Management Causal Matrix: A Tool for Organizing Model Variables and Interrelationships

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For years, the systems engineering field has developed tools to graphically represent complex system structure. Graphical representations allow individuals and teams to visually identify interrelationships and dependencies within the system. Academic research and the adoption of these tools within the industrial communities validate the utility of these tools. These tools include Unified Program Planning, Quality Functional Deployment, House of Quality, and Design Structure Matrix. Increasingly, the management consulting industry has been utilizing these tools in systems management. This paper discusses the applicability of a new tool, Management Causal Matrix, for system dynamics modeling community. The matrix is very similar to the more traditional systems engineering tools, yet has been customized for the systems dynamacist to highlight system interdependencies and organize the casual structure for a management system.

Key Words: Management Causal Matrix, System Dynamics, model boundary definition, systems engineering, value analysis

System dynamacists have an array of tools used to map a systems structure. These tools include the Model Boundary Chart, Subsystem Diagram, Casual Loop Diagrams, Stock and Flow map, and Policy Structure Diagram. (Sterman:2000) If employed properly, the tools greatly benefit both the modeler and the customer. The primary function of these tools is to visually organize the complex structure of the system and to communicate the system structure to others. Unfortunately, for large and complex systems some of the tools are less effective. Causal loop diagrams can grow to be enormous and difficult to follow. Complex subsystem diagrams often fail to provide all

of the critical information needed to build a model and often it is cumbersome to translate the information into stock and flow structure.

This paper presents a new tool and methodology to help define the structure of a system, called a Management Causal Matrix (MCM). A Management Causal Matrix enables the modeler to efficiently capture all of the critical interdependencies captured within a system using matrices to highlight causal relationships. The process in generating the information necessary to populate the MCM provides an intuitive method for eliciting the critical knowledge to create a system dynamics model.

The MCM is an adaptation of other matrix-based tools utilized by the quality and system engineering communities. The matrix structure is most similar to one of the first system engineering tools called Unified Program Planning.

Matrix Based Tools

The purpose of Unified Program Planning (UPP) was to provide an intuitive method for graphically representing the interdependencies found within a system. As the grandfather of the house of quality, UPP was created to display the multiple interrelationships that exist within a complex system. The common theme underlying system engineering tools and processes like UPP remain fundamentally constant. Each tool is developed to provide a logical flow between customer requirements and the organization of elements that are satisfy those requirements. Program managers, systems designers and product developers commonly use these tools to define the scope of development. All elements within the system have traceability back to the customer.

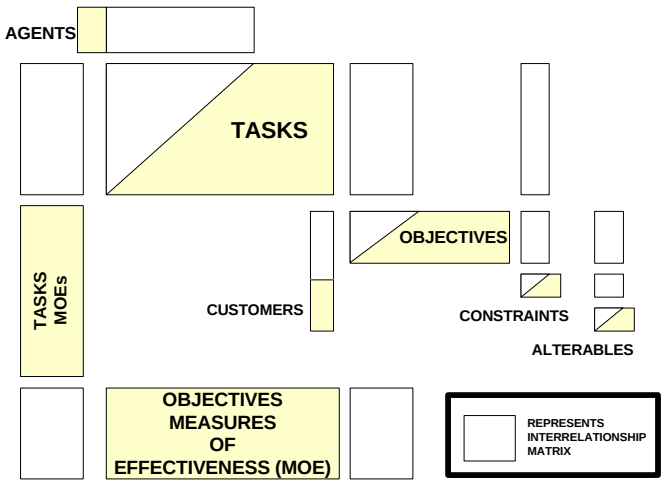


Figure 1: Unified Program Planning Model

Figure 1 is a simplified UPP Diagram. The critical elements of a system are defined on the diagram. Customers, system objectives, tasks to be performed, and measures of performance are all identified. The matrices are used to highlight interrelationships found within the system. The diagram is used by system engineers to endure they had considered all of the critical elements within the system. Hill and Warfields paper gives an excellent description of the UPP and gives a good example.

Management Causal Matrix

The original intent for UPP was to be used a program-planning tool to address of stakeholders, objectives, activities and constraints found with a system development activity. Though thorough and rigorous, it was a bit cumbersome to explain and somewhat difficult to understand. Therefore, I tailored the original flow and developed a new model, which I found was easier to understand and more conducive for the system dynamics modeling. (Bartolomei, Smith)

