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ANALYSIS OF SCHEDULED ENGINEERING DESIGN

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ABSTRACT

This paper concerns the analysis of Engineering Planning times for a Direct Fired Heater using a Six Sigma approach. The purpose is the validation of congruency between scheduled engineering design activities and the performed ones. The analysis aims to discover the relationship between scheduled times and performed ones, trying to discern the causes that may create any delay/advance in delivery dates. This because any delay may create a "reactive" *Over-Run* (where Over-Run means every extraordinary time spent by a resource over his established labour time), or that may cause the delivery to be early, thus creating a "forecast" *Over-Run*.

Since the Six Sigma methodology is strongly focused on an analytical approach in order to resolve any kind of problem attacking the route-causes, this paper shows the flexibility and the power of the methodology, even though this is a study (not a complete project), to achieve a better knowledge of the process (planning times activities), by means of numerical and statistical tools. In particular to improve the design of scheduling activities, the paper describes an application of Quality Function Deployment (QFD) and Axiomatic Design (AD)

Keywords: Six Sigma, Over-Run, Schedule Variance, Budget Variance, QFD, AD

1 INTRODUCTION

Scheduling activities, although necessary, are Not Value Added (NVA) from the Lean perspective. The state of the art shows that a Lean Six Sigma project rarely aims to resolve this kind of problem, because even if its importance is very easy to understand, it is difficult to determine a consistent Hard Savings related to them. In terms of Soft Savings, they are potentially determined from a preventive action related to good scheduling. For this reason, scheduling activities are very critical for every company where the man-hours are their main effort for Value Production, such as an Engineering Company. In particular this paper concerns an International Engineering Company, which has 35 years of experience in designing and implementing equipment and lines for the chemical, petrochemical and refining industries. This Company selected a "Pilot Project", in order to make a detailed comparison with the real delivery dates through a simulation of the progress of the activities done. It is based on a new and more in depth scheduling, according to the actual Furnaces Department planning logics. The simulation was necessary to accomplish the entire analysis into a short time period (2 months) compared to the natural length of the project (12 months).

Following the Six Sigma route, the first step requires the Problem Statement to be clarified and defined. This included the selection of a metric that would be able to show the difference between scheduling and performing times due to planning process.

The Measure phase concerned the simulation of the progress for the pilot project. This led us to see the amount of delay/advance due to planning activities.

Then, using statistical tools (Regression models and DOE) and an Axiomatic approach with Quality Function Deployment (QFD), we have been able to analyse the delay/advance times. This enabled us to find the root causes of a significant difference between the scheduled and real delivery times.

2 DEFINING RING AND VARIABLES

Once the Business Case is clearly described as the reason that it is worth understanding the causes that may create any delay in delivery dates compared to scheduled dates, the ring of the analysis is defined including every engineering activity (concerning Process Calculations, Technical Drawings and Material Requisition). We decided to consider out of scope the Prefabrication activities after the Procurement of the Material Requisition and the Commercial Proposal before the Process Calculations activities (Figure 1), because these are not engineering activities, but respectively a consequence of all the design phases and a pure commercial activity.

Then the Earned Value Analysis (EVA) was applied to choose the Scheduled Variance Indicator (SV) as the CTQ for the delay/advance measures. The EVA aims to measure, in a typical use, the project progress compared to the scheduling. In particular EVA defines the Earned Value (EV) as a performed work in terms of man-hours (and, of course, in terms of $, once the cost per hour of each resource is known). The analysis concerns the observation of the growth of the EV (which is a cumulative function) while the project develops over time.

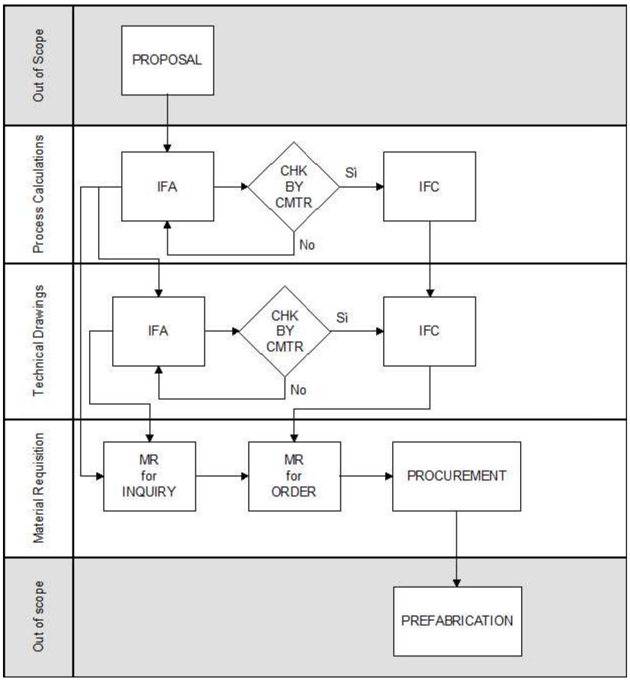

Figure 1. Ring and hierarchy definition.

