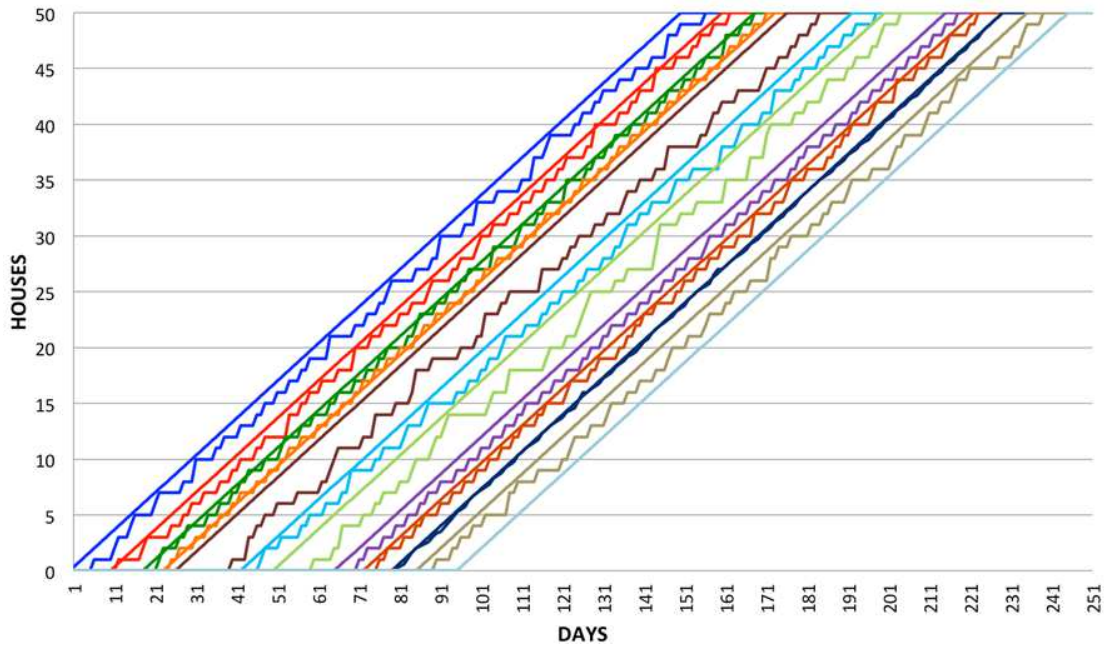
Figure 4. Line-of-balance chart for the ten analysed activities considering the proposed approach.
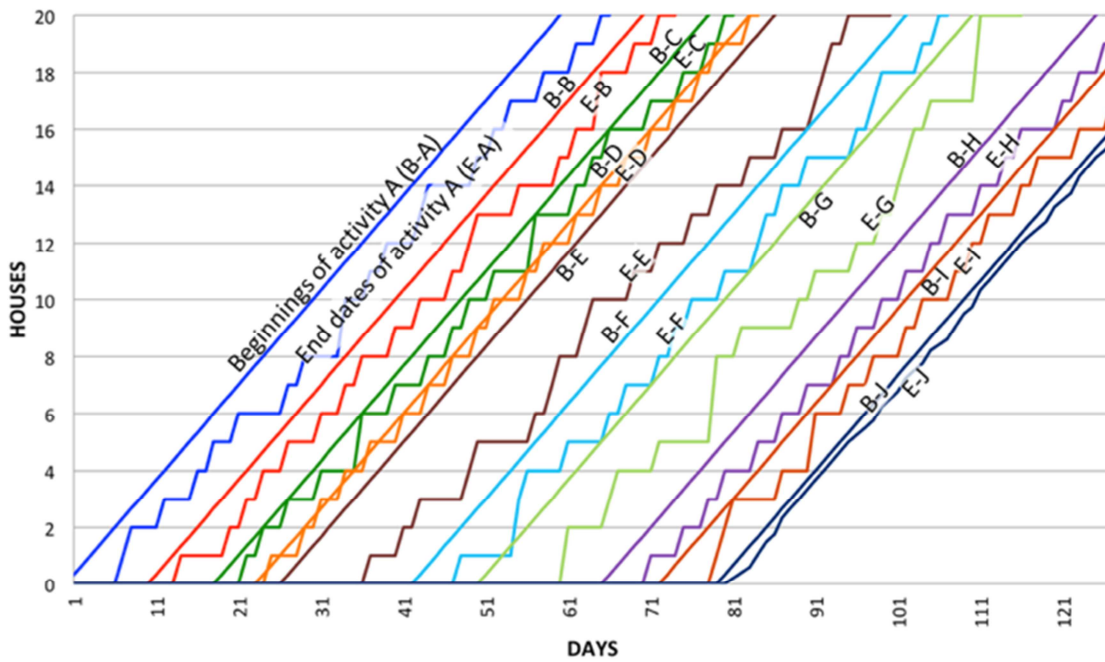
Figure 5. Line-of-balance chart for the first twenty houses considering the proposed approach.