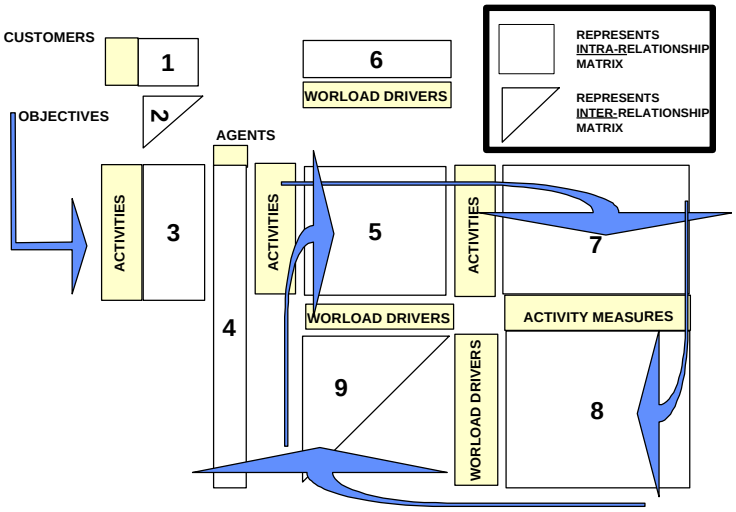


Figure 2: Management Causal Matrix

MCM Methodology:

Description of the System

The MCM described in the paper was used in the creation of a system dynamics model for the United States Air Force for determining the engineering manpower requirements for a development activity. Engineering support resides in System Program Offices (SPOs). SPOs are responsible for the government program management during the

weapon system acquisition lifecycle. The matrices described below were determined when analyzing manpower requirements of a generic SPO.

Matrix 1- Identify the customer:

The first step in creating the MCM is to identify all of the internal and external customers associated with a system. In the government acquisitions environment these customers are identified as the following:

SPO: the internal leadership of the management organization

KTR: Contractor, the commercial entity developing the weapon system.

PENT: The Pentagon

USER: The United States Air Force Major Command purchasing the weapon system

GAO: The Government Audit Office

CUST.	Max.Manpower Effectiveness	Gather Information	Monitor Performance	Inform Customer	Obtain Funding	Negotiate Contract	Manage Risk	Ensure Executability
INT	X	X	X	X	X	X	X	
KTR			X	X	X		X	
PENT	X	X	X		X	X	X	
USER	X	X	X			X	X	

Matrix 1: Customers vs. Objectives

Matrix 2 - Define the system's objectives

The next step in developing the MCM is to define the objectives of the system. These objectives should have traceability to the customers of the system. The objectives of the management system were identified using Functional Analysis Systems Technique (F.A.S.T.). (Bartolomei et al:2001) Ensure Executability was identified as the primary

SPO/IPT OBJECTIVES							
				X	X	X	Ensure Executabillity
X			X				Manage Risk
X			X				Negotiate Contract
X			X				Obtain Funding
X		X					Inform Customer
X	X						Monitor Performance
X							Gather Information
Max.Manpower Effectiveness							

Matrix 2: Objectives Intra-relational matrix

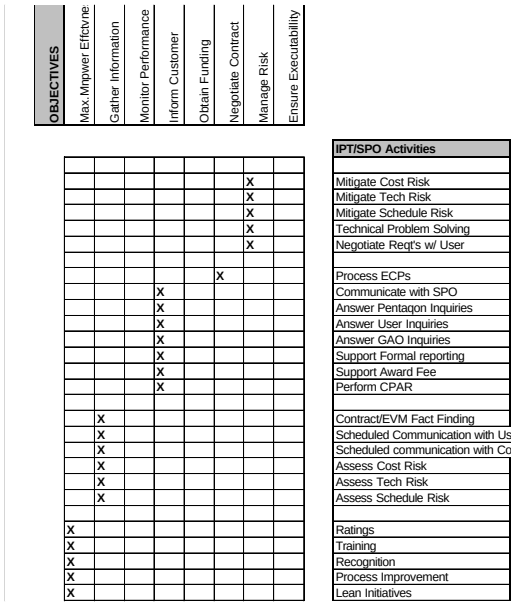
objective. The matrix is similar to an objective tree starting from the upper right and cascading down and left. For systems dynamicists, the objectives could serve as sectors, since multiple activities are performed to supports each objective.

The **X** in each box denotes that there is a relationship between two variables. Matrix 1 is an intra-relational matrix defining relationships between customers and the objectives to satisfy the customer. Matrix 2 is an inter-relational matrix, where the **X** indicates a relationship between objectives.

Defining the objectives that satisfy the customers is essential for all quality management organizations. This exercise enabled management to focus on the high value areas. Gathering information to populate these matrices accurately often requires communication and feedback from the customers.

Matrix 3:Identify Activities

Each activity performed by an organization should have traceability to an objective. Activities that do not directly support the objective should be eliminated. Matrix 3 represents the activities that an organization performs to support each objective. Group brainstorming and other knowledge elicitation methods can be utilized to capture the tasks that must be performed.



