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SIMULATION OF LARGE PRECAST OPERATIONS

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ABSTRACT

This paper presents the analysis of the optimization for the production of precast pieces in a workshop with the help of simulation to obtain several working alternatives. The main objective is to improve the productivity and therefore reduce the production costs.

Since the analysis was done with the workshop in full production, it was not possible to plan for changes that would stop the production.

A first model was designed duplicating the already established production method, which had a production rate of 75 pieces per turn. The results obtained were similar to the real method. The analyzed alternatives were based in progressive changes to the initial model: assigning tasks to the personnel, homogenizing the number of in-process pieces for the successive phases, and schedule variations.

The simulated production rate of the last model was 108 pieces per turn, with a productivity increase of 44%. Implementing the solution proved the excellence of the model when the forecasted production rate was obtained only after a few days and with absolute regularity.

Previous to the description of the case, the paper presents the changes that Dragados implemented to adopt simulation as a tool to improve productivity.

1 SIMULATION IN DRAGADOS

Dragados is a group of more than 50 firms that were born after a process of intense diversification from its main purpose, construction. Its annual sales surpass the amount of 550 billions of pesetas, with an important part of its activities developed in the international arena. In the Engineering News Record issue of the Top 225 International Firms of August 1996, Dragados was ranked 54 as International Contractor (including only contracts outside of their home country), 37 as Global Contractor (home and abroad) and 8 as Latin American Contractor.

In all its history, Dragados has been considering very essential the presence of a strong technical team of highly qualified individuals to assure the knowledge of the newest technologies and their application. This produced the appearance of technical teams specialized in each of the Dragados activities, Product Specialization.

Simultaneously the technical process arrived to all areas creating support groups to the organizational level that uses generic tools and techniques.

During the late 60s the Planning and Methods Unit (PMU) was created with the objective of improving the productivity of construction processes through the application of optimization techniques.

Usually for every operation, the product specialist designs the processes and the general manager detects the opportunities for improvement. For these cases the manager uses a technique called “Analysis of the Work”, doing comprehensive analysis and synthesis of the processes using very detailed information, like:

- Cycles divided in elements and measured in the hundredths of the minute.
- Current conditions between operations, not only for sequence purposes but also for the cyclic use of the space.
- Frequently, the synthesis is created over a Simultaneous-Activities-Chart, which is a graphic simulation that was done manually.

When the programs for simulation of construction operations began to be known during the 80s, the PMU understood how this tool would help them in their daily activities, so they decided to adopt the technique.

It can be concluded that the simulation was implemented to satisfy the operating need of an already established group that had the basic objective of productivity improvement: the function exists, the tool is useful.

The PMU tested the existing simulation programs, creating models of different construction processes, and decided to adopt the CYCLONE methodology in its PC version: MicroCYCLONE.

To our judgement, the model should comply with two essential conditions. First, the faithfully reproduction of the reality, which is done with more or less difficulty by all the tested programs. It is just a matter of a costly learning done by the specialist.

The second condition is intrinsic in the relationship between the PMU and the production personnel: the proposed modifications must be based and understood by the client. It is not possible that the client specializes in the design of the models: we consider more than enough that the client understands, with few explanations, how the designed model developed by the specialist, works.

The second condition was the major cause that made Dragados choose MicroCYCLONE as the simulation tool. The few numbers of elements used in its models facilitates its quick comprehension by the site personnel.

MicroCYCLONE, been in constant evolution, thanks to the effort of Professor Daniel W. Halpin, was adopted with enthusiasm by the PMU. The cordial relationship established between both parties allowed Dragados to create their own version of the software, called PROSIDYC. In this version of MicroCYCLONE some improvements of special interest to the PMU were added:

- A new input module, interactive and controlled key by key, to assure the quality of the information being introduced.

- Multiple Links with their origin on a single QUE. The relationship between two nodes can be defined as multiple. For example: M6, which means that 6 flow units are required in the QUE so the corresponding COMBI operation can be processed. This is especially useful to create from a single QUE, groups of different sizes for distinct operations.

- Multiple Links with their origin on a node, not on a QUE. In this case, M6 means that one flow unit is processed in the link delivering 6 flow units to the follower or successor. It works as a GEN QUE but without the need to introduce a QUE in the model.

