Multi-Domain-Matrices Industrial applications

In Systems Engineering Validation

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Abstract

Systems engineers develop always more complex and dynamical systems within shorter time to market and by stricter budgets. A strong drive from Document to Model Based Systems Engineering is characterizing this decade. Lists, matrices and graphs are at the same time historical methods for the engineer and relevant elements of current SE methodologies. This paper proposes applicative examples, focused on the validation process in the liquid food industry, of Multi Domain Matrices with the related graphical and computational methods.
Pro, cons, intrinsic limitations and opportunities are elaborated in comparison to traditional static documental methodologies.

Background

Systems Engineering aims at developing, on time and within budget, successful systems for the entire stakeholder's chain, for the benefit of the humanity and of the globe. It has to be noticed that as the fantastic achievements obtained by the founder Simon Ramo and Gen. Bernard Schriever where not replied in modern times programs. A reasonable amount of the appropriate Systems Engineering methodologies applied as soon as possible applied by skilled and interconnected persons, demonstrated practical and statistical impact on the achievement of the mission objectives.

Model vs. Document Based Systems Engineering is actually addressed as one the winning factors for the daily job of the Systems Engineers. "Model" is although one of the words which addresses a great semantic and ontological uncertainty. Leonardo da Vinci's sketches as well as more advanced dynamic simulations are part of this practice.
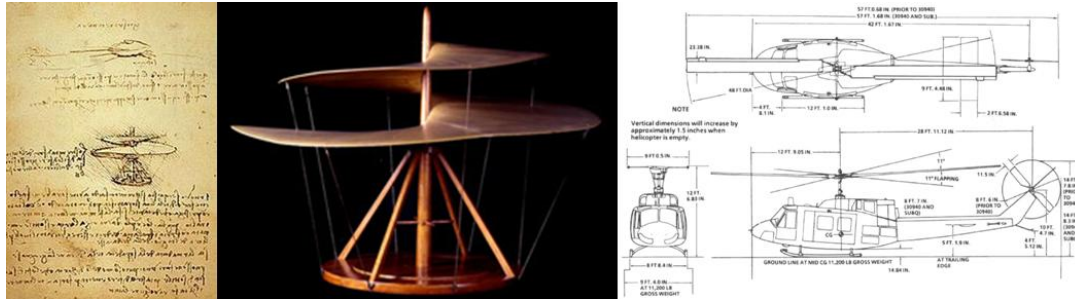
Figure 1- Leonardo da Vinci sketches, physical models and actual blue-prints models for the same concept.

Engineer's academic background encloses wide use of lists, matrices and graphs of many types. This usage is widely deployed in the professional life a System Engineer. The Incose Systems Engineering handbook (Incose10) introduces to the N2 diagrams, credited to Robert J. Lano (Lano77). It treats displaying a matrix of functional bidirectional interactions, or data flows, at a particular hierarchical level alias in a rigid bi-directional fixed framework.
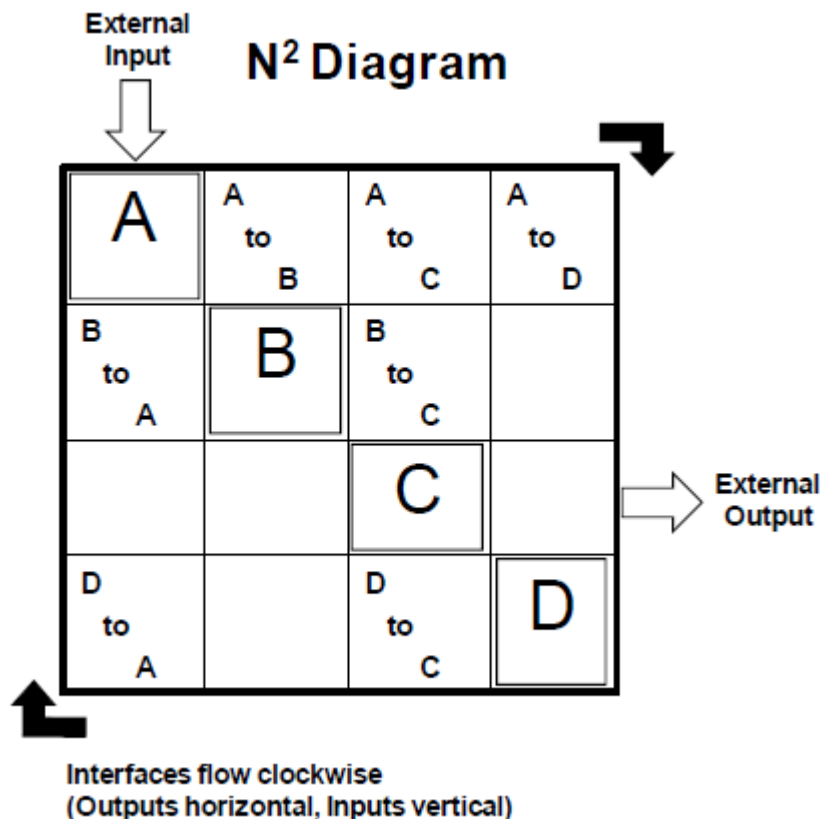

