Dynamic Analysis of the Workforce Pattern in the Construction Process

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Extended Abstract

Scope: This study concerns large infrastructure projects, and in particular their planning and management methodology.
In this study the workforce patterns of a *real* infrastructure project are analysed according to the System Dynamics (SD) approach.
The analysis of the field workforce patterns was performed in order to understand the *lesson learned* i.e. why the actual performance was different from the planned one in terms of time and cost. Moreover, the study provides an innovative modelling method for the simulation of the construction process of any large industrial infrastructure.
Such a modelling method simulates the physic of the construction process including mobilization and demobilization of the workforce and takes benefit of the "automatic" feedback driven recovery actions for the project control. If applied to new projects, the proposed modelling method can allow the Project Manager to develop the risk analysis of the project as well as to be assisted in keeping the performance of the assembly resources close to the planned one during the project execution.
The proposed method could improve the return from the investment of the infrastructure construction due to the better planning and control of the resources. This improves their use, reducing delays and litigation.
Problem Position: we want to assemble a structure that is a single Work Package (WP) of the entire WBS of the project in a defined time (target) equal to T (months). The structure is made up of a total number N_T (item) of items that we imagine to be very numerous and relatively small so that the assembly progress can be well approximated by a continuous curve.
To assemble the individual items of the structure, we can allocate resources that are able to work with the productivity P (items assembled per person and per unit of time) known and constant.
We also establish that the assembly workforce W(t) (units) that are present at the assembly site at time "t" can vary from zero in increase (mobilization) up to a maximum value and in decrease (demobilization) from the maximum value to zero depending on the assembly needs.
The problem is the following: what will the resource diagram be over time assuming that there are no other external elements that can modify the described situation?
Once this question has been solved, we will get the planned trend of the Effort (man months) of the resources with its peaks and average values and the planned progress of the construction for each single WP of the WBS. We will then have to "compose" all the WPs together to have the total planned situation.
Finally, to move from total planning to actual planning, which occurs in reality, we will have to introduce the (random) elements that can disturb the planned, as we will see later.
Methodology: To answer the problem, the following 5 steps have been followed:

Fig. 1 – Reference Plant

Step 1 - Analysis of the workforce patterns of a real project (reference plant Fig.1): the WBS of the reference plant includes, among other things, four main WPs i.e. Civil Works (Foundation), Structural (Steel Structure), Piping Works and I&C; whose total assembly effort sum up to about 1600 out of the total 2000 man-months of the full project.
The analysis of the *planned* patterns indicates some common features:
– asymmetric trend for mobilization and demobilization
– work force peak factor of about 2.4 (excluding civil which presents about 1.5)
- decreasing trend approximately exponential (more evident for WP piping and I&C)
- relationship between workforce pattern and typology of each WP due to the work front availability of each WP structure (see next step).
Step 2 - Structural Typologies – Work fronts availability After evaluating the different real workforce patterns of the reference plant, we observe that the assembly resources of any structure have to consider the availability of work fronts on which they have to operate.
Examples of structures that frequently appear in projects are:
1 – structure with elements to be positioned on site that are not connected to each other;
2 – structure with connected elements with constant work front;
3 – structure with elements connected to each other with linearly increasing work fronts;
4 – structure with elements connected to each other with exponentially increasing work fronts;
The examination of the structural typologies allows us to interpret the workforce pattern, in particular:
- The civil WP is comparable to a type 1 structure;
- The structural WP is comparable to a type 2 structure;
- The piping WP is comparable to a type 4 structure;
- The electrical and I&C WP is comparable to a mix between structure 1 and 4;
Step 3 - Dynamic analysis for planning phase: Once the structural typology of each WP has been established, which is essential to understand how the work fronts are available, we can proceed to the analysis of the dynamic system "resources and structure" trying to maintain coherence between execution time, resources, progress and work fronts.
Step 4 - Identification of the S&F model of the single WP: From the dynamic hypothesis we can identify a S&F model for quantifying the process.
Step 5 - Dynamic Analysis for actual phase: In case that actual conditions differ from planned ones, the "automatic" feedback can support the PM providing the corrective action in terms of additional work force requested to meet the target.
Result: Fig. 2 shows the result of the simulation. We note the consistency between data and simulation. Data and simulation give an increase of Effort from 1600 to 2010 man-months (+25%) due to an average actual productivity lower than planned. It is also evident the right shift of the

actual effort due to the constraint of maximum number of workforces during piping assembly works.