- Links with opposed directions or double arrowheads. It represents a double relationship: the two related nodes are origin and ending. It only has the purpose of simplifying the drawing of the model.

- Resource Reports Module expedites information about the saturation and production capacity of each resource and displays the bottleneck, which is the direction for the most useful change.

- Simultaneous-Activities Chart. This report is the most effective for implementing the optimized results. It explains with all the details how the work should be organized and it is easily understood by all the project's chain of command.

PMU uses PROSIDYC frequently in all type of construction processes: tunnels, maritime projects, dams, highways, etc.

The case that follows evolves over a precast factory. However this should not induce the error that fixed installations are the most appropriate use for this technique. Conversely, this case has been selected because of the major difficulties getting substantial results in fixed locations, where the processes are being improved more times than in regular operations.

2 THE PRECAST WORKSHOP

A tunnel of 5,850 m. long was excavated using an Earth Pressure Balance (EPB) machine for the execution of a sewer collector of 6,353 m. long and with an excavation diameter of 3.25 m. Most of its length was underground. The collector lining was made of precast concrete. The cycle of the EPB machine comprised two phases: advancement of 1.2 m. of the excavation and install of a ring of the same length, composed of 6 precast segments.

The objective of this analysis was the fabrication of the precast segments. The total production was 4,875 rings, which is equivalent to 29,250 PS. When the analysis was made 88% of the total PS were remaining to be produced: 25,600 PS.

The following description of the observed and proposed situations avoids the inclusion of details that could distract the attention over the important aspects about the improvement of the process.

2.1 Observed Situation

A production of 150 PS per day has been reached with the following schedule:

<u>Day Shift</u>

From 07:00 to 19:00 with interruptions from 9:00 to 9:20 and from 13:00 to 14:10.

<u>Night Shift</u>

From 19:00 to 07:00 stopping from 22:00 to 23:10 and from 04:30 to 04:50.

The effective schedule resulted in 21 hours/day.

2.1.1 Description of the Process.

For molding the pieces vibrating tables were used complemented with 4 lateral closings and 2 top lids. The tolerant dimensions were very strict, thus the cost of the formwork was very high.

The curing used steam to allowed several concrete pourings per day. There were 54 tables for the production of 150 PS. The production rate was about 2.78 PS per day and per mold. This is equivalent to a practical forming cycle of 8.64 hours (518 minutes).

All the activities turned around the molds. Tracing the activities reveal the complete process.

Once the steam-curing cycle of the piece is completed, the next operations follow:

Stripping Phase 1

A crew of 4 workers strips the canvas that covers 2 PS during the curing and dismantles: the top lids, the lateral closings, and hole negatives.

Lifting the pieces

An overhead crane takes the piece from the mold and transports it to the end of the workshop, where is placed over the others to form a ring.

Stripping Phase 2

The same crew of phase 1 cleans the formwork and applies oil and paraffin.

Forming

A crew of 4 workers installs the closings, lids, and the spacers.

Supply of Reinforcement Cages

A crew of 2 workers with a pushcart supplies the reinforcement for 12 PS per trip.

Concrete Pouring

A gantry crane and a crew of 2 workers pour the concrete in batches of 6 PS with two bucket discharges for each PS. Hence there are 12 discharges per batch.

Finishing

A crew of 4 workers does the superficial finish.

Canvas Covering

The reinforcement team gets a canvas to cover 2 PS.

Temperature Control

One worker is in charge of controlling the thermal cycle of the curing process.

Each piece follows its cycle up to the lifting operation previously indicated that ends with the formation of a ring. The process of each ring comprises these subsequent phases:

Transport to Stock

It is executed with a forklift and 2 workers.

Repairing

The possible damages are repaired with 2 workers that also irrigate the pieces frequently during the first day.

Final Control

The foreman is in charge of identifying and marking the PS: type, date, and fabrication number.

The complete group comprises 24 workers, 54 molds, 1 o/h crane, 1 gantry crane, 1 fork and 27 canvas.

2.1.2 Duration Analysis

As a previous step to any analysis it is fundamental to obtain reliable and detailed information about the duration of each phase and the resources that employs. The tools for this are: Time Study to measure the machine cycle, and Work Sampling to measure the human work.