The figure 5 shows a zoom on the first twenty houses and how the proposed approach isolates each activity, showing very satisfactory results. The straight lines represent the planned beginning of the different activities (e.g., the first line from left to right are the planned beginnings of activity A, B-A) and the broken lines are the end dates of activities (e.g. the second line from left to right are the end dates for activity A, E-A), which are unstable due to their own variability. Time buffers prevent – to a certain extent - that the

broken lines touch the following straight lines, which would imply that an activity is delaying the start of the following one.

Figure 5 shows how virtually in any point an activity disrupt the following one. Note that for each house all the activities have some float. This means that in case an activity causes a delay in another activity there is some room to recover the delay.

The conceptualization of this approach implies that the number of crews varies along the project. The proposed approach implies that it must start the next house even if there is no crew available, so a new crew has to be hired. On the other hand, if a crew finishes its work and there is no new activity to start, this crew had to be laid off. Figure 6 shows the number of crews that should be working simultaneously in the project every day.

In order to apply this approach in a real project, the daily required crews should have a minimum degree of variability. A contractor can't hire crews one day and lay them off the next. A simulation was performed to validate how many crews would be required each day under this approach (see Figure 6). It can be seen that the shape of the daily demand for crews is similar to a real project. However more in-depth analyses are required to even the demand of crews.
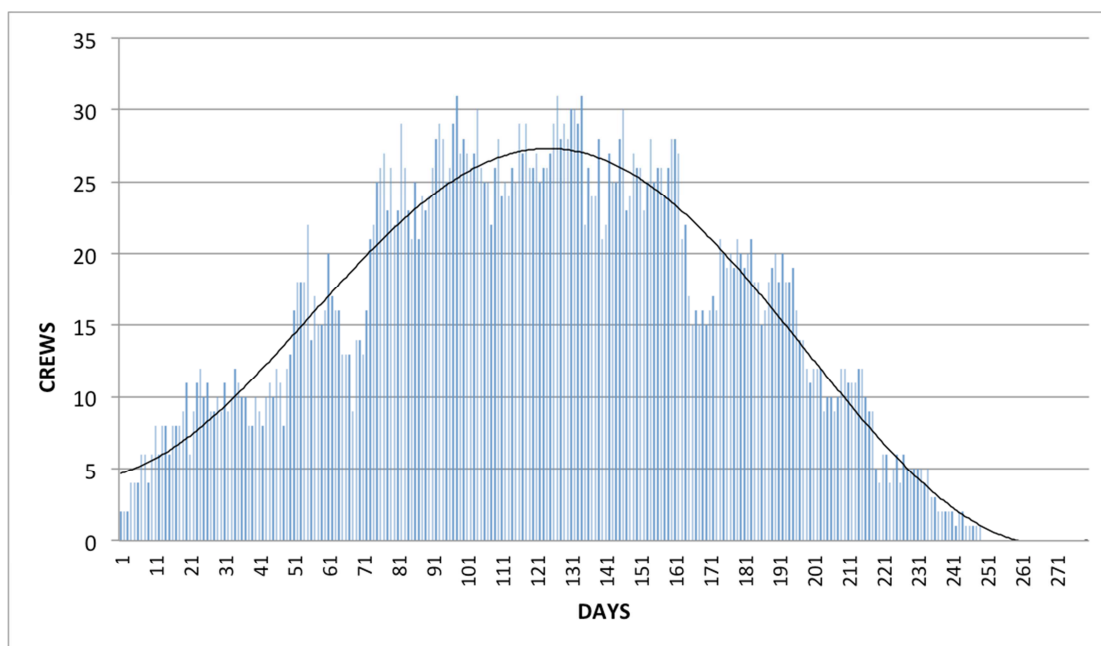
Figure 6. Amount of crews required each day along the project.

4. Conclusions and further work

Based on the results obtained when simulating a real project controlling the beginnings of the activities it can be concluded that this approach seems to be practical and feasible. The total time taken to complete the ten activities would be about 245 days. The utopic project without variability had an expectable term of 215 days. The difference between those terms

is caused by the additional days required between activities to minimize the risk of interference.

In the other hand, when analysing the amount of crews required every day in the project when applying this approach it can be observed that it could be considered feasible. The curve of personnel required (shown in figure 6) is a good approximation of a logical process of hiring crews along a regular construction project.

Further work is needed to find out how crews' variability can be handled and their impact on the proposed rhythm of activities.

Besides, it can be assumed that there will be a learning curve and it implies that the project will have less variability in activity durations as the project progresses. This effect should be analysed to find out if it could bring important benefits to consider when estimating the total duration of the project. It would also be interesting to quantify benefits in costs by implementing this approach.

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