Predicting and Measuring The Value in Process Change:
A method and automation tool to qualify process improvement investment

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Abstract

Challenges to product development (PD) groups arise when consideration is being given to the manner by which complex (always iterative) development processes might be improved, how much to invest in improvements, and in predicting what the expected improvements might yield in business terms. To answer this challenge a tool has been developed by the author, based upon a methodology that is an extensive adaptation of the Design Structure Matrix (DSM) method, Steward[1] 1981; Smith and Eppinger[2] 1997; Cronemyr, Ronnback and Eppinger[3] 2001.

The analysis of process and the qualification of investment is enabled by an Excel-based DSM Process Analysis (DSM-PA) tool. The Tool allows for the definition of, and analysis by, current (As-Is) and future (To-Be) manifestations of PD processes, in terms of:

- Overall process design
- Task sequence
- Task times
- Labor and material costs
- Process variability

The method and Tool are used to evaluate the direct time and financial impacts that can be expected from proposed changes to the process, both in its structure and the efficiency/effectiveness of each task in supporting the process as a whole. Ultimately the cost of effecting the proposed process changes is used in developing a projected Return on Investment (RoI) for the improvement program.

The methodology and the tool serve the Quantitative Process Management (QPM) requirements of capability maturity models such as CMMI and VPDMM, and the Measurement/Analysis stages of 6 Sigma DMEDI/DMAIC procedures. They might be used by any level of program manager with fiscal responsibility, providing for a way to both:

- Define and quantify changes to processes
- Qualify the removal of benefits (e.g. resources) from the system that otherwise would quickly adapt and use those generated benefits in hidden ways.
- Provide a method for constant monitoring of processes so that constant improvement can be effected.

1. BACKGROUND

The constant maturation of PD methods and environments, in both the physical and virtual contexts, demands that attention be paid to the people, technology, process and data attributes. Capability maturity models, including that of MSC.Software for VPD[4], show that to transition from low to mid-levels of capability maturity (2 to 3) requires a significant focus on process and data management. Since most manufacturers can exhibit a level-2 maturity at best, the current change emphasis within product engineering is placed upon those two attributes specifically - process improvement and data management. However, the transition from level-2 to level-3 maturity represents something of a glass ceiling (Figure 1. *Glass Ceiling: An upper limit to advancement that is not readily perceived or acknowledged*) to many PD groups because of the cultural and financial challenges that transition usually entails. I.e. A specific focus on process and data is new to many PD groups that are most familiar with their focus being upon developing people and their ability to use technology. The business driver for improved PD, though often cited as improved product quality and reduced time to market, reduces at the design and engineering level to improved efficiency and effectiveness.

Thus a fundamental question is posed: "How can the time and cost impacts of process improvements be modeled and tested prior to capital expenditure and execution so that realistic cost-benefits may be evaluated?"

The role of a technology partner to those with PD responsibility must be to provide solutions that holistically address change challenges associated with the four attributes of people, technology, process and data. MSC.Software recognizes this and has developed various methods and tools for effecting change and evaluating the RoI from it. A methodology and the associated tool (DSM-PA) for modeling the business impact of process and data management change are described in the following.

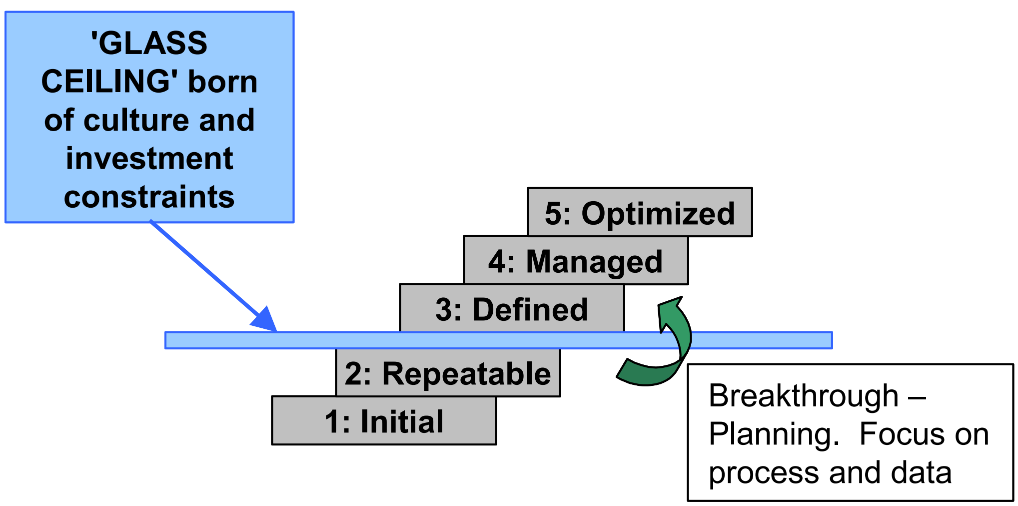


Figure 1: The VPD Maturity Glass Ceiling

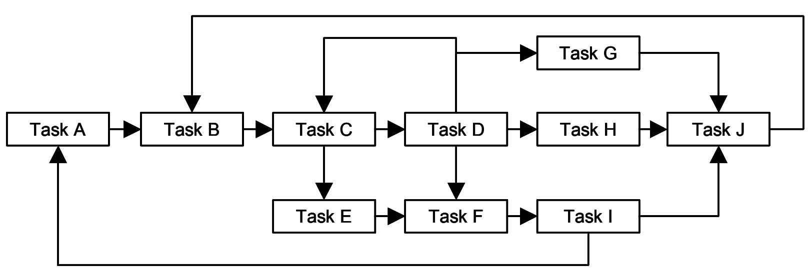
2. NUMERICAL METHODOLOGY

The numerical method of the DSM-PA Tool is based upon an adaptation of the Design Structure Matrix (DSM) method (refs 1,2,3). The latter reference indicates how a matrix-based numerical analysis might be used to evaluate the 'simulated To-Be/As-Is ratio' for the time taken for convergence of processes. The reader should read Ref. 3 for a detailed explanation of the basic mathematical model and it's usage, though in abbreviated form the method is as follows:

1. Develop a process map for the target As-Is or To-Be process, identifying key tasks within the process connected by arrows indicating the flow of data and decisions (illustrated in Figure 2 for process with tasks A through H.)
2. Convert the process map to a DSM (design structure matrix) wherein each task is represented in the rows and columns with the leading diagonal null. Populate the matrix with markers to indicate the dependency of each task (rows) upon the preceding or subsequent tasks.
3. Create the work transformation matrix (Figure 3) by converting the markers to rework fractions representing the product of (estimated probability that task will be re-worked due to iterations)*(fraction of re-work typically involved when task is re-worked). For example, if it can be estimated that during the execution of the process task G is re-worked 80% of the time as a result of the data from task D changing, and that each successive re-work requires 25% of the prior effort (a task of constantly improving quality), then the re-work fraction for task G subject to task D would be 0.2.
4. Develop a task-time vector (TTV) that represents the time taken to complete each task the first time through (Figure 3).
5. Complete the matrix algebra described in Cronemyr[3] 2001.

Work transformation factors effectively allow the amount of work (in dimensionless terms) associated with each task to be determined given a specific number of process loops (iterations). Though this metric in itself cannot guide intelligent process change, it will identify those tasks that are most highly repetitive. The cumulative work in each iteration for each task when multiplied by corresponding task times yield cumulative task times.

The numerical method imposes acknowledged limitations and assumptions, notably that the process tasks are conducted in parallel. However this is acceptable, particularly when the method is applied to a workgroup completing numerous instances of the same process simultaneously but without synchronization (i.e. in most product, application engineering or analysis groups). The method also only describes the derivation of process time to covergence (though Cronemyr[3] et. al. may have developed their methodology further since publication of the referenced material).



Process map

DSM representation

	A	B	C	D	E	F	G	H	I	J
A									X	
B	X									X
C		X		X						
D			X							
E			X							
F				X	X					
G				X						
H				X						
I						X				
J							X	X	X	

Work Transformation Matrix

	A	B	C	D	E	F	G	H	I	J
A									.5	
B	.2									.4
C		1		.2						
D			.6							
E			.5							
F				.3	.3					
G				.2						
H				.2						
I						.2				
J							.2	.3	.3	

Task time vector

A	9
B	7
C	5
D	2
E	10
F	4
G	4
H	7
I	18
J	4

Figure 2: Process map and DSM

Figure 3: WTM and Task Time Vector

2.1. Methodology Extension and automation

DSM Process Analysis

The author has significantly extended the mathematical method and encoded it all as a Microsoft Excel tool (the DSM-PA Tool). The Tool enables extensive automated process analysis to be completed quickly for As-Is and To-Be process states and for the RoI from change to be projected. The Tool differs significantly from the basic DSM method of Ref. 3 in that:

A. **The dimension of Labor Cost is added.**
The dimension of process labor cost is evaluated by mathematical product from the time dimension. Labor costs, in cost per unit of time, are defined for each task in the Labor Cost Vector (LCV). If a task represents a time-delay only then the labor cost can be reduced (or zeroed) so that an effective cost per unit time is used. Total task labor costs for a given number of process iterations are calculated as the product of cumulative task time multiplied by task labor cost. Similarly process cost is a summation of task costs.

B. **The dimension of Material Cost is added.**
Fixed costs associated with the acquisition of materials or services associated with each task are defined in the Material Cost Vector (MCV). Material costs for each task over numerous process iterations are computed from the cumulative work for each task. Material costs are independent from labor costs or task times but contribute to total process costs.

C. **A stochastic engine has been devised and included**
In the stochastic analysis the tool assumes the deterministic data values to be mean data values and permits definition of a standard deviation of each individual data value. Thus variability matrices are created quickly for all process data. Once defined a stochastic process analysis, analogous to a robust design evaluation, is completed. The tool does this using a Monte-Carlo algorithm to sample every data value in the deterministic data set for a unique value with a normal statistical distribution.

D. **As-Is and To-Be State Comparison is included**
The investigator can work in the parallel states of As-Is (baseline) process, and To-Be (conceptually improved) process, and automatically compare the variability, time and cost content of the two states.

E. **Calculation of RoI is included**
A RoI calculator can quickly use defined estimated change costs to calculate the net value of change benefits over a 5 year period.

F. **Usage Logic**
A usage logic has been developed so that the method can be effectively applied in real situations

3. ILLUSTRATED APPLICATION

Processes suitable for analysis with the DSM-PA Tool are manifold. The methodology and the tool may be applied to most hierarchical levels within product development, however the reader may find it convenient to consider application in the context of a common product functional evaluation or engineering process. The complete methodology and the tool are best described by illustrative example (following).