The following tables show the durations measured for each phase of the process. In order not to overwhelm the reader the analysis is shown with slight detail for the first phases of the process. Afterwards is the summary of the results of the complete process.

Team for Stripping Phases 1 and 2: 4 workers.

There are three types of PS. The work was measured for the three types. The information related to the most frequent PS is:

Phase 1

Task	Worker.minute/PS	%
Retrieve canvas	1.75	10.7
Loosen screws	3.65	22.3
Withdraw inserts	1.25	11.9
Retrieve woods	0.35	2.1
Open closings	6.90	42.1
Remove negatives	0.25	1.5
Lift lids	0.35	2.1
Total	16.40	100.0

Phase 2

Task	Worker·minute/PS	%
Clean forms	19.25	72.6
Air blow	1.25	4.7
Apply paraffin	6.00	22.7
Total	26.50	100.0

The work used in both phases and in the 6 PS of a ring is 240 Mn (4 Man·hour/ring).

Lifting the Pieces : 1 overhead crane.

The cycle of the overhead crane comprises the following durations for a transport distance of 58 m.:

The cycle, in minutes, based on the distance d is:

$$Ci = 2.7 + 0.05d \qquad 12\text{ m} < d < 110\text{ m}$$

Fluctuating within a minimum of 3.30 min. and a maximum of 8.20 min.

<u>Summary of the measured durations</u>

Stripping: 4 workers.

Work quantity 240 worker·min/ring.

Average time 60.0 min/ring.

Task	OhC·minute/PS	%
Grab	1.05	18.8
Lift	0.20	3.6
Move	1.45	25.9
Drop	1.10	19.6
Return	1.45	25.9
Approximate	0.35	6.2
Total	5.60	100.0

Capacity 1.00 rings/hr.

Forming: 4 workers.

Work quantity 151 worker·min/ring.

Average time 38.0 min/ring.

Capacity 1.58 rings/hr.

Concrete pouring: 2 workers + 1 gantry crane

Work quantity 43 worker·min/ring.

Average time 21.2 min/ring.

Capacity 2.80 rings/hr.

Finishing: 4 workers.

Work quantity 76 worker·min/ring.

Average time 19.0 min/ring.

Capacity 3.16 rings/hr.

Canvas, forms, spacers: 2 workers.

Work quantity 42 worker·min/ring.

Average time 21.0 min/ring.

Capacity 2.86 rings/hr.

PS transport: 2 workers + 1 overhead crane.

Work quantity 66 worker·min/ring.

Average time 33.0 min/ring.

Capacity 1.80 rings/hr.

Ring transport: 2 workers + 1 forklift.

Work quantity 24 worker·min/ring.

Average time 12.0 min/ring.

Capacity 5.00 rings/hr.

Vibrating tables:

Work quantity 518 table·min/PS.

Average time 57.6 min/ring.

Capacity 1.04 rings/hr. (24 hr/day)

150 PS/day

2.1.3 Comments to the durations

Based on the measured durations, the bottleneck is the labor in the Stripping team, which has a production of 1 ring/hr. With the 21 hours per day, the production per day would be 21 rings, or 126 PS/day.

The composition of the teams were as described above, but in reality the foremen corrected the number of members transferring a worker from finishing to stripping, so the durations of those operations end up as follows:

Stripping: 5 workers

Work quantity 240 worker·min/ring.

Average time 48.0 min/ring.

Capacity 1.25 rings/hr.

Finishing: 3 workers

Work quantity 76 worker·min/ring.

Average time 25.3 min/ring.

Capacity 2.37 rings/hr.

This practical alignment gives a production of 1.25 rings/hr, equivalent to 26.25 rings/day and 157.5 PS/day. This production was slightly superior to the production that resulted from the cycle of the vibrating tables (150 PS/day).

A model was designed to simulate the process. First, the theoretical and real specifications were introduced to validate the design.

The duration information suggest changes toward the following directions:

a) Balance the team crews.

b) Improve the cycle of the vibrating tables. Their cycle comprises 300 minutes for curing and the time that last the crews from the stripping to the beginning of the curing phases. It was observed that to avoid interference between the crews, some tables were left without being used between successive phases. In the proposed alternatives these lags were eliminated.

c) For the same purpose, the number of vibrating tables processed simultaneously in each phase of the process is being balanced.

d) Different schedules were simulated with the purpose of maintaining an established cycle of the work for each shift and to be able to use the break time of the operators for the steam curing.