The EV scheduled is normally different from the one performed, so the EVA compares the EV scheduled (called the BCWS function, that is *Budget Cost Work Scheduled* function) with the real EV in terms of effectiveness (the BCWP function, that is *Budget Cost Work Performed* function) and in terms of efficiency (the ACWP function, that is *Actual Cost Work Performed* function). This comparison determines two different indicators: the Schedule Variance (SV) and the Budget Variance (BV) as shown in Figure 2. The first provides an delay/advance measure, while the second provides a costs/savings measure. In this paper we considered just the first indicator.

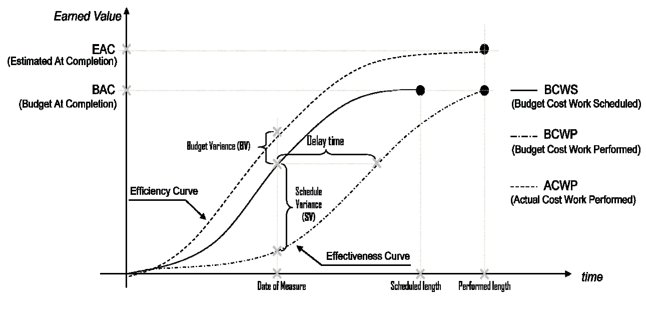

Figure 2. Elements of the Earned Value Analysis.

3 PROGRESS MEASURE

Before starting new scheduling, a definition of a criterion to determine which deliverable can be representative of a significant step of the project was necessary. Therefore it was decided to include in the scheduling every released document as:

- IFA (Issue For Approval), IFC (Issue For Construction) and CHK BY CTMR (Check By Customer) for Process Calculations and Technical Drawings activities;
- MR for Inquiry, MR for Order and Procurement, for Material Requisition activities (Figure 1).

Then the Earned Value Analysis was applied to weight every released document in a man-hours dimension. Thus, it has been possible to measure man-hours as CTQ and, of course, calculate:

$$BCWS_i = \sum_{j=1}^{i}(man\_hours_{scheduled})_j \quad (1)$$

$$BCWP_i = \sum_{j=1}^{i}(man\_hours_{performed})_j \quad (2)$$

$$SV_i = \sum_{j=1}^{i}(man\_hours_{performed})_j - \sum_{j=1}^{i}(man\_hours_{scheduled})_j \quad (3)$$

$$SV_i = BCWP_i - BCWS_i \quad (4)$$

that implies:

$$SV > 0 \Rightarrow Advance$$

$$SV < 0 \Rightarrow Delay$$

Where:

$$j = early\ date,$$

$$i = late\ date$$

As a consequence of the SV definition, SV becomes a Cumulative Indicator and provides the advance/delay information except when it is zero, indicating agreement between scheduling and performance. Further, the BCWS (Budget Cost Work Scheduled) is the cumulative curve that defines the scheduled man-hours due for the entire project and the BCWP (Budget Cost Work Performed) is the cumulative curve that defines the same man-hours for the entire project, but at a different date (indicating a different length for the entire project). The SV indicator, calculated as the difference between BCWP and BCWS, is an indicator of effectiveness for scheduling activities.