3.1. Usage

3.1.1. Develop the DSM numerical model of the current state (As-Is) process by objectively analyzing the process for principle tasks, data and decision flow, labor, material costs and estimated variability of all data.

3.1.2. Analyze the As-Is process and tune the model. This requires: objective evaluation of convergence rate, work, time, and cost components for each task and totals for the whole process; objective evaluation of task and process time and cost variability;

correlation of results to known or estimated total departmental/divisional expenditures per year for the process.

3.1.3. Develop and analyze the process model in its To-Be state. This requires the use of the now validated baseline As-Is state: Evaluate each task in the As-Is model in turn for it's contribution of work, time and cost to the overall process; consider the potential for changes to each task in terms of data and decision flow, re-work, task times, labor/material costs, and variability; develop the To-Be DSM model given the task by task potential changes.

3.1.4. Develop a summary of the impact from change in terms of time, costs, and reduced process variability.

3.1.5. Develop a cost model for effecting the proposed changes and complete a return-on-investment analysis using the benefits derived from process change.

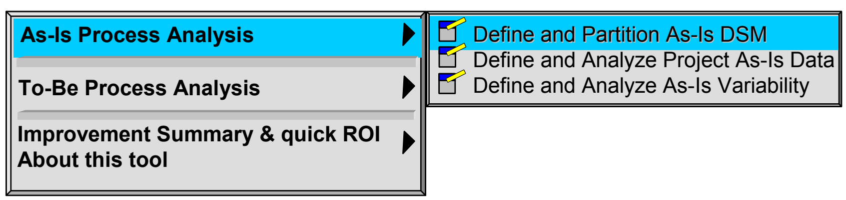
3.1.6. Use the To-Be model as a target against which to repeatedly measure the process after change has been effected. In this way validating the methodology and the investment strategy.

3.2. Background to Illustration

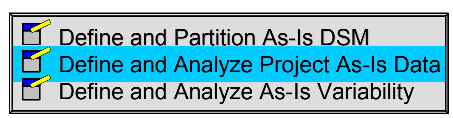
For illustration of the methodology and tool an actual product development process is used. The process is that of the application engineering of a product in response to a request for quotation (RFQ) from an automotive OEM. This process is now the subject of change, the DSM model being used for confirmation of the business justification, and for the measurement and verification of change value as it is developed. Confidentiality dictates that neither the product nor the company can be disclosed here. Additionally all data has been uniformly factored so that percentage improvements remain true but absolute values are masked. The example is rendered illustrative.

3.3. The Illustration As-Is process DSM

The As-Is (current state) process comprises 20 principle tasks. They are illustrated in the flow diagram of Figure 4. and the resultant DSM of Figure 5.



Work transformation factors replace the DSM markers in the WTM of Figure 6, together with the defined task times, labor and material costs.



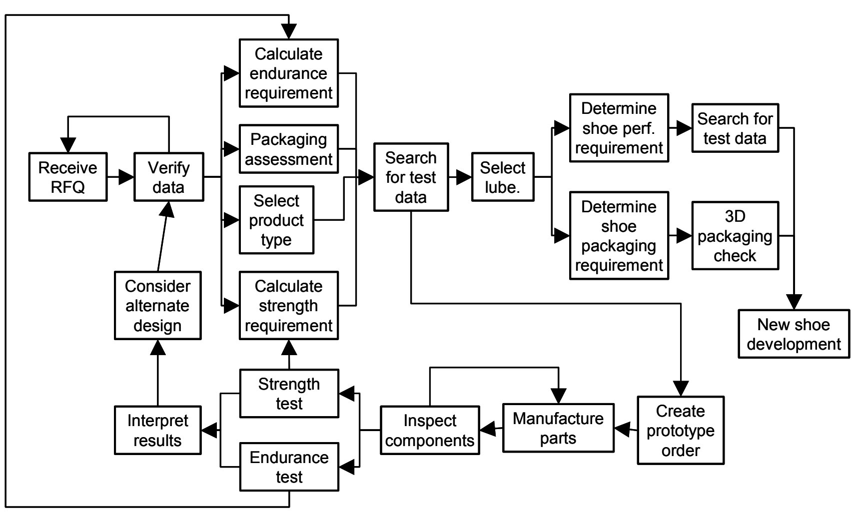


Figure 4: Process Map of Illustration Application Engineering Process

Task Names		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Receive RFQ	1		*																		
Verify required data present	2	*																			*
Calculate endurance requirement	3		*															*			
Packaging assessment	4		*																		
Select product type	5		*																		
Calculate strength requirement	6		*																*		
Search test reports for data	7			*	*	*	*														
Select lubricant	8							*													
Determine shoe performance requirement	9								*												
Determine shoe packaging requirement	10								*												
Search test reports for data	11									*											
3D Packaging check	12										*										
Kickoff new shoe development	13											*	*								
Create prototype order	14							*													
Manufacture parts	15														*		*				
Inspect components	16															*					
Endurance test	17																*				
Strength test	18																*				
Interpret Results	19																	*	*		
Consider alternate designs	20																			*	