The introduction of the changes is done in subsequent alternatives and as a consequence of the corresponding simulations.

2.2 Alternatives

Alternative 1. Production: 94 PS/shift

The lags between teams are eliminated; hence the operations are done as soon as possible. Moreover the number of workers on the teams are changed: 2 workers from finishing go to stripping. The remaining teams stay the same.

After the simulation a check is done to certify that the stripping, forming, and PS transport phases are saturated while the pouring and the covering phases are still under utilized.

Alternative 2. Production: 96 PS/shift

Another worker is incorporated and the assigned tasks changes to the following:

Stripping phases 1 and 2 + PS transport: 5x2 workers.
Forming and concrete pouring: 3x2 workers.
Finishing and others: 2x2 workers.

Alternative 3. Production: 104 PS/shift

The alternative 2 team is maintained. The stripping schedule starts 30 minutes earlier.

Alternative 4. Production: 105 PS/shift

Similar to alternative 3, but the stripping team does the forming of the first three molds of the shift. The improvement in the production is not important, so new ideas are tested.

Alternative 5. Production: 105 PS/shift

The balance of the teams is done including a condition to work on the same number of PS in each phase. It is decided to pour batches of 3 PS, therefore the work for stripping and forming will be also in batches of 3 PS. The teams comprised the following:

Stripping phase 1 + PS transport:3x2 workers.

Stripping phase 2 + Forming: 3x3 workers.

Concrete pouring, finishing, others:3x2 workers.

The beginning of the stripping and forming is 30 minutes before the pouring. A reduction of the cycle of the vibrating tables is obtained. The simulation shows that the teams are left without molds one hour before the lunchtime.

Alternative 6. Production: 108 PS/shift

Identical solution to alternative 5, but the schedule is 30 minutes earlier to the lunchtime. In this solution an exact repetition of the work is reached for both shifts: 54 molds are used 2 times in each shift, leaving at the end a final situation similar to the one found at the beginning.

2.2.1 Summary of the alternatives.

The following table summarizes the important information of the performed simulations.

Alternative	PS/shift	Nº workers	W·min/PS
Original Operation	64	18	179.4
Alternative 1	94	18	120.6
Alternative 2	96	18	131.2
Alternative 3	104	20	121.2
Alternative 4	105	20	123.8
Alternative 5	105	21	126.0
Alternative 6	108	21	120.5

Each of the alternatives is documented with their corresponding model and a Simultaneous-Activities Chart of the teams. Its inclusion in this paper is impossible for its size. The Chart showed a solution that used 14 pages with size DIN A4, representing work durations of a few minutes along 750 minutes, more than half a day.

2.3 Implementation

Alternative 6 was proposed to the factory management in a meeting realized on September 9. The presentation took place following these steps:

a) Explanation of the initial situation model.

b) Comments about the results obtained from the simulation of that situation.

c) Successive modifications to the model, including the proposed changes.

d) Comments to the problems detected when simulating each modification.

e) Presentation of the proposed alternative model.

f) Detailed analysis of the reports from the proposed simulation, especially from the cycle obtained from the Simultaneous-Activities Chart.

Top and middle managers easily understood the presented information, both the models and the charts.

The simulation was a persuasive tool. The meeting ended at 18 h. The factory management decided to begin the proposed changes with the shift that began at 19 h.

The production evolve as showed in the following table:

Date	Shift 1	Shift 2	Total day
Sep. 13	78	103	181
Sep. 14	91	108	199
Sep. 15	100	101	201
Sep. 16	99	86	185
Sep. 19	108	108	216
Sep. 20	108	108	216
Sep. 21	108	108	216
Sep. 22	108	102	210
Sep. 23	108	105	213
Sep. 26	108	108	216
Sep. 27	108	103	211
Sep. 28	108	108	216
Sep. 29	108	101	209
Sep. 30	108	108	216
Oct. 03	108	108	216

The established production of 216 PS/day was reached during the 5^{th} day and it kept constant during 3 consecutive days. Afterwards there were some slight losses due to the slower adjustment to the steel supply.