OBJECTIVES	Max.Mnpwer Effctvne	Gather Information	Monitor Performance	Inform Customer	Obtain Funding	Negotiate Contract	Manage Risk	Ensure Executability	IPT/SPO Activities
							X		Mitigate Cost Risk
							X		Mitigate Tech Risk
							X		Mitigate Schedule Risk
							X		Technical Problem Solving
							X		Negotiate Reqt's w/ User
						X			Process ECPs
				X					Communicate with SPO
				X					Answer Pentagon Inquiries
				X					Answer User Inquiries
				X					Answer GAO Inquiries
				X					Support Formal reporting
				X					Support Award Fee
				X					Perform CPAR
	X								Contract/EVM Fact Finding
	X								Scheduled Communication with Us
	X								Scheduled communication with Co
	X								Assess Cost Risk
	X								Assess Tech Risk
	X								Assess Schedule Risk
X									Ratings
X									Training
X									Recognition
X									Process Improvement
X									Lean Initiatives

Matrix 3: Objectives vs. Activities

Matrix 3 illustrates the traceability between the Objectives and the Activities performed by the organization. The **X** indicates a relationship.

Matrix 4 – Define the Agents Who Execute the Activities

Each activity requires some organizational function to execute the task. Some activities requires more than one (i.e. Identify Risks often requires engineering, management, and financial officers). Matrix 4 illustrates the agents required to perform each activity.

Multiple functional organizations are performed within the SPO organization. Agents represent the different functional areas and were defined as follows:

PM:	Program Management
EN:	Engineering
FM:	Financial Management
PK:	Contracting
ADMIN:	Administrative Support
DCMA:	Defense Contracting Management Agency

IPT/SPO Activities	PM	EN	FM	PK	ADMIN	DCMA
Mitigate Cost Risk		X	X			
Mitigate Tech Risk		X				
Mitigate Schedule Risk		X	X			
Technical Problem Solving		X				
Negotiate Reqt's w/ User	X	X				
Process ECPs	X	X		X		
Communicate with SPO	X	X	X	X		
Answer Pentagon Inquiries	X	X	X	X		
Answer User Inquiries	X	X	X	X		
Answer GAO Inquiries	X	X	X	X		
Support Formal reporting	X	X	X	X		
Support Award Fee	X	X	X	X		
Perform CPAR	X	X	X	X		
Contract/EVM Fact Finding	X	X	X	X		
Scheduled Communication with User	X					
Scheduled communication with KTR	X	X	X	X		
Assess Cost Risk		X	X			
Assess Tech Risk		X				
Assess Schedule Risk		X	X			
Ratings	X					
Training	X					
Recognition	X					
Process Improvement	X					
Lean Initiatives	X	X	X	X	X	X

Matrix 4: Activities vs. Agents

The EN column highlights the activities that engineers perform within the organization. An **X** defines the activities each agent is responsible to perform in order to meet the objective requirements.

Matrix 5 – Identify System Workload Drivers (Customer Interest/Involvement)

Every management system provides products and services for customers. Customer interests and involvements drives the workload with positive and negative information feedback. Matrix 5 defines the associations between activity and customer.

CUSTOMERS	Customer Interests/Involvement	GAO Inquiries	Pentagon Inquiries	User Inquiries	Political Satisfaction	Pentagon Satifaction	User Satisfaction	GAO Satisfaction	KTR Motivation	Confidence in SPO Leadership	Requirements Stability	Number of ECPs	Award Fee Percentage	KTR EVM Performance	Cost Risk Performance	Tech Risk Performance	Schedule Risk Performance	Contract Complexity	Technical Maturity	Funding Stability	National Exposure	# of User Driven Requirement Changes	Confidence in Risk Assessment	Risk Reporting Accuracy	SPO/IPT Task Efficiency	SPO/IPT Producivity	Information Flow Efficiency	Job Satisfaction
SPO									x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
KTR								x		x		x	x	x	x	x	x		x		x	x	x			x		
DC			x		x	x		x		x		x	x	x	x	x	x		x	x			x	x			x		
USER				x			x			x		x	x	x	x	x		x	x				x	x			x		
GAO																												

Matrix 5: Customers vs. Customer Interests/Involvement

Matrix 5 highlights several of the workload drivers for engineering workload in a SPO. An **X** is used to indicate a relationship between the customers and the workload drivers associated with the customers' interest and involvement with the system.

Matrix 6 – Identify the Dynamic Relationship between Workload Drivers and Activities

Matrix 6 represents what I call a causal intra-relational matrix (Cintergram). The word causal refers to the dynamic relationship that exists between the variables. The **X** is replaced with a "+" of "-", which represents the reinforcing or balancing relationship between variables.

The information illustrated in Matrix 6 reveals the causal relationships between the activities and the workload drivers. For example, Pentagon Inquires relates to the activity Answer Inquiries. Therefore, the greater the number of Pentagon Inquiries there is an increase to the manpower required to Answer Inquiries. A "+" is used to identify this relationship.

