AGENT BASED STOCK AND FLOW MODEL FOR PROJECT PLANNING AND CONTROL

DYNAMIC ANALYSIS OF CONSTRUCTION PROCESS FOR PROJECT MANAGEMENT

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ABSTRACT

This study analyzes the ex post patterns of resources employed in the construction of an industrial plant. The aim of the study is to understand the rational of *planned* resource allocation and hence to extrapolate the *actual* pattern when conditions change. The study explains how the identified logic of resource allocation becomes the basis of a Stock and Flow dynamic model applicable to any construction Work Package (WP). The model takes into account the delay time of resource allocation, the erection sequence constraints and the feedback control generated by the *actual* vs. *planned* recovery actions.

KEYWORDS

System Dynamics, Agent Based, Stock & Flow, Project Management, Project Control, Construction simulation

FOREWORD

"Construction is the biggest industry in the world, and yet, is not performing well. The construction ecosystem represents 13 percent of global GDP, but construction has seen a meager productivity growth of 1 percent annually for the past two decades. Time and cost overruns are the norm, and overall earnings before interest and taxes (EBIT) are only around 5 percent despite the presence of significant risk in the industry." (McKinsey Global Institute, June 4, 2020).

A statistic carried out by the Construction Industry Institute (USA) on 975 industrial projects of various sizes, found that only 5.4 percent of these were able to meet the schedules and costs budgeted (PricewaterhouseCoopers LLP report, 2013). As regards in particular the large projects (Megaproject), the statistics confirm what is called the "iron law of Megaproject" or nine out of ten end up late with extra costs that frequently reach up to +50 percent and in some cases even more (Flyvbjerg, B.,2014).

Fortunately, project planning and management techniques have been refining more and more during last 30 years and this improvement has reduced the negative impact on performance (PMI's Pulse of Profession, 2017). However, the results remain poor and seem difficult to improve due to the intrinsic complexity of the projects (Girmsheid, G., Brokmann, C., 2007).

Among the main causes, if not the main cause, of these disappointing results is the bad forecast of time and costs (PricewaterhouseCoopers LLP report, 2013).

Unfortunately, in several project plans, resources are not even quantified (White, J.C., Sholtes, R.M., 2016) notwithstanding they are the mean that bear the construction effort.

Project planned duration is often based on predefined duration of each single WP that is part of the project Work Breakdown Structure (WBS) whose critical path gives the overall project duration. This means that each single WP duration and the overall project duration are mainly based on the experience of the person or team in charge for planning the project more than on a rational evaluation about the amount of resources that have to be mobilized and how effectively they can work.

This fact has the following negative consequences:
1 – The plan becomes a simple monitoring tool of the project progress that can only provide a "picture" of the project delay and extra effort without any control on it;
2 – The plan does not consider those constraints that may affect the resource allocation to each single WP of the WBS. This may "hide" the real project critical path and therefore the overall project duration.

This study aims to provide a contribution to the understanding the rationale of workforces allocation in the construction that is essential to define the WP work duration. To do that, we start analyzing the ex post resources data of the typical Work Packages (WP) of a real infrastructure (a power plant) i.e.: civil works, steel structure erection, piping network erection and cable laying. After the data split and their analysis, each WP has been simplified into its essential terms and its causal relationships. The simplified construction process was used to tune up a dynamic simulation model. The model will reproduce the pattern of workforce resources and the progress of the construction of the plant in the initial planning of the project. The following step was the simulation of the actual WP conditions in order to check the consistencies between the model and the actual data in the new condition. Through the model, we try to highlight the growth limiting factors of the construction.

WHY SYSTEM DYNAMICS? - CONSTRUCTION AS A SYSTEM DYNAMIC PROCESS

The construction of a large infrastructure requires the coordinated action of a significant amount of resources with different specializations that must operate in a well-defined time frame.

The presence of several agents (i.e. resources) that, executing the project (i.e. following the design and construction rules) eventually achieve the target (i.e. the infrastructure or also called emerging structure), meets the definition of dynamic system (Meadows, D. H., 2008).

There is also another evidence of the dynamic nature of the projects. There is in fact just one parameter that is used by practitioners to assess the intrinsic difficulty (or risk) of a project and this parameter is the ratio between the overall investment (that gives an idea of the "dimension" of the project) and the estimated time for its completion.

Such a dynamic nature of the project suggests the use of a dynamic model to simulate the construction process.

To do that, we take as reference project an industrial project (power plant) whose engineering, procurement and construction (EPC) is known in detail by the author that managed it since its very beginning. We will use the ex-post data to create a dynamic model that should reproduce the resource and progress patterns. For the sake of simplicity, we will focus the study on the aspect of the construction only because, in this specific case, the upstream phases of design and procurement did not significantly affect the overall result being well prepared therefore executed faster than construction.

By means of a dynamic model, we want to highlight those key parameters that can fix the minimum construction time of any generic WP and, once the planned duration has been defined, to understand how it is possible to control the actual behavior in order to meet the plan.

REFERENCE PLANT RESOUCE DATA

This study takes advantage of available ex-post data of a real project. Fig. 1 shows the monthly hours spent in the construction of the reference project (left scale: planned in gray, actual in black) and the cumulative hours (right scale x 1000: planned in gray, actual in black).