Figure 2: N2 diagram and matrix representation (Incose SE 3.2.2. Handbook)

The Design Structure Matrix, extension of the N2 diagrams, is a powerful Systems Engineering approach for representing, understanding, sharing and analyzing system complexity. The eclectic and powerful representation and calculation capabilities of the DSMs can be combined into a Multi Domain Matrix, MDM, by the DMMs Domain Mapping Matrices in order to model complex frameworks including different views and levels.
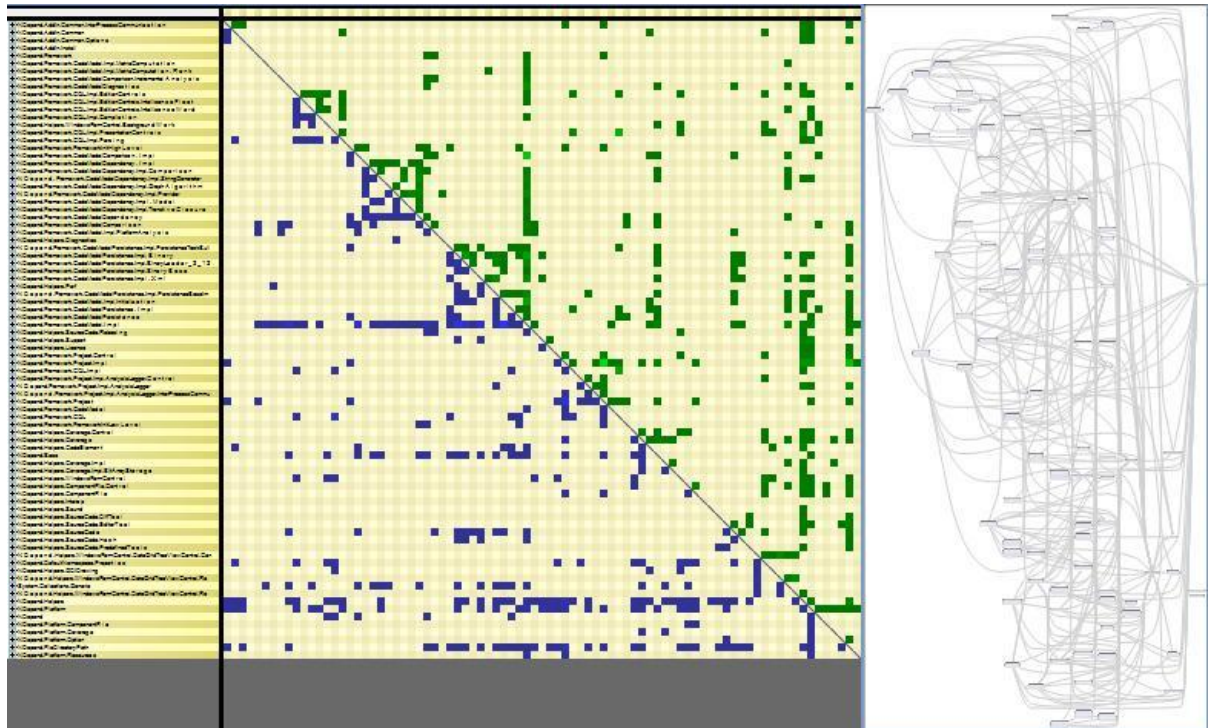
Figure 3: Design Structure Matrix, T. Browning S. D. Eppinger from "Design Structure Matrix Methods and Applications"