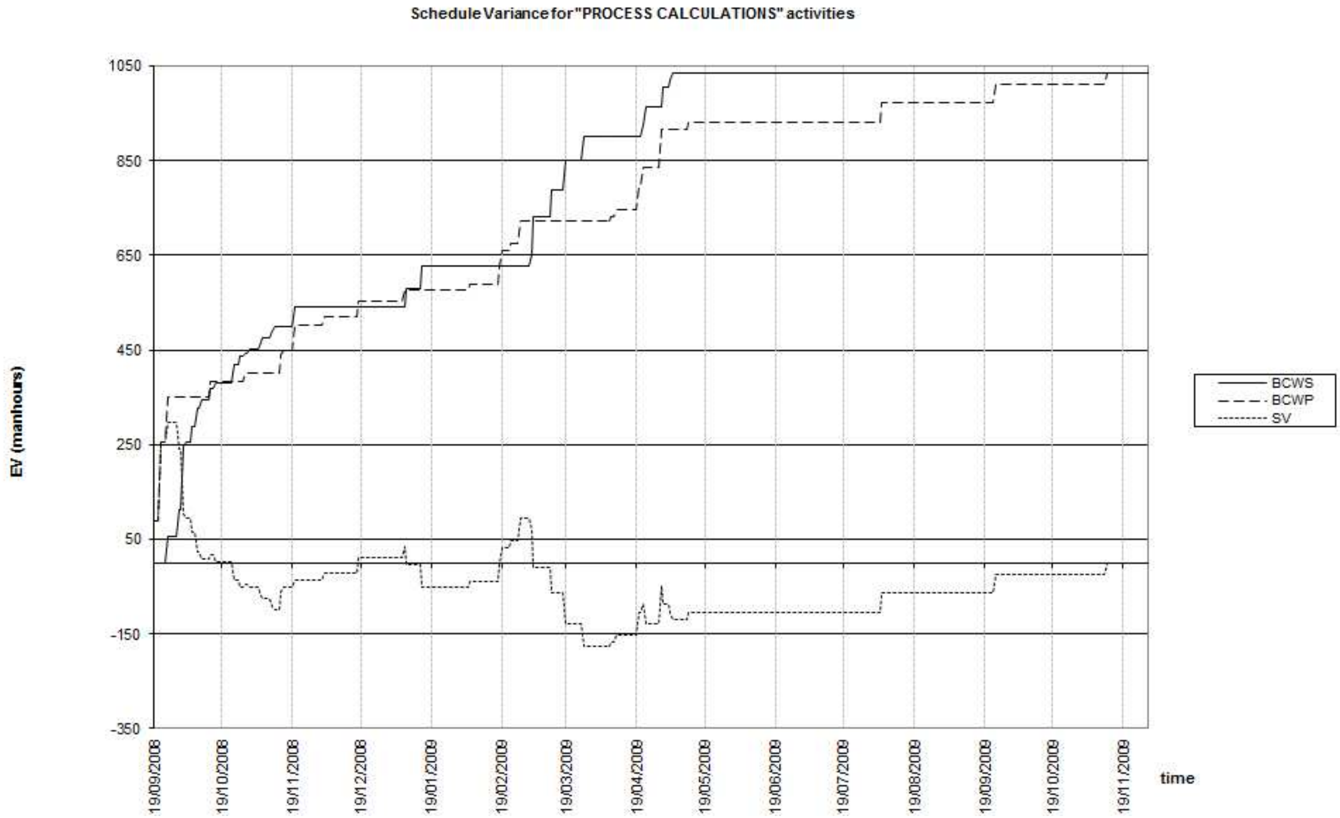

Figure 3. Schedule Variance for "Process Calculations" activities.