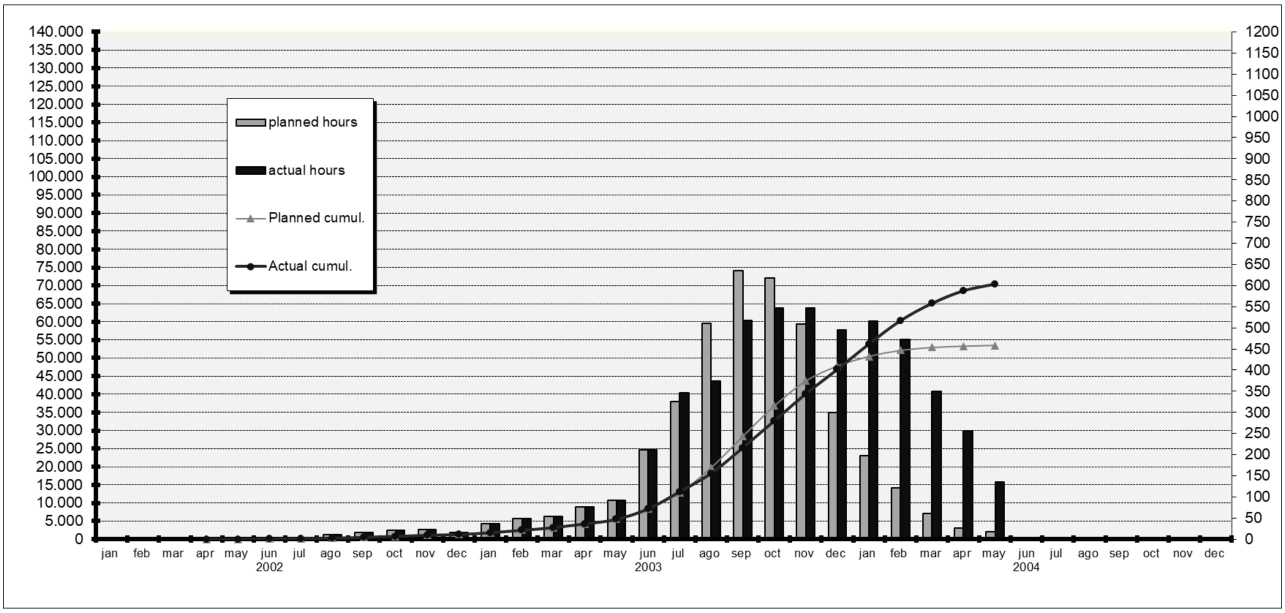


FIG. 1 – CONSTRUCTION MAN-HOURS – MONTHLY (LEFT) AND CUMULATIVE (RIGHT X 1000)

The graph shows that the actual hours were about 600,000 hours higher than 450,000 planned (+ 33%) and there was a two months time "shift" to the right (the gray peak falls in Sept 2003, the black one in Nov 2003).

The histogram in the figure is the sum of several histograms of different WPs, the main ones of them are four: civil works, steel structure erection, piping network erection and cable laying.

Splitting the overall pattern into the four mentioned WPs patterns, we see that each of them shows a similar trend: bell-shaped for resources and “S”-shaped for cumulative effort. We will analyze each single pattern of them.

STOCK & FLOW (S&F) MODELS FOR DYNAMIC ANALYSIS

Dynamic simulation models have been developed as part of the study of system dynamics. The method was used in the first half of the 90s by Jay Forrester (MIT-Boston USA) to initially study complex business problems and later to study the growth and decline dynamics of urban centers, environmental sustainability problems and more recently, for the climate change analysis.

In the following, we refer in particular to the modeling method called Stock and Flow (S&F) (Meadows, D.H., 2008). Several applications of S&F method exist in the manufacturing and services sector (Sterman, J.D., 2000). Particular attention was also paid to construction management problems (Lyneis, J.M., Ford, D.N. 2007).

The simplest S&F model is shown in fig. 2 in which is represented a tank (stock) of a certain quantity of a generic material (item) of which the variation over time is of interest. The tank is fed by a flow of that same material. In other words, the Stock represents the integral of the Flow. The flow can be varied by means of a control element (Flow control).

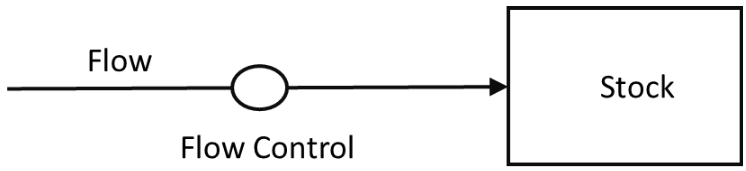


FIG. 2 – S&F MODEL OF A SINGLE WP

A dynamic system can include several stocks like fig. 2 whose levels can influence other flows, generating in such a way a "complex" system in the sense that the value of levels and flows are not easily predictable a priori. Levels and flows are described by the numerical solution of differential equations.

AGENT BASED S&F MODEL OF CONSTRUCTION – ONE LEVEL MODEL

We refer to the S&F diagram in fig. 2. Let us consider a single WP of the project WBS. According to the Project Management Institute (PMI) PMBoK definition, a WP is an activity characterized by an average Productivity value. We assimilate the scope of the final construction like a stock of materials, ordered according to the design, which the contractor in charge of the WP assembles over time. We outline the materials we have to install, like a set of several elements (steel frames or pipes or cables, etc) that we generically call "items". We suppose that such items are sufficiently small (we use the term "granular") and similar to each other. Therefore, we could approximate the construction progress to be a continuous function over time.