Figure 5: Corresponding DSM of Process

	20	Matrix Order																				Task	Labor	Mat.
Task Names		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Time	Cost	Cost
Receive RFQ	1		0.3																			0.5	728	0
Verify required data present	2	0.1																			0.1	1	728	0
Calculate endurance requirement	3		1															1				0.5	728	0
Packaging assessment	4		0.5																			0.25	728	0
Select product type	5		1																			0.13	728	0
Calculate strength requirement	6		1																1			0.13	728	0
Search test reports for data	7			0.3	0.3	0.3	0.3															2	728	0
Select lubricant	8							0.3														0.13	728	0
Determine shoe performance requirement	9								0.5													0.25	728	0
Determine shoe packaging requirement	10								0.5													0.13	728	0
Search test reports for data	11									0.3												1	728	0
3D Packaging check	12										0.3											3	728	0
Kickoff new shoe development	13											0.1	0.1									0	728	0
Create prototype order	14							0.3														2.5	728	0
Manufacture parts	15														0.1		0.1					20	0	8000
Inspect components	16															0.1						5	80	0
Endurance test	17																0.1					20	80	0
Strength test	18																0.1					2	440	0
Interpret Results	19																	0.5	0.5			2	440	0
Consider alternate designs	20																			0.3		2	728	0

Task times in Days, Costs in $/Day, $

Figure 6: Numerical Description of As-Is Process

3.3.1. Deterministic Process Analysis

Analyze the As-Is DSM Data

All As-Is process data having been defined the process is analyzed, in this case over 6 iterations. Options are for a fixed number (non-converging processes), or for an extended number (assumes convergence). Results data by task and for the whole process is given both by iteration and by cumulative totals (Figure 7).

Not all processes converge in the work, time or cost dimensions. Tasks that exist as major drivers, with high re-work fractions or numerous data dependencies can cause fixed levels of additional time and cost with each successive process iteration. In reality, in most cases the process is terminated when a specific ‘acceptable’ quality of outcome is reached.

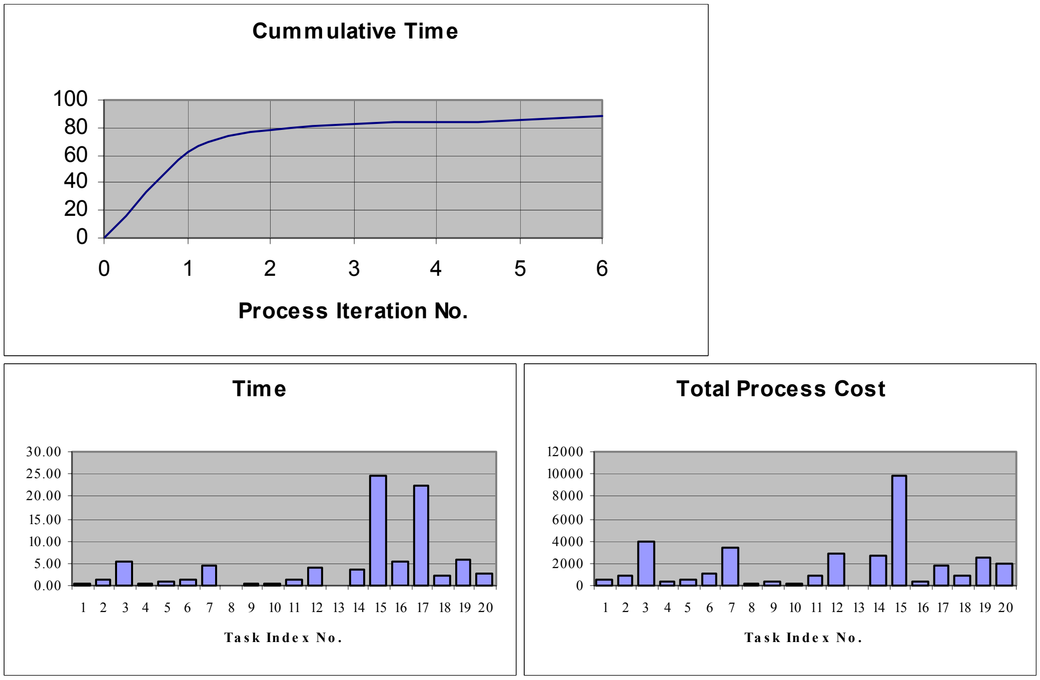
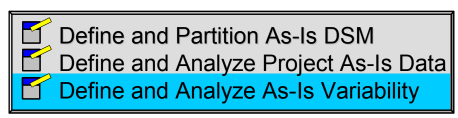


Figure 7: As-Is Process Analysis – Sample of Deterministic Results

Deterministic results quickly illustrate that tasks specific to hardware prototyping (15-Manufacture Parts, 17-Endurance Testing) are strong drivers of process time and, though on a cost basis it can be seen that all of tasks 3, 7, 12, 14, 15, 17, 19, and 20 are prominent. These deterministic results are validated both by the experienced perception of senior engineers and by departmental costs. It represents a validated baseline process model and quickly illustrates where efforts should be focused if process time and costs are to be reduced.

3.3.2. Stochastic Analysis of Process Variability



Based upon the user defined data variability – whereby % values are used to represent the data value standard deviation as a percentage of the mean (basic) value. The tool completes approximately 250 unique deterministic analyses and automatically summarizes the results (Figure 9).