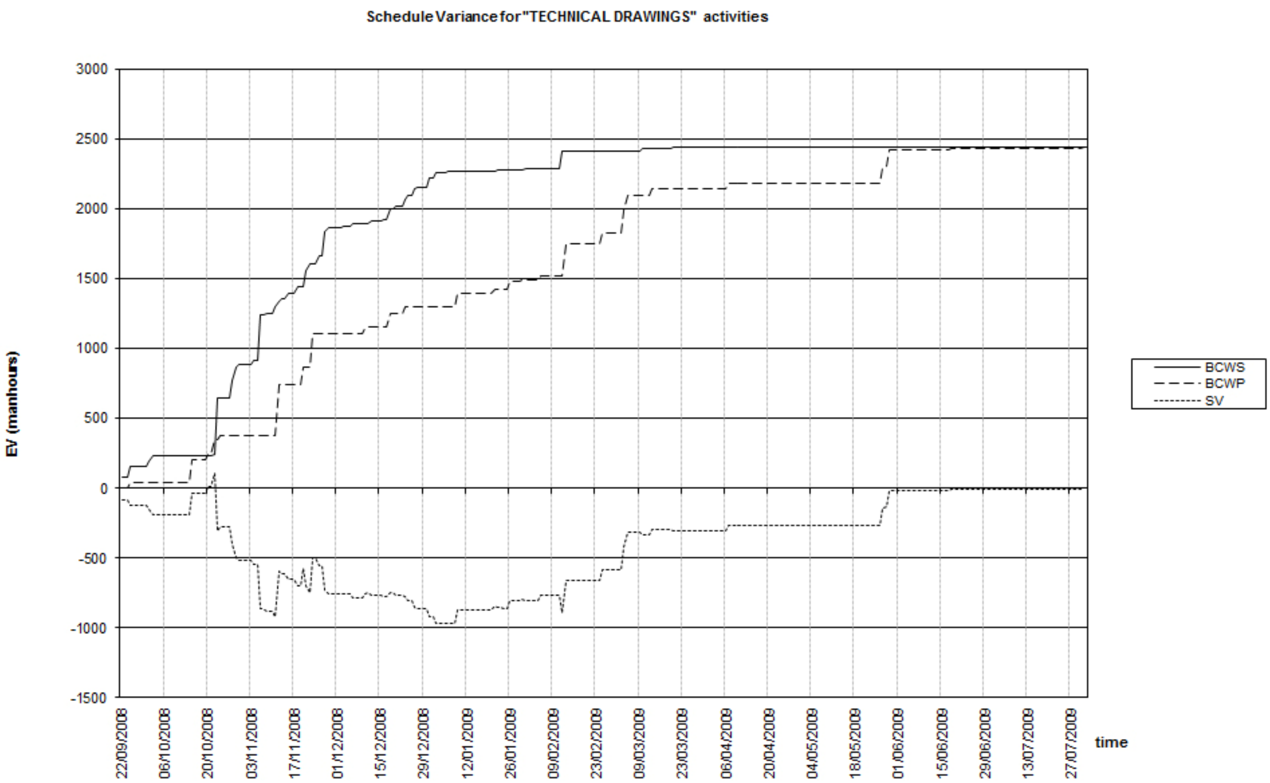

Figure 4. Schedule Variance for "Technical Drawings" activities.

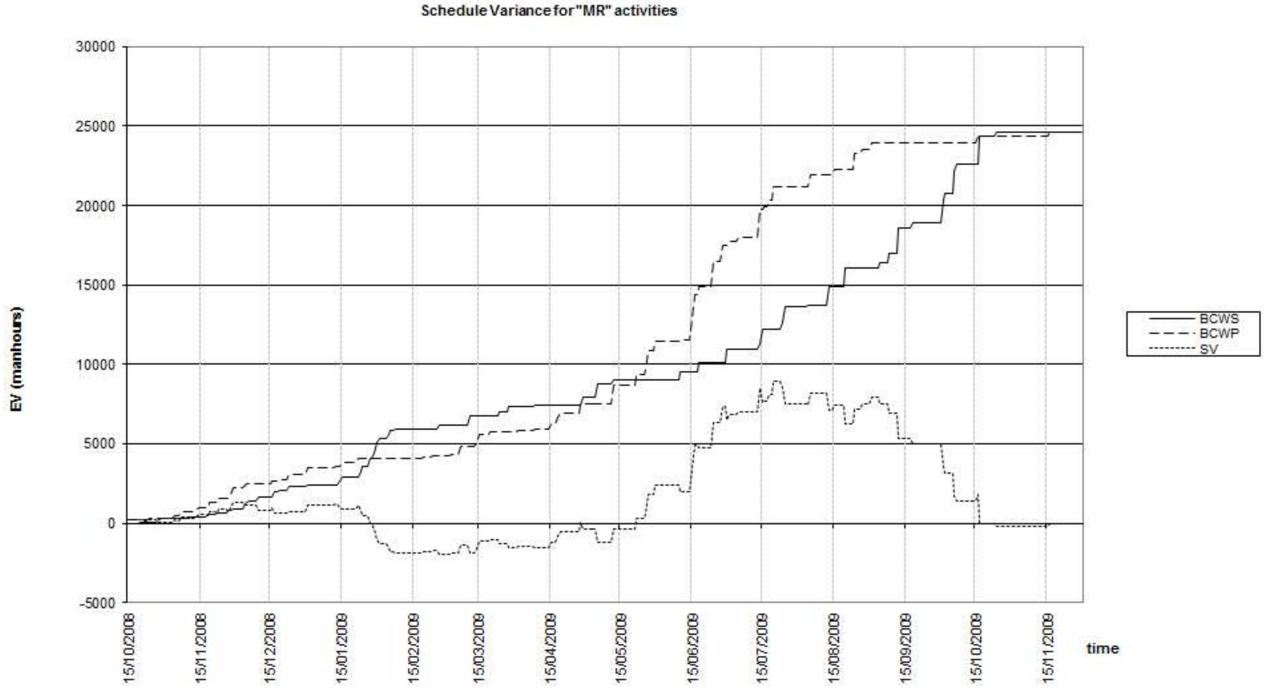

Figure 5. Schedule Variance for "Material Requisition" activities.