If we want to install a total quantity of N_T items (scope) in T months (planned duration in months), we will need an average erection rate equals to:

$$ER_{av} = N_T / T \text{ (items / month)}$$

In order to evaluate the need for resources W (resources in units or ppl) necessary to perform the assembly work, we introduce the physical productivity of resources P_{ph} (item/ppl/hour). This is an average value that is estimated during the project budgeting on the basis of experienced ex-post data for similar jobs. It depends on the typology of work (casting, welding, connecting, etc..) and the efficiency of manpower.

The product of P_{ph} (item/ppl/hour) times the monthly working hours h (hours/month) gives the productivity P useful for the workforce estimation.

$$P = P_{ph} * h \text{ (item/ppl/month)}$$

In the reference plant, it was decided to adopt for erection the single "extended shift" of 50 hours/week (i.e. 200 hours/month) since a longer single shift was not possible for labor regulation and 2 or more shifts were considered less productive by experience. Therefore, in the following, we will use the constant value for monthly working hours:

$$h = 200 \text{ hours/month}$$

Therefore, the physical Productivity P_{ph} is always proportional to the Productivity P (items / ppl / month). The 200 (hours/month) or 50 (hours/week) is known as "the 50 hours rule" which states that "on the average, no matter how many hours a week you work, you will only achieve fifty hours of results."

Therefore, being P the erection rate of a single resource, that is the number of items that one assembly unit installs in one month, we can express the average Erection Rate also like P times the number of resources:

$$ER_{av} = P * W_{av}$$

Consequently, we get the following relationship between the four typical quantities of the construction process:

$$W_{av} = N_T / (P * T)$$

This simple formula already tells us that a drop in productivity (for example 10%) would require a 10% increase in resources to keep constant the construction target duration T.

Note that the terms of the equation:

$$W_{av} * T = N_T / P$$

represent the total value of the assembly work in man months that we call Effort.

Due to the "granular assumption", we can move from the average to instantaneous values. Then the relationship between Erection rate, Productivity and Resources becomes the following:

$$dN(t) / dt = P * W(t)$$

where we introduce a Progress function of time N(t) and a resource function of time W(t) and we assume the Productivity to be constant.

In reality, we know that P is influenced by numerous factors such as:
- the availability of design, construction procedures, tools, room etc. It may happen that, if the construction room is limited, then work becomes more and more difficult due to the congestion of assembled material. For this reason Productivity may decrease with the increase of progress N(t).
- the excess of resources W(t) in a limited area can be also a reason of Productivity decrease;
- the interference of other tasks (like x-ray execution) in the same area;
- external factors (weather, people stress, etc ...);

Notwithstanding the above, we begin our analysis assuming P constant and we will check the alternative later on simulating the variability with the model.

The Instant Erection Rate formula says that if resources and their productivity remain constant over time and if there are no other obstacles due to design variations or material shortages, then construction will grow steadily over time according to the following linear law:

$$N(t) = P * W_{av} * t + N_0$$

Fig. 3 shows the trends over time of the resources (constant) and of the progress (linear increasing), from the beginning of the construction up to the end when al N_T items have been installed.

As said before, we can simulate what would happen if there were a decrease in productivity during construction due to one or more reasons listed above or also to interference with other tasks or to the slowdown of the workers due to the approaching end of work. (known as "slack on" effect).

In the example of fig. 3 we assume that productivity decreases as the assembly progresses up to 50% of the initial value at the end of assembly. We see the comparison of the new situation with the planned baseline.

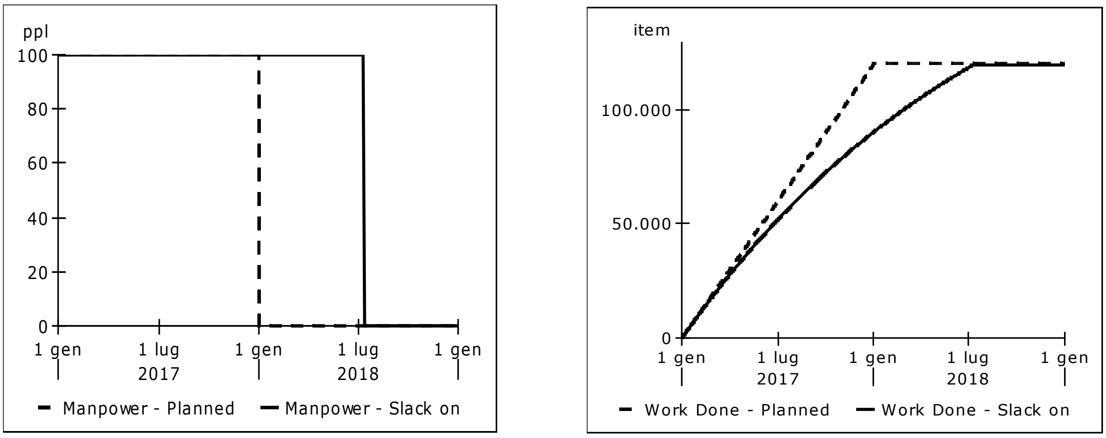


FIG. 3 – WORKFORCE AND PROGRESS PLANNED (DASHED) VS ACTUAL (CONT.) WHEN PROGRESS AFFECTS PRODUCTIVITY

As can be seen from figure 4 on the left, the overall work (the area of the rectangle of resources) has increased from 217 to 300 man-months as the average productivity has decreased and the work ends with a delay of 4 months compared with the Baseline.