Domain mapping matrices can link these domains by specific, justified and documented rationales on order to manage the system complexity.

"Verify as soon as possible and validate always" addresses the scope of the industrial examples of matrix and graphical representations proposed in this paper. The Validation process allows crossing the overall system life-cycle, from needs elicitation to disposal facing different issues and problems. A walkthrough of the validation process is proposed with industrial applications from the liquid food packaging industry.

Needs elicitation

One of the key success factors during need elicitation is matching the stakeholders influence and their explicit and implicit dependencies. Validating the needs involves clear understanding the sources of influence.

An example of domain mapping matrix is proposed where different type of stakeholders are mapped: the general voice of the market, the market leader, follower and niche, the company board, the generic consumer and its organizations, the regulatory organizations.

A Quality Function Deployment-like scoring approach is proposed for the quantitative of the influence of five different stakeholders needs: higher capacity equipment, better and lasting appearance, different processes implemented, comparable reliability, improved performance and environmental profile.

The score grade: 0,1,3,5 and 7 expresses the level of interest of the stakeholder from null to the unique and highly interested one. The matrix in figure 4 already expresses the aggregations but its graphical visualization immediately highlights the clusters of market requests vs. the consumers/environmental/regulatory one.

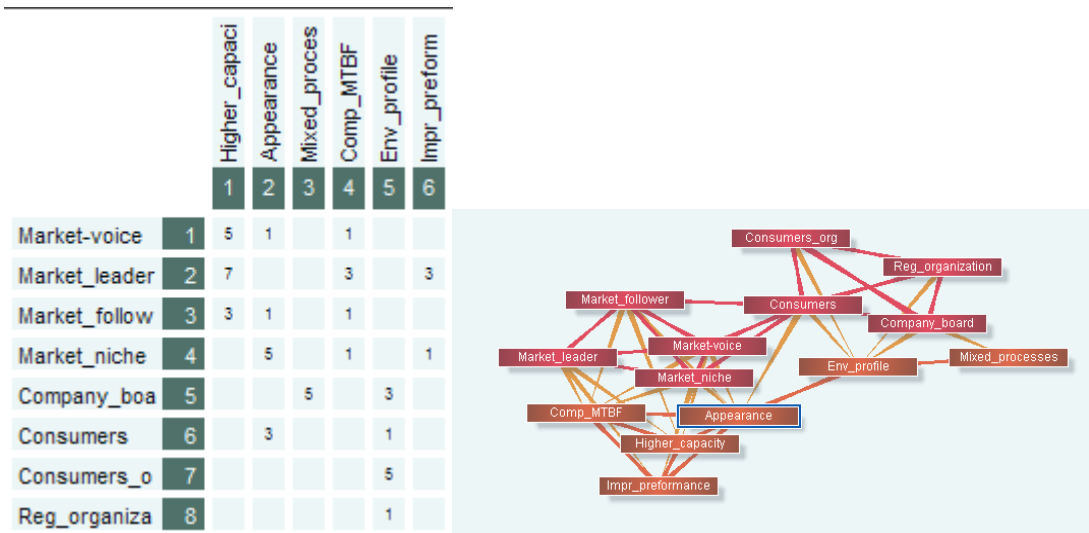|		Higher_capaci	Appearance	Mixed_proces	Comp_MTBF	Env_profile	Impr_preform
		1	2	3	4	5	6
Market-voice	1	5	1		1		
Market_leader	2	7			3		3
Market_follow	3	3	1		1		
Market_niche	4		5		1		1
Company_boa	5			5		3	
Consumers	6		3			1	
Consumers_o	7					5	
Reg_organiza	8					1	

Figure 4: DMM un-direct dependencies stakeholders-needs, DMM matrix and graphical representations

The physical proximity of the elements underlines immediately the strengths of the dependencies, alias the interest of each stakeholder for the specific need. It allows focusing the validation strategy to the "right" stakeholders, by the appropriate approaches and through the expected communication evidences and format. The expected benefit is a validation effort optimization by avoiding to addressing the wrong stakeholder with non requested or not perceived evidences of needs satisfaction.