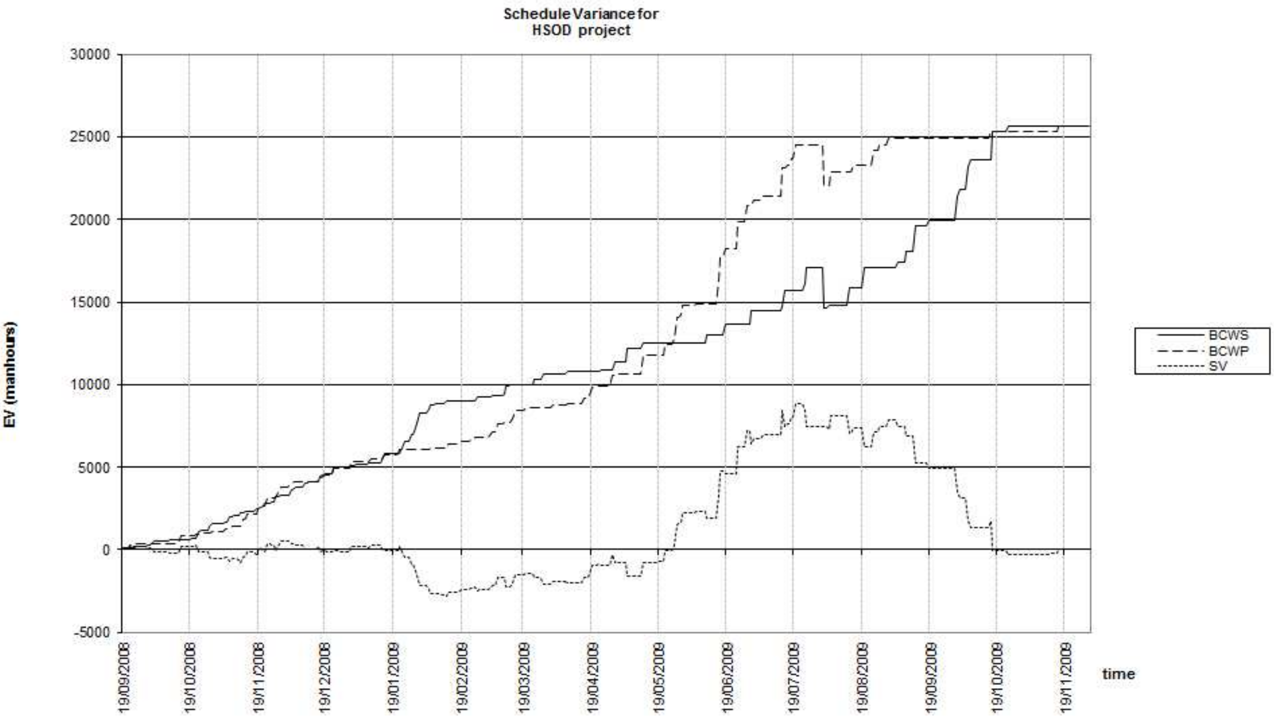

Figure 6. Schedule Variance for “HOSD” entire project.