AGENT BASED S&F MODEL OF CONSTRUCTION – TWO LEVELS MODEL

Two levels model without constraints – sinusoidal pattern

We have seen how the model in fig. 1 reflects the dynamic aspect of construction and how it is possible to describe the role of Resources, their Productivity and their Progress.
However, the assumption we made of a planned performance with a flat pattern of resources is a limit of the model.

In reality, the evidence shows that allocated resources of a sufficiently large WP (i.e. greater than 100 man-months) do not remain constant during the work; they increase according to the demand for work and leave the job when such a demand decreases.

Our scope is to identify the rational staying behind the pattern.
Therefore, we can formulate the question in the following way:

We want to perform the scope of a generic WP of the project WBS. It consists to install a structure made of N_T elements (items)* in a total time T (time).
We know that the Workforce will work with a productivity P (items/ppl/time)** and it needs a delay time to enter and leave the site***.

We want to finish the job with no workforce at site.
The question is the following: is it possible to forecast the required workforce pattern during the job?

(*) items almost equal each other
(**) assumed constant
(***) it takes time to enter and leave

Before to answer the above question, here some comments:
When we mention the "delay time" we introduce the idea of inertia of the workforce. This inertia is evident for several reasons: instruction time, induction needs, etc...
When we say that "We want to finish the job with no workforce at site", we refer to the fact that the system tries to finish the erection without any resource still at site otherwise this would mean that such workforce is not productive from that time on.
Finally, we state the condition that the flow of resources in and out from the site is not constrained other than their same inertia.

In order to find the answer to the above pattern problem, we begin considering the Workforce like a Stock due to its delay time to enter and leave the site mentioned above. Therefore, we include also the Workforce Stock in the WP model whose content can change over time according to the needs of the construction. The model becomes a system with two state variables: the resources W(t) and the progress N(t).
We assume that the Workforce Flow entering the site is proportional to the Work to Do and the Workforce Flow leaving the site is proportional to the Work Done. In this schematization, the Work to Do causes resources to increase and resources cause the Work to Do decreases. This is a "circular" interdependence, which determines, as will be seen below, the non-linearity of the functions W (t) and N (t).

The two-level S&F representation of fig. 4 (actually, the levels represented in the figure are three, being two of them complementary to each other).

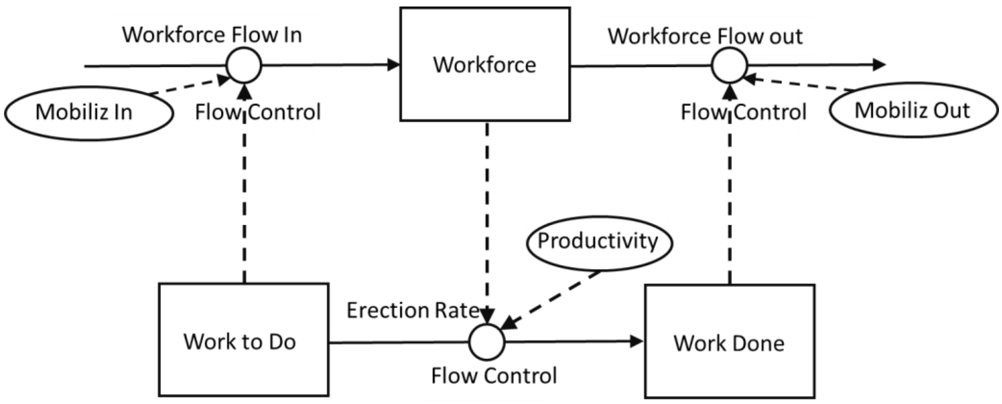
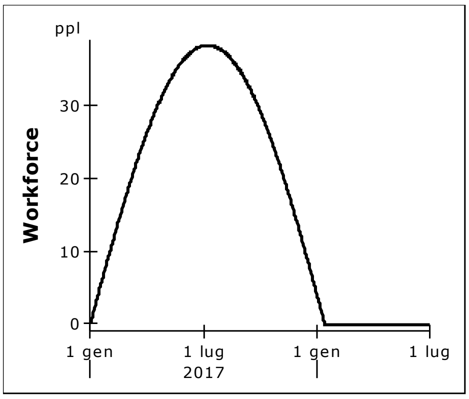


FIG. 4 – S&F MODEL WITH TWO LEVELS (PLUS ONE COMPLEMENTARY)

The basic assumption of this model is that the workforce flow of resources entering the WP at time t (Workforce Flow in) is proportional to the quantity of items that still remain to be assembled at that time (Work to Do). The proportionality constant (Mobility in) takes into account the system's ability to find them, mobilize them and put them in the condition to operate with the required productivity.