3 OTHER STUDIES MADE BY DRAGADOS

The number of processes analyzed with the help of PROSIDYC/MicroCYCLONE is now very large. Only a reference will be made to some cases that could provide more interest for the application to certain objectives that are different for each case.

3.1 Transportation of a Floating Caisson

For the construction of a pier floating caissons of large dimensions (42.25 m. long, 15.65 m. wide and 16.5 m high) were fabricated.

The shaft was poured using two pumps of 50 m3/hr capacity each, located below a concrete plant. The plant prepared the concrete and discharged it to a hopper that fed the pumps.

When the support structure for the sliding formwork were passing, the pumps had to interrupt the pouring process. Because of the severity of these frequent stops the capacity of the hopper had to be reconsidered so the fabrication and pump worked independently.

The simulation allowed the calculation of the precise volume, getting a very important increase in the production (45%).

3.2 Concrete Fabrication

A concrete plant was bought to a supplier that assured a production of 50 m3/hr. In its first use the production did not pass the 33 m3/hr.

Due to a Dragados request, the supplier dispatched a technical team to the site to try to improve the production. They made some corrections that improved the quality of the process but not the real problem.

Doing a simulation of the plant cycle a possible improvement was detected that allowed to reach a production of 43 m3/hr. The supplier adopted the improvement impressed by the tool that was used.

3.3 Pouring of Roller Compacted Concrete dams

The arrangement of the work, layer by layer, needed to pour the concrete of a Roller Compacted Concrete dam, is design very easily using a model for the concrete extension, compaction, upstream and downstream formwork, and other needed operations.

For this, the plant is divided in the layers that are going to be extended. Each layer is divided in zones that can be poured on a single pass. All the work is related to those zones.

The result of the simulation, specifically the Simultaneous Activity Chart that is obtained, is a detailed plan of the activities to be done in each zone.

3.4 Track Renovation

Train tracks are being renovated, changing the grade and the entire infrastructure. The work is being done in a short schedule (6 hours per night) where the traffic is interrupted.

Intense coordination, in addition to the space limitations, is required between the different resources necessary to complete a segment each night and open it to traffic. Simulation can solve the problem without the risk of adopting a wrong set of tasks.

Being cautious hampers the execution of tests that have the risk of failure. The consequence is that only short production objectives are then planned.

Simulation has been applied to avoid these problems, getting increases in the daily production that doubles what was initially estimated. The improvements are then adopted for the next projects.

3.5 Blasted Tunnels

The excavating cycle of a tunnel always depends on the scarcest resource: the available space. At the front of the excavation all the operations are done one after the other: shooting the alignment, excavating the front, shoring, blasting, and debris removal, etc.

The improvement of the excavation cycle usually pass through two paths:

- Simultaneous activities in the front.
- The flow of the communications with the exterior.

Both cases try to use the space in the best possible way: the front space for the first one and the space between the front and the exterior for the second.

The analysis of the simultaneous activities in the front and the transports, with the use of simulation allowed important improvements of 20% in the excavation cycles.

3.6 General Directions.

We understand that simulation is especially useful in the analysis of processes that require a strong coordination, regularly because of imposed conditions by a limited space.

Similarly it is very useful in those cases of opposite characteristics: the activities are not done with a mandatory sequence of tasks but rather with already defined priorities.

In general, the models that have been more useful encompass QUEs and COMBI operations. The NORMAL tasks are very rare. This reveals that there are several conditions and options. The presence of large number of NORMAL tasks shows that the modeler already made certain decisions. This could be mandatory in which case the simulation will not be very useful. If the tasks are sorted, all the best possibilities for improvement are eliminated: that is an error.

AUTHOR BIOGRAPHY

EDMUNDO BALBONTIN-BRAVO is the Dragados head of the Planning and Methods Division. He received a B.S. degree in industrial engineering from Escuela Técnica Superior de Ingenieros Industriales de Madrid. With 30 years of experience in the application of planning and project management techniques that he constantly transfers to the new generations in several academic activities, both in internal courses for Dragados and in collaboration with academic institutions that offer construction related Masters degrees.