Requirements management

Needs are translated into Stakeholders Requirements for the determination of the "right system" to be designed and implemented. Requirements validation is usually implemented on the base of various attributes like as: unique, clear, complete, testable, feasible, ownership, etc. Independently from the selected attributes a matrix of the Systems Requirements can be expressed in terms of translation effectiveness, alias the degree of needs contents addressed by the requirements. The evaluations are than normalized to one.

The proposed simplified graph to the left highlights the un-direct relations between needs and System Requirements. The graph to the right shows the verifiable/testable attribute for the different systems requirements.
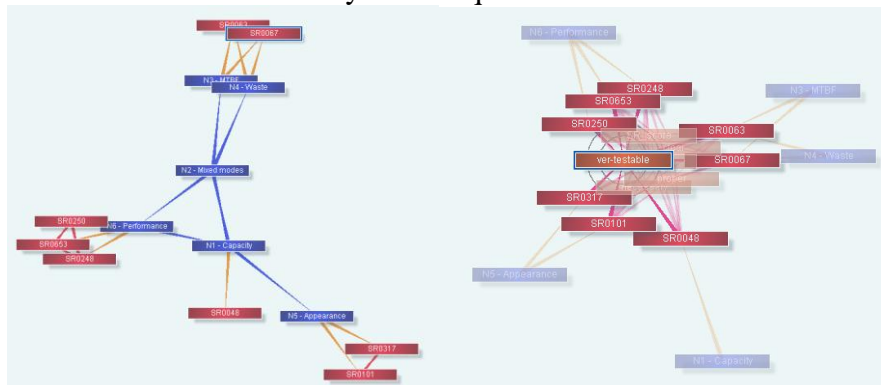
Figure 5: Needs and Systems Requirements. Sys-Req. Validation testability

Un-clear, not univoque or un-complete system requirements can be easily identified and fixed by avoiding late and costly rework. A reduction of at least 30% verification effort has been evaluated during one mid-size project in the liquid food packaging industry.

Technical risk assessment

Every Verification and Validation process is based on the technical and project risk profile.

The FMECA, Failure Modes Effects and Criticality Analysis, tables are typically densely populated and even difficult to be understood correctly even by the same session facilitator after a couple of weeks from the session. A graphical representation can help to understand better the downstream impact of most relevant failure modes. The matrix elements are then depicted according to the expected frequency, the impact and the detectability. A three layers matrix framework can be implemented and the single aspects can be further investigated. It has to be noticed that in this way it is possible to identify at the same time, in a wool-ball of hundreds elements, the low frequency, high impact, low detectability failures as well as the high frequency, med impact, med visibility ones.
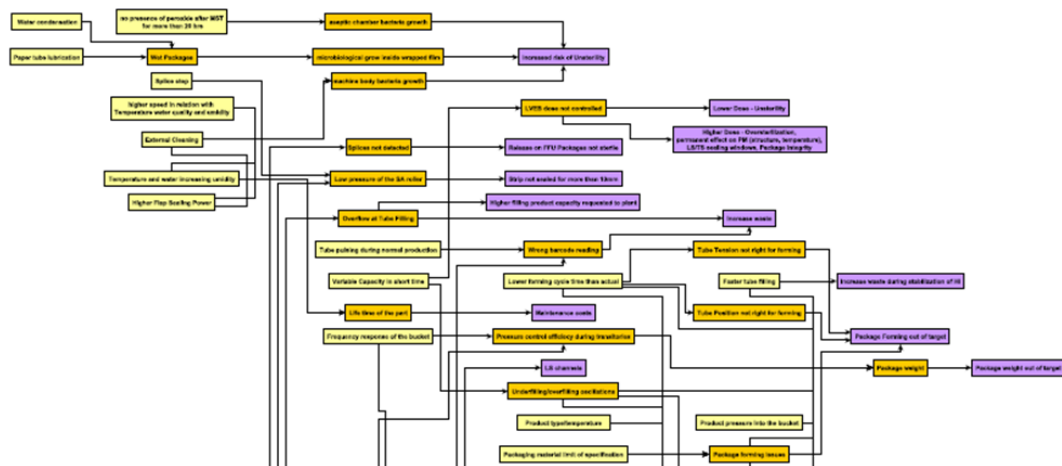