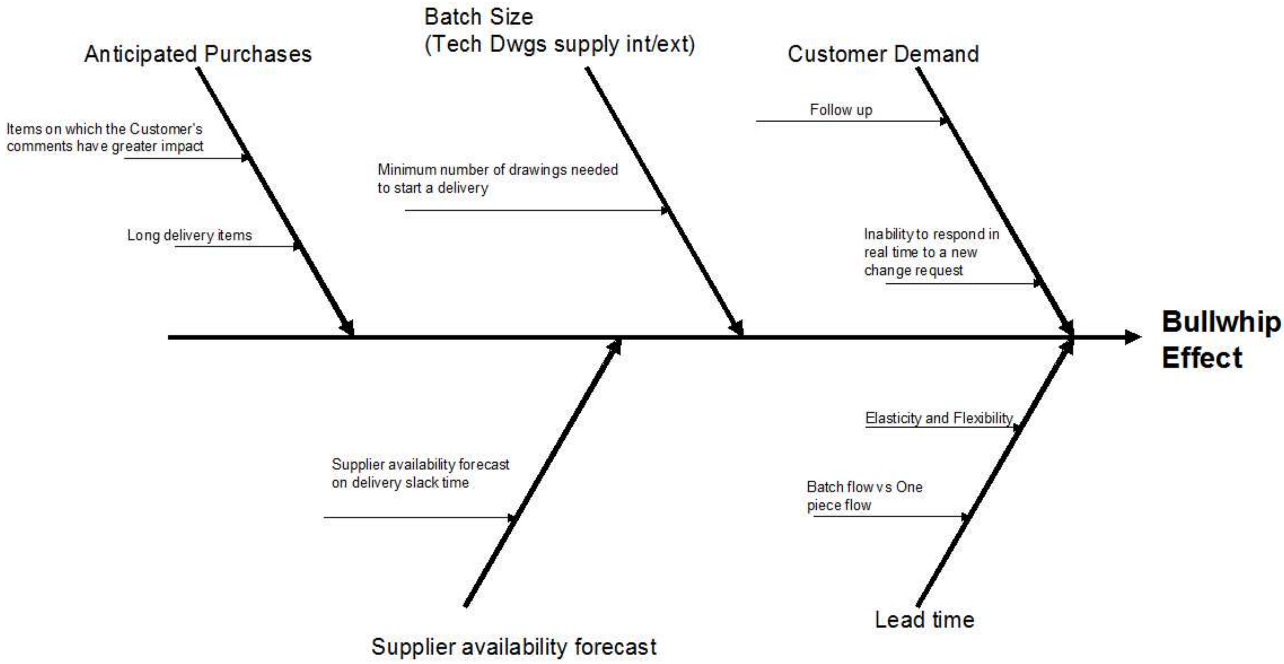

Figure 7. Fish-bone diagram for Bullwhip Effect.

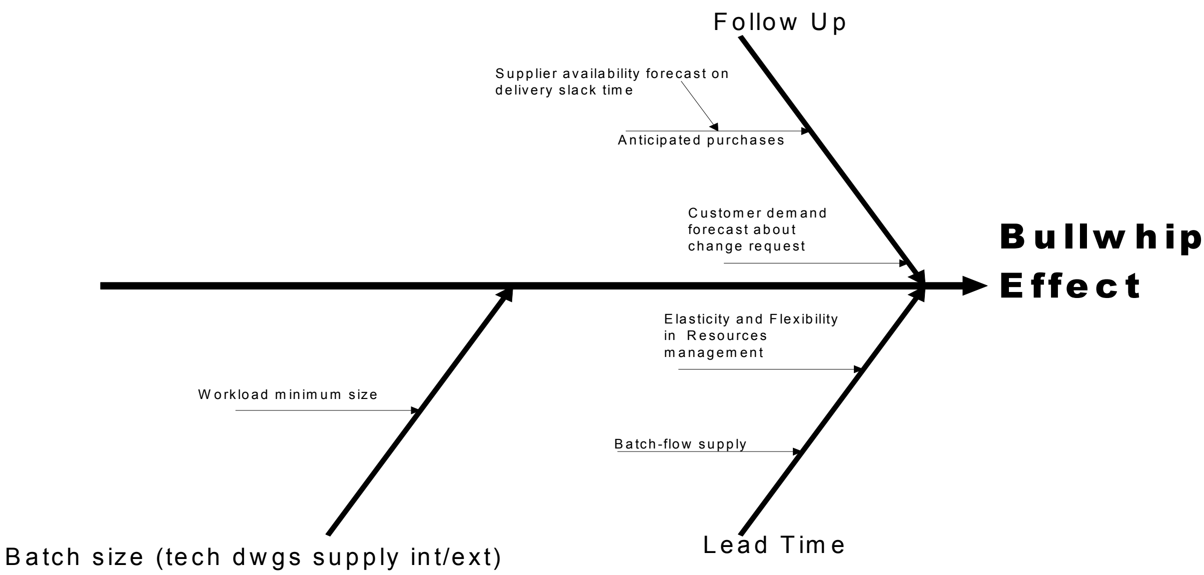

Figure 8. Fish-bone diagram for grouped causes.