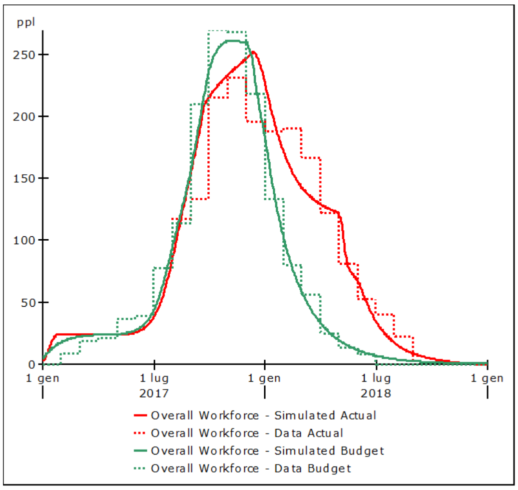

Fig.2 – Overall Workforce Pattern – Planned (green) vs Actual (Red) Patterns - Data (dotted) vs Simulation (cont.)

Conclusions: This study introduces an innovative method of planning and control of large infrastructure projects based on Stock and Flow (S&F) models created through the analysis of the construction process typical of System Dynamics approach.
The analysis is based on the work force patterns of construction of a *real* project (reference project) and allows to simulate the trend of the resources required in the project planning phase and their actual implementation during construction including mobilization and demobilization trend.
The proposed method has some important features, in particular:
- The consistency between the allocation of resources and the progress of construction;
- The presence of the driver of the project that is the target timing and cost. The driver is necessary to define the workers mobilization and demobilization;
- The possibility of allocating resources taking into account the different structural typologies and the related work fronts;
- The possibility of highlighting the productivity (planned and actual) of resources;
- The possibility of highlighting the actual constraints and the interference between different parallel WPs;
- The possibility of "assisting" the PM in real time about the corrective actions required in the actual course thanks to the automatic feedback function;

Finally, the proposed methodology does not "overturn" the traditional way of generating project networks based on WPs and WBSs as is already done with the popular Gantt representation.
The new proposed method, based on realistic simulation of resources, could increase the average returns for the investor and contractors thanks to better use of resources, greater attention for deadlines and less litigation of actors.
A demo video of the simulation is available at [Gantt Navigator - Powersim Software]

References

Eden, C., Williams, T., Ackermann F., Howick, S. 2000. The role of feedback dynamics in disruption and delay on the nature of disruption and delay (D&D) in major projects - Journal of the Operational Research Society, 51, 291-300, 0160-5682/00

Flyvbjerg, B. 2011. Over Budget, Over Time, Over and Over Again – Managing Major Projects. Retrieved from https://www.researchgate.net/publication/235953357_Over_Budget_Over_Time_Over_and_Over_Again_Managing_Major_Projects

Flyvbjerg, B. 2014. What You Should Know about Megaproject, and Why: An Overview Project Management Journal, vol 45, n.2 Retrived from https://www.researchgate.net/publication/261411676_What_You_Should_Know_About_Megaprojects_and_Why_An_Overviewfrom DOI:10.1002/pmj.21409

Girmsheid, G., Brokmann C. 2007. The Inherent Complexity of Large-Scale Engineering Project. Research collection.ethz.ch ETH Zurich ETH Library Originally published in Project Perspective 29 https://doi.org/10.3929/ethz-a-005994701

Lyneis, J.M., Ford, D.N. 2007. System Dynamics applied to Project Management: a survey, assessment, and directions for future research. System Dynamic Review Vol 23, No 2/3 John Wiley&Sons, Ltd. Retrieved on line in Wiley Interscience 157-185 (www.interscience.wiley.com). DOI:10.1002/srd.377

Meadows, D.H. 2008. Thinking in Systems – A Primer – White River Junction (Vermont- USA). Diana Wright, Sustainability Institute – Chelsea Green Publishing

Sterman, J.D. 2000. Business Dynamics – System Thinking and modelling for a Complex World. Irwin McGraw-Hill

White, J. C., Sholtes, R. M. 2016. The Dynamic Progress Method – Using Advanced Simulation to Improve Project Planning and Management. CRC Press Taylor and Francis Group. ISBN 13: 978-1-4665-0437-0.