Figure 6: System FMEA graphical representation by Yed

The main demonstrated benefit is in connecting two key roles in the system development and avoiding overlapping or duplicated risk mitigation actions.

The same company wiki is used by the System Engineer for the FMECA and by the Project Manager for the project risk management. The team can consult the overall risk management evaluation into one simple graphical tool and dig into the details if necessary.

System functional models

One of the more classical applications of matrices is the wide field of the functional models where system requirements, functions and components are treated in the same environment.
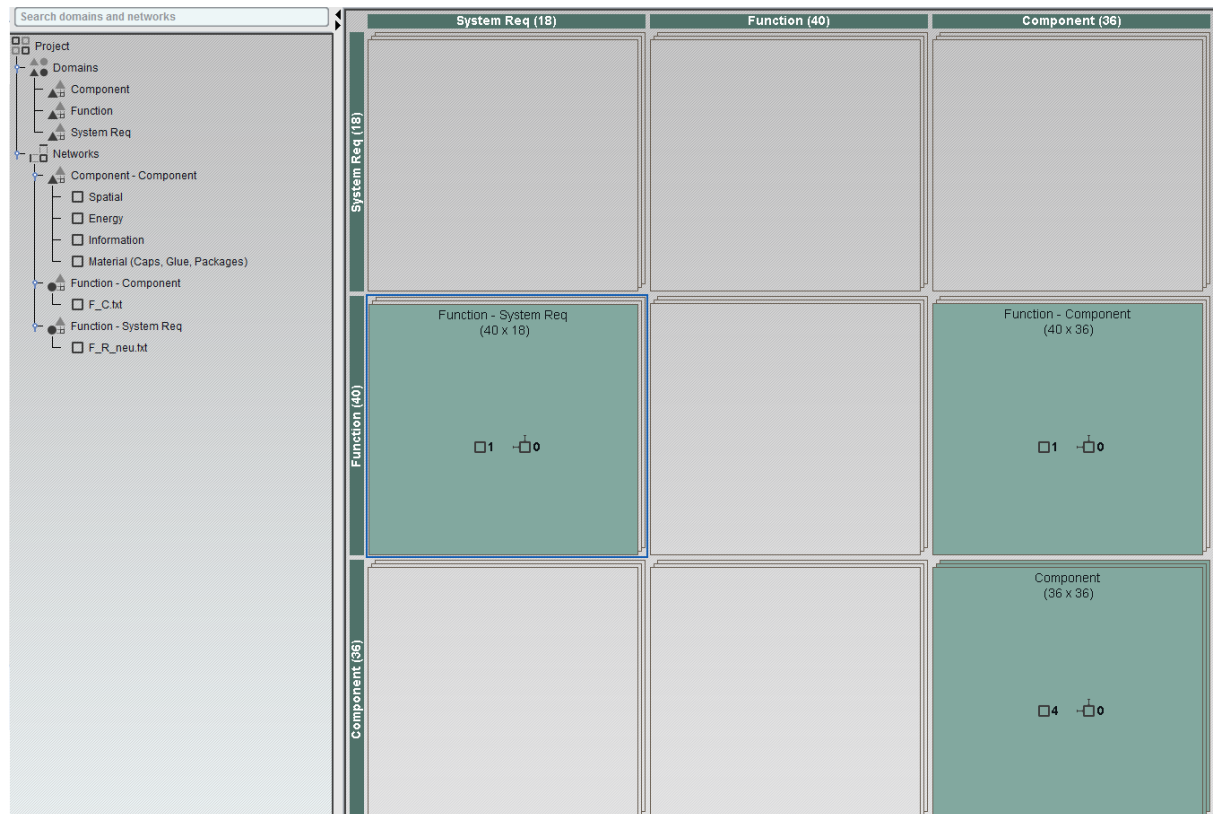
Figure 7 – Functional model DMM and DSMs matrices