4 DATA ANALYSIS

Observing the graphs for the three steps of design activities (Process Calculations in Figure 3, Technical Drawings in Figure 4, Material Requisition in Figure 5 and the entire project in Figure 6) it is possible to find three different behaviors for the SV indicator (one for each step) that are sequentially and physically linked to three events, such as:

1. Phase displacement (and small amplitude, Figure 3);
2. Oscillation (with increased amplitude, Figure 4);

3. Amplification (with more increased amplitude, Figure 5).

A behavior that follows this sequence of events may be explained by means of the "Forrester Effect" (or "Bullwhip Effect") and it is more evident in the MR activities, because of the great number of man-hours dedicated to them and the great distance between the prevision date and the performance date (according to the supply chain, in which the Bullwhip Effect is as larger as the forecast is more distant from Customer demand). Thus, referring to this effect, it is necessary to search for the root-causes among the five known causes of the bullwhip effect, such as:

1. Customer demand;
2. Supplier availability forecast;
3. Lead time;
4. Anticipated purchases;
5. Batch size of supply.

So, the first analysis was conducted trying to address any possible activity inside the design planning management to the five Bullwhip causes, by implementing a Fish-bone or Ishikawa Diagram (Figure 7). Then, by a successive affinity diagram, a group has been created for each activity that addresses the same effect (where each effect was a Bullwhip cause). In this manner it has been possible to create a new Fish-bone (Figure 8) grouped by potential Over-Run causes that may generate one or more of the five known Bullwhip causes.

For a better understanding of the Bullwhip Effect generation, the SV on the Critical Path that was calculated for all three steps has been examined. Since the indicator has a normal distribution (Figure 9), it means that no special causes affect the scheduled delivery time, but, as shown by the IP Chart (Figure 10), the MR activities are those that suffer the most variability: Thus, these activities are the probable source of an Over-Run generation.

5 DESIGN IMPLEMENTATION USING QFD AND AD

Once the macro-causes of the Bullwhip effect are identified we want to do the scheduling activities on a more robust perspective.

Up to now we have followed the DMAIC approach, typical of Six Sigma, but after a correct application of a Define, Measure and Analyze step it's necessary to redesign the process and not only improve it. So it is more correct to apply the Design for Six Sigma (DFSS) approach using QFD and AD.

In particular, the application of only the third step of QFD Cascade (QFD3) is enough due to the information collected so far. The FRs are previously identified through SV. In the Physical Domain, we can define the DPs such as the 5 steps of the activity (IFA, IFC, MR for Inquiry, MR for Order e Procurement), while in the Process Domain (by means of the Fish-bone) the PVs are Numbers of Customer's Comments, Follow up, Long delivery items, Numbers of drawings and Forecast activities.

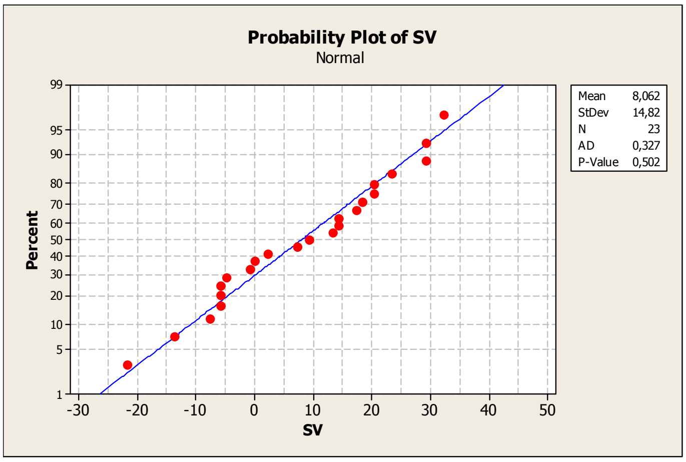

Figure 9. Normality Test plot of SV for activities on critical path (normal distribution).

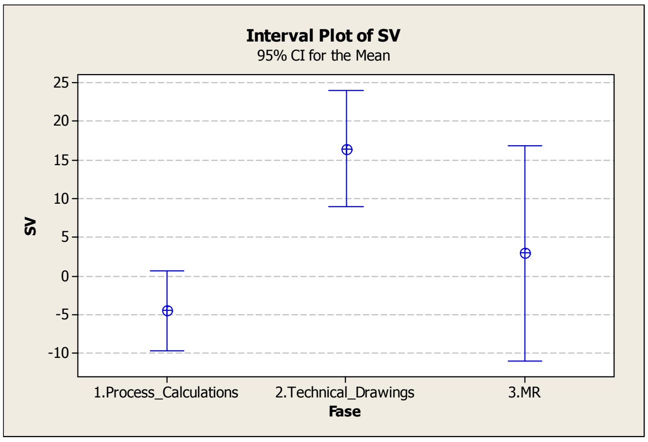

Figure 10. Interval Plot of SV for activities on critical path (sensible difference in variability between 3 steps).