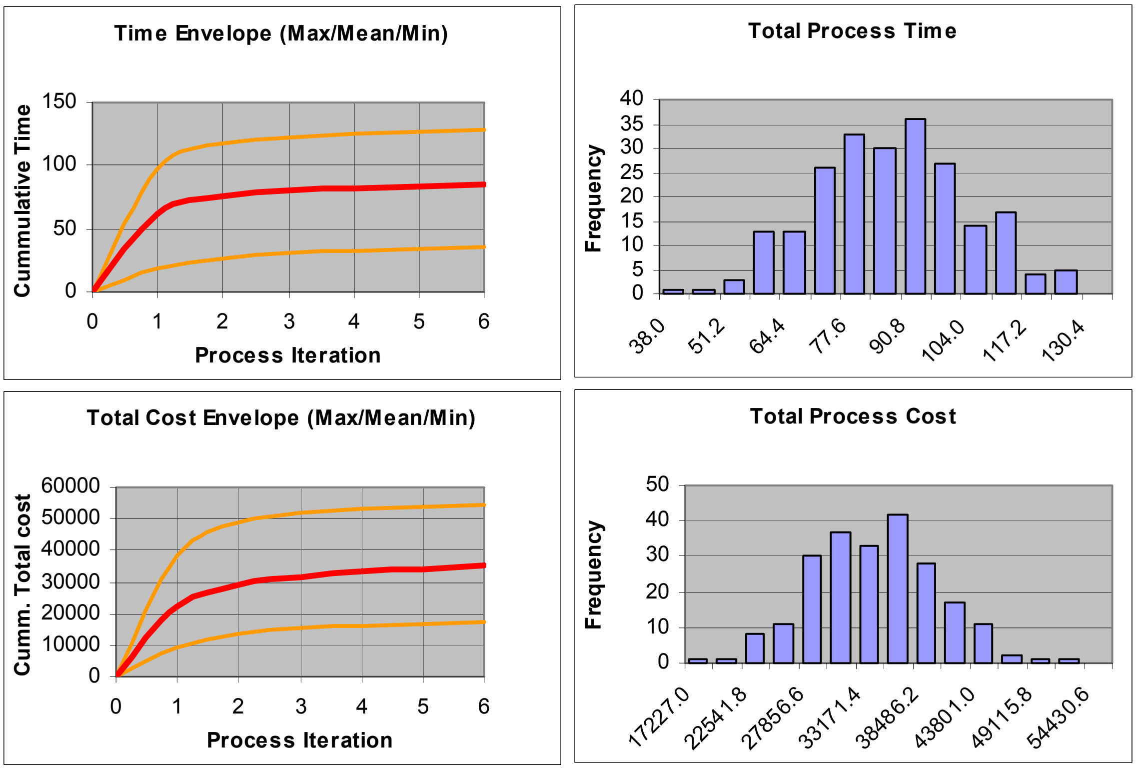


Figure 9: Sample Results from Stochastic Analysis of As-Is Process

3.4. To-Be Process Development

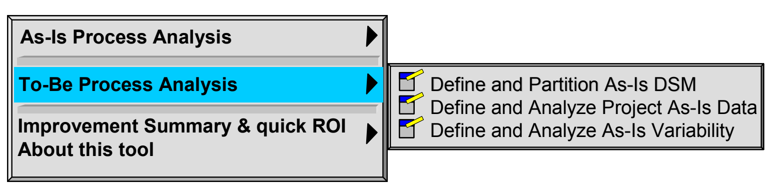
The baseline process is used to both guide the changes that could have the greatest impact upon the overall process, and to predict/measure the impact of changes in the time and cost dimensions, and the variability therein. In the illustration the defined process change was that of moving from the As-Is state, characterized by:

- Limited ‘manual’ process and data management practices with regional variation
- Limited ‘manual’ knowledge management
- Regional variability with regionally ‘preferred’ tools and practices
- Hardware-based product validation

To the To-Be state of a globally distributed web-based AE system that has the principle attributes of:

- AE process management and control
- AE knowledge and data management
- Definition and standardization of best AE tools and practices
- Virtual product validation (reduced reliance on prototype testing)

3.4.1. To-Be Process Model



The overall structure of the AE process remains unchanged in the To-Be state, however the resolution available on a task-by-task basis (rather than the higher level process basis) permits for an objective and accurate estimate of a revised process data set (Figure 10) under the proposed paradigm (automated process and data managed system). The revised data set is based directly upon the baseline set, and therefore represents a carefully considered change to individual parts of the baseline process, given knowledge of the capability and expected impact of modern applicable technologies. The data set is used to develop the To-Be DSM, data matrices, vectors and variability sets and analysis completed in a manner identical to that for the As-Is state. Summary results for the To-Be state, after stochastic analysis, are shown in Figure 11.

Task Names	20	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Task Time	Labor Cost	Mat. Cost
Receive RFQ	1		0.3																			0.5	728	0
Verify required data present	2	0.1																			0.1	1	728	0
Calculate endurance requirement	3		1															1				0.5	728	0
Packaging assessment	4		0.5																			0.25	728	0
Select product type	5		1																			0.13	728	0
Calculate strength requirement	6		1																1			0.13	728	0
Search test reports for data	7			0.3	0.3	0.3	0.3															2	728	0
Select lubricant	8							0.3														0.13	728	0
Determine shoe performance requirement	9								0.5													0.25	728	0
Determine shoe packaging requirement	10								0.5													0.13	728	0
Search test reports for data	11									0.3												1	728	0
3D Packaging check	12										0.3											3	728	0
Kickoff new shoe development	13											0.1	0.1									0	728	0
Create prototype order	14							0.3														2.5	728	0
Manufacture parts	15														0.1		0.1					20	0	8000
Inspect components	16															0.1						5	80	0
Endurance test	17																0.1					20	80	0
Strength test	18																0.1					2	440	0
Interpret Results	19																	0.5	0.5			2	440	0
Consider alternate designs	20																			0.3		2	728	0