Similarly, we assume that the workforce flow of resources leaving out the project at time t (Workforce Flow out) is proportional to the quantity of items already installed at time t (Work Done) being Mobility out (or Demobilization constant) the relevant constant. This second basic assumption reflects the fact that the system tries to finish the erection without any resource still at site because otherwise this would mean that such workforce is not productive from that time on. Finally, we state the condition that the flow of resources in and out from the site is not constrained other than their same inertia.
Some example of such kind of structure can be excavations, foundations, installation of single item independent each other, etc...

Translating the above assumptions into mathematical relationships, we obtain a system of differential equations that we can solve exactly under the particular condition M=D (see fig. 5). In this particular case, we get a symmetric function: specifically a sinusoid arc that starts and ends at zero for workforces and a double sinusoid arc that starts from zero item and ends at N_T for progress. We will discuss later on the other two possible conditions: M>D and M<D.



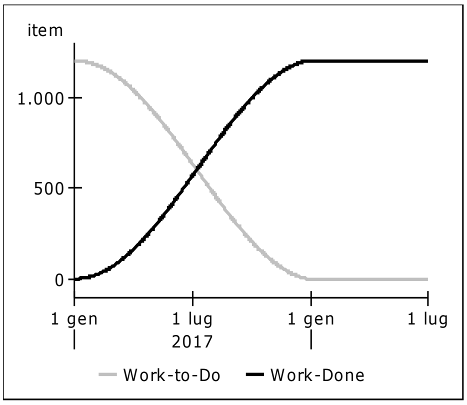


FIG. 5 – TWO LEVELS S&F MODEL WITHOUT CONSTRUCTION CONSTRAINTS

By imposing the condition that the integral of resources over time T for productivity P equals the total scope N_T, we get the following relationship involving the characteristic quantities of the problem:

$$T^2 = \pi^2 / 4 * (N_T / P\ M)$$

In which the factor M (ppl / month) represents the flow of resource mobilization at the beginning of construction and the flow of resources demobilization at the end of the construction.

The term:

$$\sqrt{(N_T / P\ M)}$$

has the dimensions of a time characteristic of the two-level dynamic system.

The formula tells us that, in dynamic terms, in order to be able to respect the target duration of the construction of a work consisting of N_T items, it is not sufficient to get the average W_{av} resources operating with productivity P, but it is also necessary that the initial (and final) workflow should not be lower than the M.

Furthermore, for practical purposes, it is important to note that the maximum value of Workforce (i.e. the maximum Erection Rate) is $\pi/2 = 1.57$ times the average resources. This means that the inertia of the system requires about 60% more resources at the peak than the average amount mentioned before with the linear model.

We have solved the problem posed above to find the pattern of resources but such a solution is valid in the particular case of $M = D$. We discuss now the other two possibilities: $M<D$ and $M>D$.

$M<D$ means there is a shortage of mobilization and this fact will keep the level of resources too low, preventing the achievement of the target progress N_T regardless the available time T;

$M>D$ means there is an excess of mobilization and this fact will keep the level of resources too high. The system achieves the target progress N_T with an excess of workforce allocated to the job.

Two levels model – 2tau version

Mobilization phase without assembly constraints

The sinusoidal pattern model seen before provides a first solution of the problem posed above i.e. to find the pattern of workforce needed to perform a certain WP. The solution shows that the role of the mobilization constant M (the initial and final workforce flow) is as relevant as the role of productivity P. This is the consequence of the need to contrast the mobilization force with an opposite demobilization one when workforce has its own inertia.

However, such a "sinusoidal" pattern model has some limitations because it implies that, during the WP execution, we can have both a workforce flowing inside the work site and flowing outside of it at the same time. This feature of the sinusoidal model can be acceptable for the whole project since there are several WPs with some of them in parallel but it is not realistic for a single WP. Moreover, the sinusoidal pattern seems to overestimate the workforce peak if compared with ex-post data.

In fig.7, we note that:

1 – the real pattern of resources shows in average a flat steady level;
2 – the derivative of mobilization phase shows a discontinuity when the demobilization phase starts.

In order to reflect such evidence we will split the model in two phases: a mobilization phase followed by a demobilization one. The model of the mobilization phase is shown in fig. 6

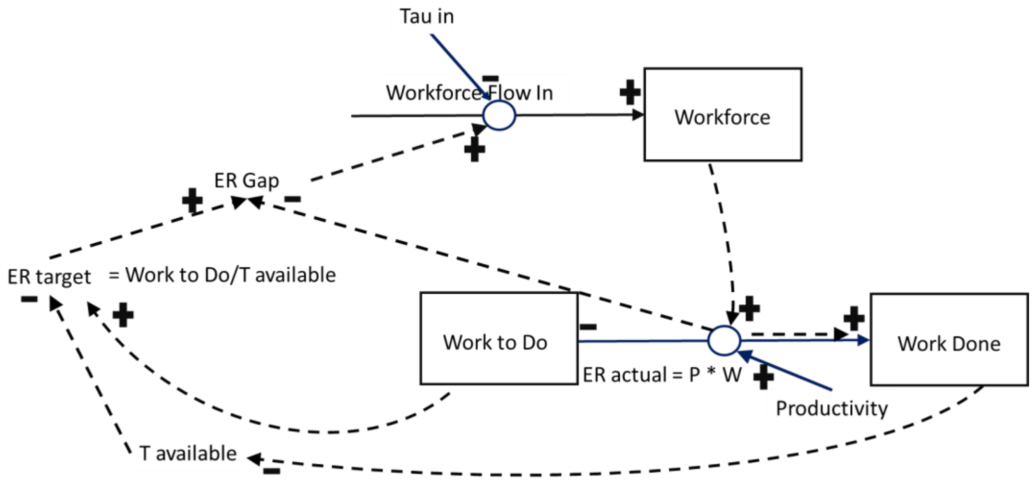


FIG. 6 – S&F MODEL OF MOBILIZATION PHASE WITHOUT CONSTRUCTION CONSTRAINTS

Fig. 6 describes the assumption that the system dynamic tends to "import" the resources into the project as soon as it is possible in order to match the target Erection Rate of the WP that is:

$$ER_{\text{target}} = \text{Work to Do} / \text{Time available to finish}$$

Note that initially, the Work to Do equals N_T and the Time available to finish equals T. During the construction process, Work to Do decreases but also the Time available to finish decreases, so ER target is almost constant.
Regardless to ER_{target}, the construction process begins with a current ER equals W(t) times P that is generally very low at the beginning (min W = 1 ppl * P (item/ppl/month)) and increases more and more with the incoming workforce flow.

We assume that the driving force that moves resources inside the project is the gap between ER target and ER current.

$$ER_{\text{gap}} = ER_{\text{target}} - ER_{\text{current}}$$

or:

$$ER_{\text{gap}} = (\text{Work to Do} / \text{Time available to finish}) – W(t) * P$$

The increasing workforce flow rate is taken into account by the delay time Tau-in, which reflects the workforce inertia to join the project.

Similarly to the sinusoidal pattern model, also the mobilization model of fig. 6 shows the “circular” link between Progress and Resources and between Resources and Progress.

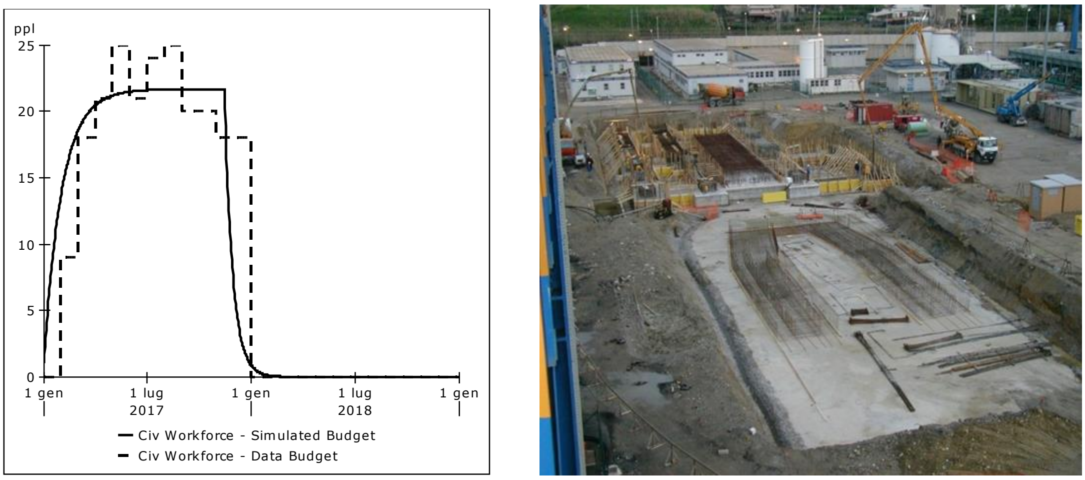


FIG.7 – COMPARISON MODEL VS DATA FOR MOBILIZATION PHASE OF CIVIL WORKS (LEFT) – REAL CIVIL WORKS (RIGHT)

In fig. 7 we see the fast mobilization of workforces followed by the achievement of an almost steady value.
As far as the demobilization phase (the fast decreasing line), we will discuss it later on.

Mobilization phase with assembly constraints

We have seen the workforce pattern that is generated when the only limiting factor to increase the mobilization flow rate is the inertia (or delay learning time or induction delay time). Such a condition does not cover all the possible structural topologies. The reference project includes also more complicated structures than those not constrained we have seen before (excavations, single independent items, etc..).

In figure 8, for example, we show a typical – schematic- fluid distribution network (water, steam, air…) that is frequent in almost all industrial plants. Such a structure will limit the workforce flow entering the construction work as explained below.

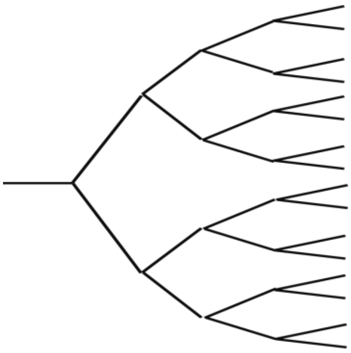
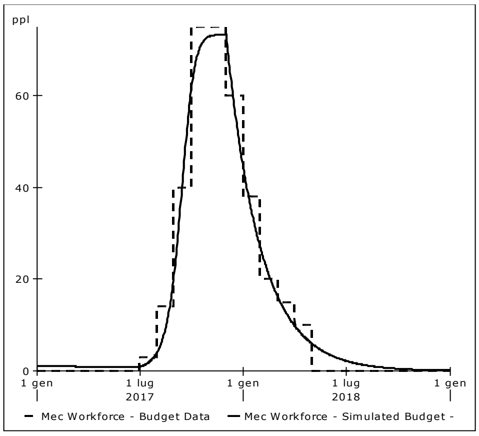


FIG. 8– DRAFT VIEW OF A "TREE" DISTRIBUTION NETWORK

In this case, the workforce growth during the first two to three months of the mobilization phase is much slower than that one we have seen previously for foundation (fig. 9). This fact happens because the resources, during the initial steps of the construction, are limited by the few number of available work fronts. Later on, during the intermediate steps of structure assembly, as soon as the available interfaces grow, it becomes possible in principle (and necessary in order to fulfill the time schedule) to parallelize the work of more and more resources.