The QFD (Figure 11) DPs vs PVs allows us to find the Relationship Matrix necessary to find the Transfer Function to be optimized through the first Axiom of Axiomatic Design.

In the Relationship Matrix Θ indicates a strong relationship, O indicates a moderate relationship, and ▲ indicates a weak relationship. In the correlation matrix, ++ indicates a strong positive correlation, + indicates a positive correlation, - indicates a negative correlation and -- indicates a strong negative correlation.

This aims to reduce the misalignment between BCWS and BCWP in a oscillation randomly distributed to each other (reducing the Bullwhip effect in phase displacement).

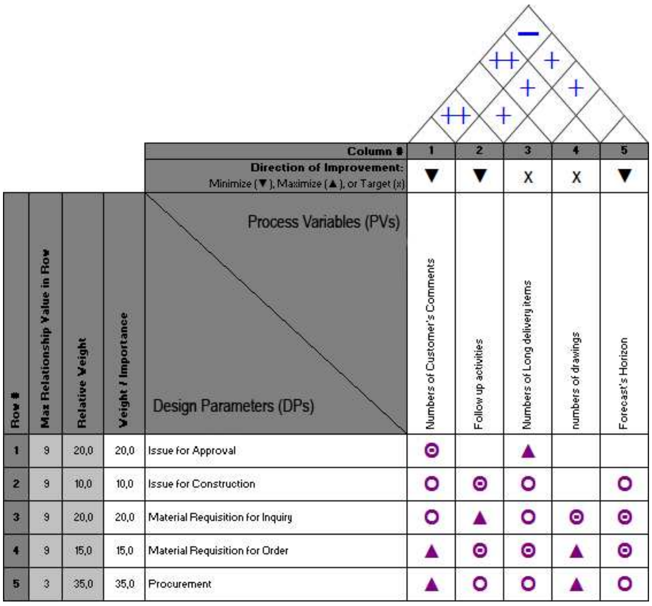

Figure 2. QFD3 Relationship Matrix DPs vs PVs

After obtaining the Relationship Matrix (Figure 11), it is possible to study the relationship deeply through a Regression model (it is ongoing) where the database is available. Otherwise, in the absence of data it is necessary to use Design of Experiments.

6 CONCLUSIONS

Some tools of Six Sigma/Design of Six Sigma and the rigor of the approach allowed a clear comprehension of the planning times through a numerical analysis. Further, through the usage of the EVA it has been possible to discover that the Bullwhip Effect for the SV indicator increases during the three steps of the pilot project. This means there are one or more Bullwhip Effect causes inside the scheduling activities, as synthesized in Figure 8.

Of the three potential Over-Run groups just the Lead Time is strictly dependent on the internal planning management. Thus, it is the first one which must be addressed in order to solve the Bullwhip Effect, because Follow-Up and Batch Size management are bound to Customers and Suppliers agreements respectively. Furthermore, since the activities on the Critical Path are normally distributed, they are not involved in variability generation. For this reason it is useful to focus on non-critical activities because it is easy to manage slack time to reduce global Lead Time for non-critical activities. In fact, slack time is like a “stock” of time that could be cumulated. For instance, consider the case where the Customer demand forecast about change requests (Figure 8) is greater than the effective one. This could cause an excess of advance time as shown in Figure 6. That, in turn, amplifies the behavior of the Bullwhip Effect. So any improvement that reduces the Customer demand forecast implies a reduction of slack-time management and, consequently, the Bullwhip Effect and its related Over-Run. The proposed improvement in terms of Robust Design of scheduled times required the use of some tools of DFSS such as QFD and AD. This allowed the creation of a Design Matrix (called in QFD Relationship Matrix) DPs vs PVs and the relative Transfer Function between the Physical and Process Domain. At the present time, data collection is ongoing in order to create Regression Models able to calculate the coefficients of the Relationship Matrix that will be the Sensitivity Matrix for the Transfer Function.

7 REFERENCES

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