Figure 10: Numerical Description of the To-Be Process

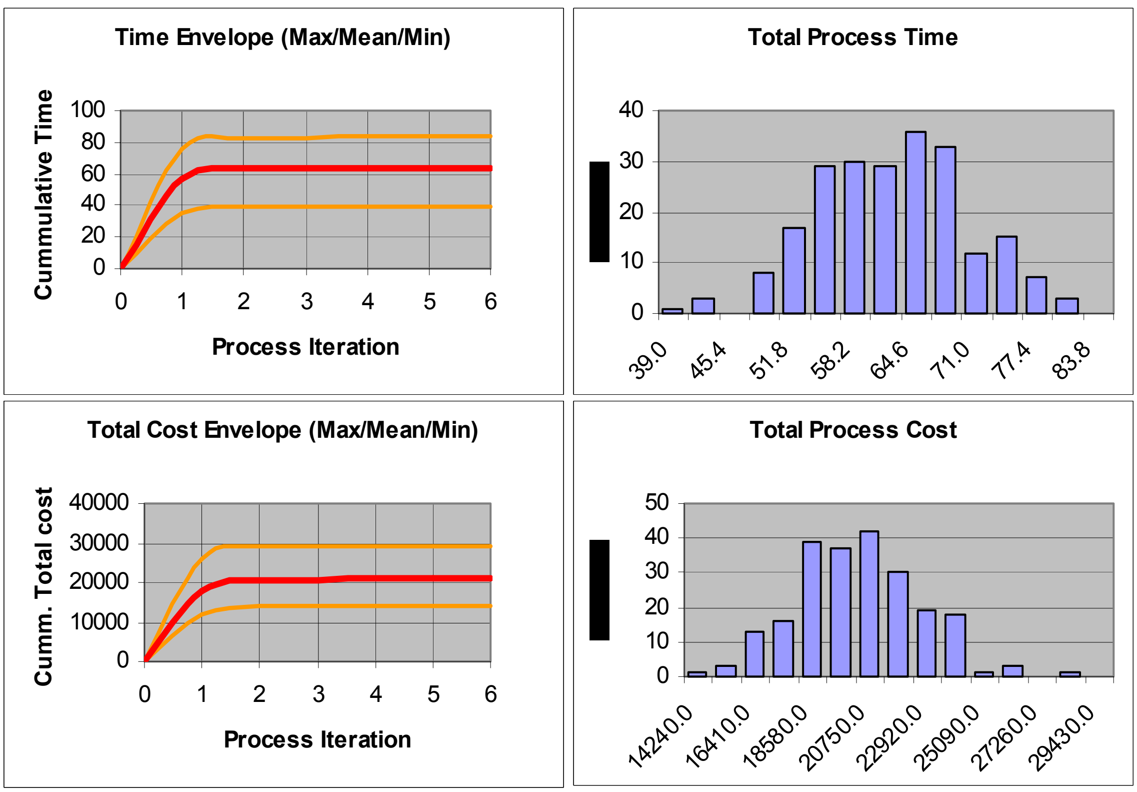
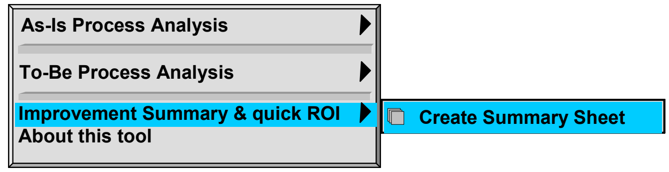


Figure 11: Sample Results from Stochastic Analysis of To-Be Process

3.5. Process Improvement Summary

The DSM-PA Tool creates a comprehensive process improvement summary so that the net impact of the process changes can be evaluated in terms of process time, cost, and variability. The improvement summary for this illustration is shown in Figure 12.



	Deterministic Converged Results						
	# Iterations	# Tasks	Work	Time	Total Cost	Labor Cost	Mat.l Cost
As-Is Process	6	20	54.5	87.7	35487.8	25710.0	9777.8
To-Be Process	6	20	28.5	63.9	20682.4	11840.3	8842.1
Process Change	0	0	-26.0	-23.7	-14805.3	-13869.7	-935.7
Process Change %	0.0%	0.0%	-47.6%	-27.1%	-41.7%	-53.9%	-9.6%

	Process Variability Evaluation Results								
		Process Time Variability				Process Cost Variability			
	# Iterations	Min.	Mean	Max.	Std. Dev.	Min.	Mean	Max.	Std. Dev.
As-Is Process	6	38.0	88.9	130.4	16.8	19115.0	37019.0	55587.8	5553.7
To-Be Process	6	39.0	63.9	83.8	7.9	14240.0	20855.9	29430.0	2340.7
Process Change	0.0	1.0	-25.0	-46.6	-8.9	-4875.0	-16163.2	-26157.8	-3213.1
Process Change %	0.0%	2.6%	-28.1%	-35.7%	-53.2%	-25.5%	-43.7%	-47.1%	-57.9%