The multi domain model structure showed in picture 7 synthesises a relevant complexity: 40 functions, 18 System Requirements, 36 components over 4 layers: physical proximity, energy, materials and information.
The European funded AMISA project (AMISA12, AMISA14), leveraged on the design structure matrix approach to evaluate the system architecture value for all the stakeholders through the overall life-cycle.

VandV Strategies

Its has been estimated by the European research project SysTest than around 60% of the programs budget is associated to the Verification, Validation and Testing activity (Engel10) At the same time these processes are affected by a wide variety of sources of uncertainty.
Efficiency and effectiveness of the verification and validation strategies is so critical for the system's success. An optimization methodology and tool based on the DSMs was developed during the research project (Systest04).
A relevant VVT cost reduction was reported as conclusion of the pilot project, mainly due to the application of new VVT activities, to an efficient VVT planning, and to the improved VVT process guidance.
Since additional VVT activities were performed, a better confidence level on the product robustness with using less equipment and raw material was achieved; this increased the VVT effectiveness and efficiency. Although new VVT activities were added, a VVT cost reduction was experienced. This is because some of the most expensive tests, which have high personnel and equipment cost, were substituted by cheaper tests upfront. Moreover, the share of VVT cost on the overall pilot project cost could be reduced from 59% to 51%.

The share of the VVT cost in the total project cost relative to a comparable historical project was 59%. The rework cost share was 26%. Hence, the cost of quality-related activities sums up to 85% of the overall project cost. With the measured VVT cost reduction of 3% and the rework cost reduction of 53%, an overall project cost reduction of 15,6% was achieved.

Figure 8 shows the four main causes for the measured cost reductions. It can be seen that the VVT Methodology Guidelines and the VVT Process Model are mainly responsible for the improvements (SysTest05).

SysTest products ...			... lead to improvements in ...	... lead to a reduction in ...	
VVT MG [1]	VVT PM [2]	VVT S&P [3]		VVT cost	rework cost
	++	+++	VVT process guidance	+	+
+++	+		rate of virtual versus physical testing	++	++
+++	+		VVT effectiveness	++	
+++	+		failure detection rate		++

[1] VVT MG = VVT Methodology Guidelines
[2] VVT PM = VVT Process Model
[3] VVT S&P = VVT Strategy & Planning Procedure

Figure 8 – Functional Relation between SysTest products and improvements

A demonstrative example of dynamic modelling for these processes is currently under development. It combines Graph Theory, Network and Motif Analyses and Multi Domain Matrices by merging heterogeneous environments.