The new constrained model differs from the unconstrained one seen before due to a limiting mobilization “resistance” as explained below.

The constrained model pattern is shown in fig. 9 compared with ex-post data.



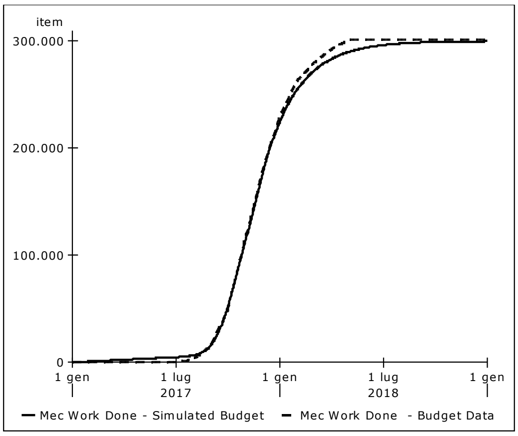


FIG. 9 – WORKFORCE (LEFT) AND PROGRESS (RIGHT) PATTERNS OF TREE STRUCTURE: MODEL (CONTINUOUS) VS DATA (DASHED)

In this case, the workforce growth during the first two to three months of the mobilization phase is much slower than that one we have seen previously for foundation (fig. 8). This fact happens because the resources, during the initial steps of the construction, are limited by the few number of available work fronts. Later on, during the intermediate steps, as the available interfaces grow exponentially, it becomes possible (and necessary in order to fulfill the time schedule) to parallelize the work of resources.

The resources increase is therefore concentrated in a limited time frame in the central part of the assembly. As a result of the "slow" construction start, it is necessary to "push up" the peak towards values significantly higher than the average value and, consequently, due to the proportionality between erection rate and resources, the erection rate will also reach a peak equals to 80/35 = 2.28 times the workforce average value. If this "bottleneck" effect at the beginning of the construction is not properly taken into account in the planning phase, delays in the implementation phase will result. Note that the peak factor of such a constrained structure is about 1,5 (= 2,28/1,57) times the peak of the sinusoidal pattern of not constrained model.

It is possible to describe mathematically the constrained model but this detail is out of the scope of this study.

Demobilization phase with or without assembly constraints

Ex-post reference data in fig. 9 show the same discontinuity of the workforce derivative between the mobilization and demobilization phases. The latter closely approximates the exponential decrease, the trend of which seems to depend on a demobilization time constant Tau-out.

If we preliminarily assume that the Demobilization Pattern has an exponential trend and the Productivity of resources remains constant throughout the demobilization phase, then it is possible to calculate the moment when it is necessary to plan workers to leave the construction site because the remaining resources can complete the missing work in the remaining available time. Having in mind that, we wish to have zero resources when the assembly is completed.

An additional point concerning demobilization is the following: we have to take into account the demobilization delay time during the planned mobilization. This is because the demobilization delay time reduces the total available time for mobilization and this fact gives a higher ER_{target} than the ER_{target} without demobilization according to the relationship

$$ER_{gap} = (\text{Work to Do} / \text{Time available to finish}) - W(t) * P$$

we have seen before.

If we neglect to include the expected demobilization time in the available time for mobilization or we assume that such a demobilization time is almost zero, then we will finish the erection in delay due to the demobilization of workforce. The delay could further increase due to the loss of productivity during demobilization (workforce "slack on").

ACTUAL CONTROLLED MODEL

Any system, whose construction progress has been planned, is subject to diverge from the plan due to the actual conditions that occur during the construction. Typical are the "environmental" variations that can affect all the parameters that characterize each WP.
A frequent case is the scope variation also called "scope-creep" i.e. the variation of the quantities N_T to be installed, which we have assumed constant. Other variations may concern the Productivity P, the time constants Tau-in and Tau-out, the variation (decreasing) of available room for the erection and / or the maximum achievable peak of resources we have seen before.

The dynamic model allows to apply the System Control Theory for evaluating the effects of these variations and to "control" them during construction fig. 10.