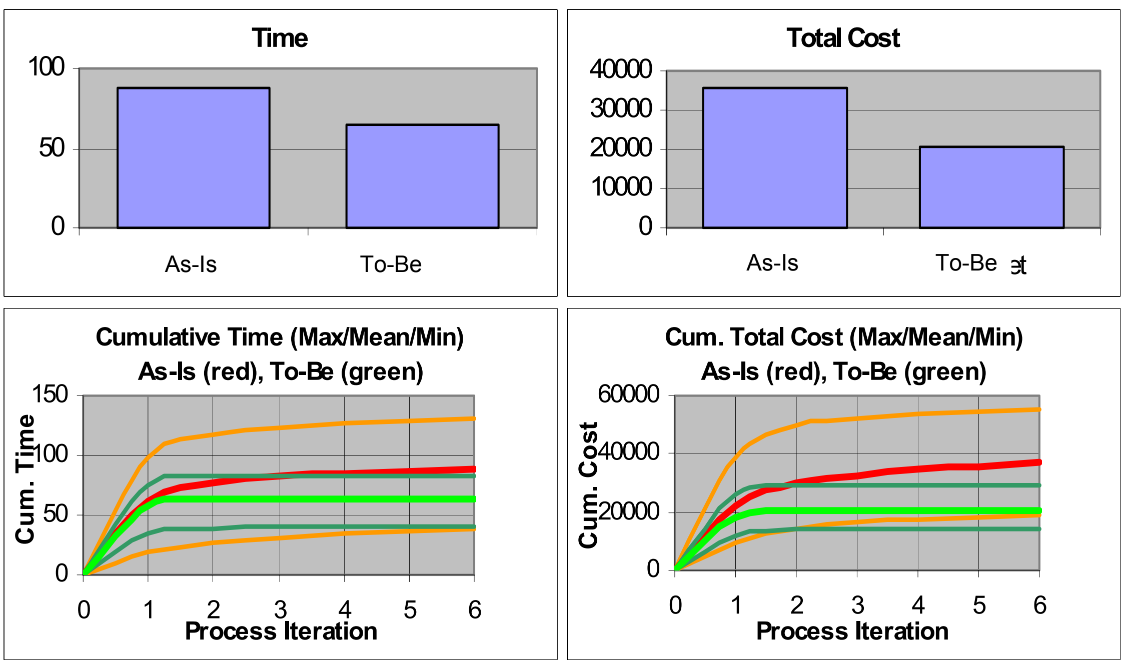


Figure 12: Summary Comparison of As-Is (current) and To-Be Process States

Results from the deterministic and stochastic analyses of the process regarding it's relative effectiveness/efficiency in the two states (As-Is and To-Be) are clear. The analytical models indicate that the proposed process changes will develop approximately:

- Average reductions in process time of 27%
- Average reductions in process cost of 42%
- Reductions in process time variability (standard deviation) of 53%
- Reductions in process cost variability (standard deviation) of 58%

3.6. ROI - The Big "So What"

In-spite of the compelling business potential from process improvements illustrated by the analyses of the DSM-PA Tool, process change cannot and will not take place unless the change benefits can be seen to outweigh, by some pre-defined degree (internal rate of return, net present value, break-even period), the required change investment (financial cost). In evaluating this we must consider both the following factors controlling benefits:

- The number of times per year the process under scrutiny is executed
- The time-frame over which the new process paradigm can become fully effective (and change potential fully realized)
- Additional soft benefits (increased sales, increased quality, etc.);

And we must consider the following factors that control cost of change:

- Cost of new technologies/services/systems
- Cultural change and implementation labor costs
- Cost of capital and rate of investment

It is reasonable to assume that a company acting alone or with a technology partner could readily develop reasonable estimates for the cost of change to the process, particularly given that the nature of change is already explicitly known and implicitly contained in the To-Be process model.

The DSM-PA Tool includes an ROI calculator that uses the summary data for cost savings, and additional user input to define the costs and benefits sides of the financial model. The calculator yields the basic metrics of internal rate of return (IRR), net present value (NPV) and break-even period. Figure 13 contains a set of calculations for the illustrated process. It assumes that the To-Be process:

- is executed 60 times in a year
- has a graduated deployment (accrual) rate beginning in the second year
- has estimated cost components over a period of 5 years
- cannot rely upon 'soft' benefits to improve the financial picture

Results indicate that the To-Be state can be fully realized at a total investment of $526,000 over 5 years, but that the break-even point is at 21months and the NPV and IRR of the project would be $1.37M and 225% respectively.

	Year 1	Year 2	Year 3	Year 4	Year 5
Investments					
Services	150,000	150,000	50,000	30,000	30,000
Software	0	60,000	12,000	12,000	12,000
Systems	20,000	0	0	0	0
Total Investments	**170000**	**210000**	**62000**	**42000**	**42000**
Savings					
Labor	13,869.7	13,869.7	13,869.7	13,869.7	13,869.7
%age accrual	0%	50%	88%	94%	100%
Process Multiplier	60				
Materials	935.7	935.7	935.7	935.7	935.7
'Soft' Benefits	0	0	0	0	0
Total Benefits	**0**	**444,160**	**777,281**	**832,801**	**888,321**
Annual Profit (Cash)	**-170,000**	**234,160**	**715,281**	**790,801**	**846,321**
Cummulative Profit	**-170,000**	**64,160**	**779,441**	**1,570,242**	**2,416,562**
Interest Rate %	15%				
Net Present Value	**1,372,455**	Re-calculate based on input			
Internal Rate Return	**225%**				
Break-even period	**21**	months			

Figure 13: Quick ROI Evaluation For Achieving the To-Be Process State

4. Application To Hierarchical Processes

A low-level process is one in which the constituent tasks are just so – self-contained well-defined packets of work that have a simple structure and require little internal process to ensure completion. Higher-level processes comprise sub-processes in place of tasks. Thus processes are hierarchical. The PD process is eminently hierarchical. The illustration of this paper is for a process wherein the components are referred to as tasks, some of which may be sufficiently complex to warrant sub-division (in order to realize greater process analysis fidelity). Additionally the illustrated process is, in itself, a task (albeit very complex) within the overall PD process.