Decision support

Systems Engineers often face providing recurrent support information to the decision-makers under uncertain conditions. Availability of a re-usable decisional model based on the MDM approach demonstrated high effectiveness in action plans coherence and waste reduction also but not limited to the application of sequencing algorithms. An example of re-usable decisional framework implemented by multi domain matrices in proposed in Leardi14. Among the capabilities of this framework it is allowed a fruitful return of experience by evaluating the correspondence between expected and effective test results before and after one specific action plan. Bayesian inference has been applied into the design structure matrices for this industrial case application.
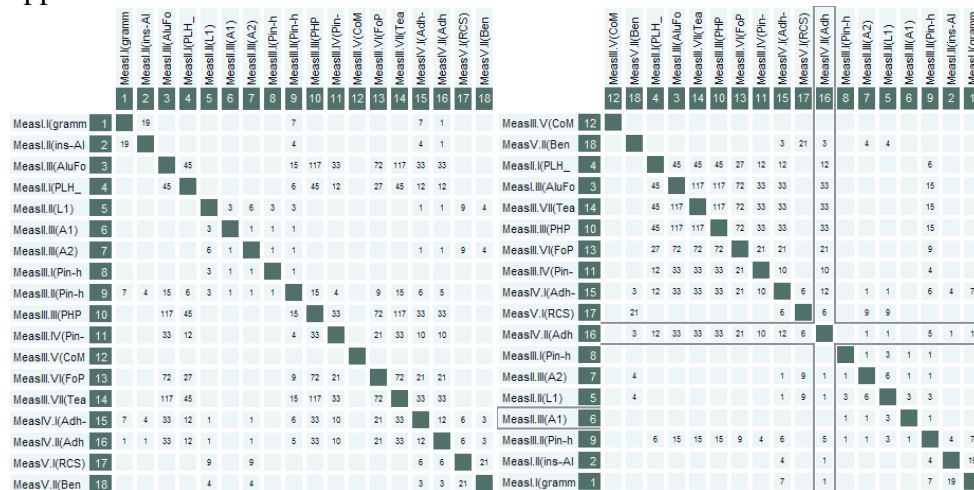

Figure 9 – Empiric evidences as-is and sequenced by DSMs

Multi domain matrices methodological pro and cons

Multi domain matrices allow collecting and validating the relevant info into an essential ontology by using a unique vocabulary. Design Structure Matrices and Multi Domain Matrices provide the modelling capabilities while Graph Theory, Network and Motif Analyses provide the analytical one. Among a huge quantity of global structural metrics, it has been proven how four of them: degree, clustering coefficient, distance centrality and average distance to node can provide the great majority of the information. (Biedermann12).

These characteristics point one of the key success factors in model buildings alias "data validation".

This aspect can however be seen as one limit of the approach. An un-complete ontology, missing key aspects, will surely lead to failing the specific objectives.

Matrix methods combined with graphical visualizations involves storing the information in a dynamic and easy to use environment. The models are so re-usable and retrievable and maintain their consistency. This is one of the low-hanging fruits to catch the opportunities of Model Based Systems Engineering.

Reversely a certain tool dependency can affect the highlighted opportunity.

The key advantage is surely managing a level of complexity not affordable with traditional static tools in an affordable and repeatable way. The effort is efficiently moved from filling-in the data to designing the model and validating the inputs. In this way the System Engineer is relieved from trivial or waste activities and can focus on value-related items.

All these examples are produced by Loomeo[tm] and other free-ware tools like as Yed. It is anyhow useful to mention that the tools are not, at the state of the art, a critical aspect. Building effective methodological frameworks and validating input data is

Future plans

The convenient benefit/effort ratio achieved in previous applications fosters future applications. The available models shall be extended, re-used and enhanced in order to foster the system value through the entire system life-time and for the overall stakeholders' chain. The scope of future applications is intended to further integrate the Systems Validation process within the overall system development and sharing key information among different team members.

Acronyms

DSM = Design Structure Matrix
DMM = Domain Mapping Matrix
MDM = Multiple Domain Matrix
FMECA = Failure Modes Effects and Criticality Analysis
AMISA = Architecting Manufacturing Industries and Systems for Adaptability
www.amisa.eu
SysTest = Developing Methodologies for Advanced System Testing
www.incose.org/secoe/proj.htm
VVT = Verification Validation and Testing

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Biography

Dott. Ing. Carlo Leardi graduated 1989 in electronic engineering in Genova Italy. His professional background starts with quality assurance responsibility evolving in the last years to full verification, validation and testing commitment within complex systems development deployment projects in the following areas: automotive, freight railways and packaging industry. As a passion before and today as a full job, he is dealing with Quantitative Systems Engineering on a day-to-day application and coaching of a full range of statistical and simulation methodologies supporting the decisional process. He published several articles in Engineering and Systems Engineering journals and acts as teacher at Systems Engineering Masters. He is one of the founders and past-president of the INCOSE Italian Chapter.