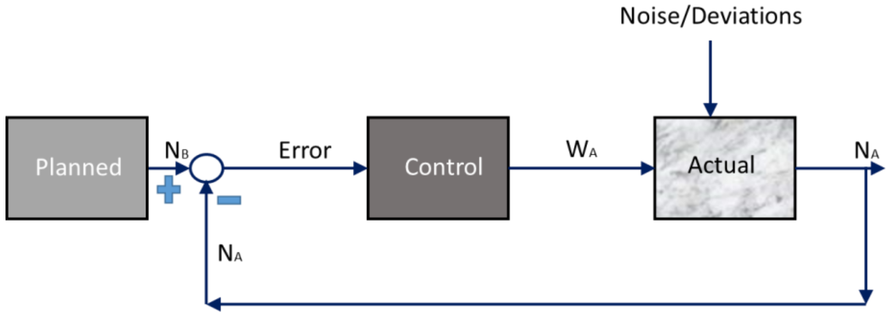


FIG. 10 – S&F MODEL CONTROLLED MODE

To understand the behavior of the regulation system with an example let us take the WP of the fluid distribution network (fig. 8 and 11).

In fig. 11 we see that the planning (green lines) would have required the achievement of a peak of about 80 resources and, after a couple of months, the demobilization phase should have started. In reality, it happened that productivity was 6% lower than planned and the maximum achievable number of resources did not exceed 42 units.

The combination of these two factors generated the actual patterns represented in black.

The final amount of man-hours (effort) has obviously increased due to the reduced productivity and the duration has been lengthened due to the actual limit on the maximum working resources and therefore on the maximum ER.

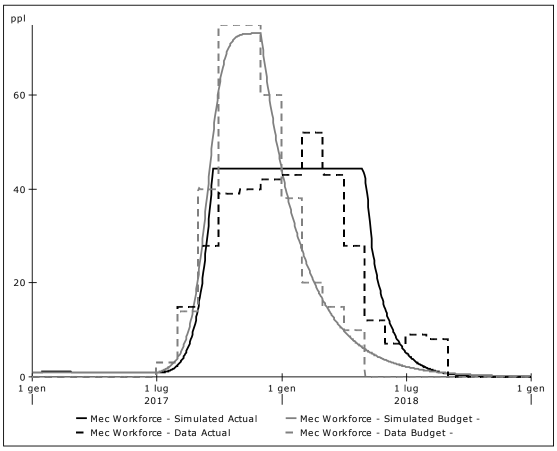


FIG. 11 – WORKFORCE PATTERN OF PIPING TREE STRUCTURE: TARGET (GREY) VS ACTUAL (BLACK), DATA (DASHED) VS. MODEL (CONTINUOUS)

OVERALL WORKFORCE PATTERN OF FOUR MODELED WPS

In fig. 12 we see the superimposed effect of the 4 tasks examined for the reference project, both the target trends (gray lines) and the actual ones (black lines), both real (dashed lines) and modeled (continuous lines) are represented.

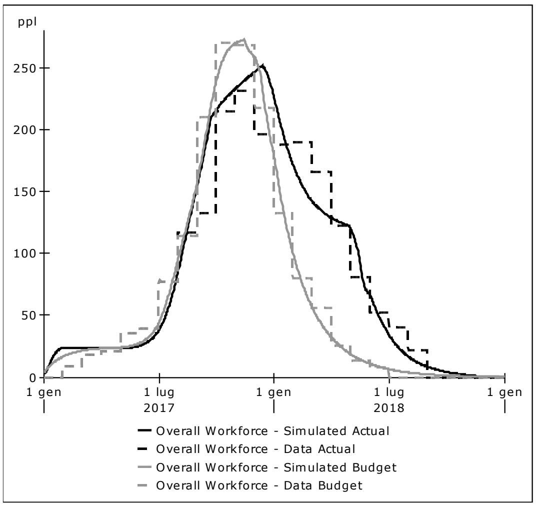


FIG. 12 – OVERALL WORKFORCE PATTERN CURVE TARGET (GREEN) AND ACTUAL (BLACK), DATA (DASHED) VS MODEL (CONTINUOUS)

CONCLUSIONS

This study moves from the analysis of the ex post pattern of the resources employed in the construction of a power plant and sets up a Stock and Flow (S&F) model in order to provide a possible explanation of them. The model suggests that delays and extra costs that happen during the construction might be due to a poor forecast estimation of workforce allocation that does not take into account the delay time and the erection sequence constraints that limit the workforce flow rate.

The S&F methodology allows identifying the forecast of construction progress based on workforce flow entering (mobilization) and leaving (demobilization) the construction process for large infrastructures. The model makes it possible to highlight the role of some dynamic parameters that are critical for the feasibility of the target duration of the assembly.

In addition to the Productivity of the resources, already known to be a critical parameter, the study highlights the role of other three parameters that play a critical role for the construction process. They are the time constants of mobilization and demobilization of the resources and the construction sequence deriving from the topology of the structure to be assembled.

Those parameters create limitations to the growth of the construction but, since the usual project-planning phase is not resource driven, unfortunately several projects finish in delay. When these limitations arise, in order to keep the target duration of the task, it is necessary to concentrate the assembly effort in the central phase of the work, thus generating a peak of resources and a consequent erection rate much higher than the average. If actual resources fail to meet the required peak then the WP completion will delay. In case they achieve the peak but the productivity drops, the WP will delay too. Hence, the advice is to evaluate carefully the planned duration for each WP of the project taking into account the mentioned constraints.

Once the forecast plan has been correctly defined based on resources, it may happen that actual conditions differs from those planned. In this case, the system control theory allows identifying the requested correction to compensate the deviation. Such a feature of the model allows the PM to perform a risk analysis of the project choosing those strategies to tackle the problem or assuming the proper contingencies.

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