The DSM-PA methodology and tool could be applied to hierarchical processes in two ways: Either as one DSM at the highest process level of interest with an extensive and elaborate task content sufficient to represent all sub-process tasks; Or as a nested set of DSM's wherein each sub-process is represented separately, the metrics of the process cascading upwards through the hierarchy as parts of the higher level process data set. The latter of the two options is the more favorable (illustrated in Figure 14) for it permits the de-coupling of sub-processes. De-coupling of sub-processes is important in over-coming one of the numerical limitations of the method – that of the assumed parallel execution of tasks. De-coupling is alluded to by Cronemyr[3] and is an important aspect of high level process design.

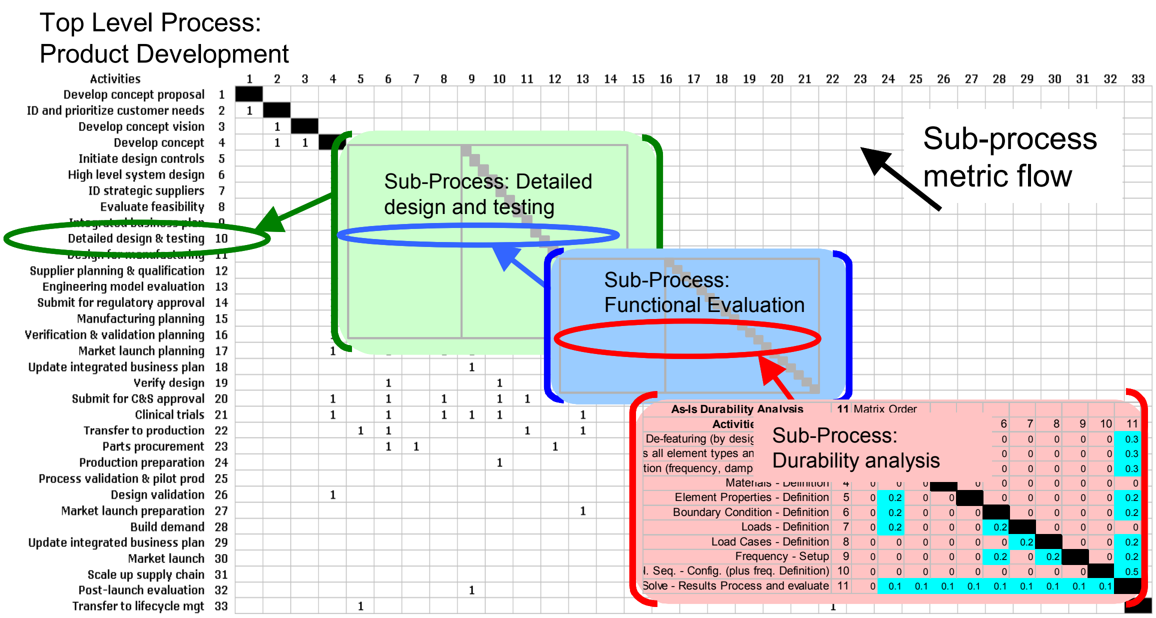


Figure 14: Cascading DSM metrics in a hierarchical process structure

5. CONCLUSIONS & FURTHER DEVELOPMENTS

Design Structure Matrices are but one of several methods for evaluating processes (others include Signal Flow, Gantt, PERT). The relative merits and shortcomings of different methods is not matter for discussion herein. Instead the intent is to illustrate the practical application of the extended DSM methodology, as enabled by an easy-to-use tool with extensive practical capability, demonstrating that reliable insights into process improvement initiatives can be made.

Conclusions here noted are borne of the author's experience with customers and peers in the use of the methodology and the tool in assessing the validity and value of process improvements in the product development environment. The methodology and the DSM-PA tool, in application, demonstrate the ability to:

- Effectively mathematically model product development processes with acceptable reliability.
- Assist in the analysis of processes and in the identification and definition of how processes should be changed.
- Develop time and cost baselines for processes, against which the effect of task-based changes can be measured.
- Develop process variability baselines, against which the effect of task-based improved control can be measured and project forecasting improved.
- Provide for the ready comparison of existing and conceptual process states in the time and cost dimensions, and the variability therein.
- Provide for rapid cost-benefit based assessment of the validity or potential of proposed process change.

Future proposed developments of the DSM-PA method and tool include the development of a quality dimension to augment those of time and cost. Because many processes in product development never truly reach convergence (a non-changing data state), but are stopped at an acceptable quality of output, it is apparent that the tracking of task quality and process output quality, as they increase by iteration, could be a very useful addition.

REFERENCES

1. Steward, D. V., 1981 "The Design Structure System: A Method for Managing the Design of Complex Systems", IEEE Transactions of Engineering Management.
2. Smith, R. P., Eppinger, S. D., 1997, "Identifying Controlling Features of Engineering Design Iteration", Management Science.
3. Cronemyr, P., Ronnback, A. O., Eppinger, S.D., 2001, "A Decision Support Tool For Predicting The Impact Of Development Process Improvements", Journal of Engineering Design, Volume 12, No 3.
4. MSC.Software Corporation, 2002, Virtual Product Development Maturity Model (VPDMM)

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