Depending on the number of interdependencies found within the system, only a small percentage of the squares should be filled. It is not uncommon for some variables to a have a very weak correlation. For weak relationships, modelers can use "+" versus "**+**".

IPT/SPO Activities	GAO Inquiries	Pentagon Inquiries	User Inquiries	Political Satisfaction	Pentagon Satfaction	User Satisfaction	GAO Satisfaction	KTR Motivation	Confidence in SPO Leadership	Requirements Stability	Number of ECPs	Award Fee Percentage	KTR EVM Performance	Cost Risk Performance	Tech Risk Performance	Schedule Risk Performance	Contract Complexity	Technical Maturity	Funding Stability	National Exposure	# of User Driven Requirement Changes	Confidence in Risk Assessment	Risk Reporting Accuracy	SPO/IPT Task Efficiency	SPO/IPT Producivity	Information Flow Efficiency	Job Satisfaction	Age of Workforce	Productivity	Turn Over Rate
Customer Interests/Involvement																													
Mitigate Cost Risk													-	-	-														
Mitigate Tech Risk													-	-	-														
Mitigate Schedule Risk													-	-	-														
Technical Problem Solving (TIMs)																													
Negotiate Requirements w/ User															+														
Process ECPs											+															+			
Communicate with SPO	+	+																								+			
Answer Pentagon Inquiries (unscheduled work)		+																								+			
Answer User Inquiries (unscheduled work)																													
Answer GAO Inquiries (unscheduled work)	+																												
Support Formal reporting (Briefings, MAR, DAES)																													
Support Award Fee																													
Perform CPAR																													
Contract/EVM Fact Finding													-	-											+				
Scheduled Communication with User										-				-	-					+					+				
Scheduled communication with Contractor													-	-	-					+					+				
Assess Cost Risk														-	-										+				
Assess Tech Risk														-	-										+				
Assess Schedule Risk														-	-										+				
Ratings																										+			
Training																										+			+
Recognition																										+			
Process Improvement																										+	+		
Lean Initiatives																											+		

Matrix 6: Activities vs. Customer Interests/Involvement

Matrix 7 – Identify the Measures of Performance for the Activities

Once the Activities are defined, the next step is to define the measures of performance for each of the activities. For the system modeler, identifying the measures of performance for each of the activities will provide good data to be used to validate and verify the simulation models. For management, defining the measures of performance for each activity will provide essential insight to internal business performance. These metrics, if tracked, can enable the program manager to identify and focus on the areas of improvement within their organization.

Matrix 7 illustrates the associations between activities and corresponding activity performance measures. Each engineering activity was given a meaningful measure of performance. Little data was available for several of these activities. However, as a result of the activity, management was motivated to start tracking metrics to ensure they were satisfactorily executing the required activities.

IPT/SPO Activities	Performance/Requirements Gap	% Complete of Risk Mitigation Plans	% Complete of Technical Risk Assessm	% Complete of Cost Risk Assessment	% Complete of Schedule Risk Assessm	% Complete of Management Feedback	% Complete of CPAR	% Participation in Award Fee	% Timely formal reporting	% of Timely ECP resolution	% of Timely DR resolution	% on time tasker Responses	% Tasker Rework	% of workweek spent communicating wi	% Complete for Recognition	% of Personnel Meeting Training Requir	% unplanned work
Assess/Mitigate Cost Risk		X															
Assess/Mitigate Tech Risk		X															
Assess/Mitigate Schedule Risk		X															
Technical Problem Solving																	
Negotiate Requirements w/ User	X																
Process ECPs										X							
Staff Meetings																	
Answer Pentaqon Inquiries												X	X				
Answer User Inquiries												X	X				
Answer GAO Inquiries												X	X				
Formal reporting (MAR, DAES)									X								
Support Award Fee								X									
Perform CPAR							X										
Contract/EVM Fact Finding																	
Scheduled Comm. with User																	
Scheduled comm. with KTR						X							X				
Assess/Mitigate Cost Risk				X													
Assess/Mitigate Tech Risk			X														
Assess/Mitigate Schedule Risk					X												
Ratings																X	
Training															X		
Recognition														X			
Process Improvement																	X
Lean Initiatives																	

Matrix 7: Activities vs. Activity Performance Measures

Matrix 8 – Identify the Dynamic Relationships between Activity Performance Measures and Workload Drivers (Customer Interests and Involvement)

Matrix 8 is another causal intra-relational matrix to identify the casual relationships between the activity measures of performance and the workload drivers. For example, if the management organization has a high *% of on Time Tasker Responses* (User Inquires) then the there is a positive feedback to User Satisfaction denoted by the "+" in the matrix box. Identifying the causal relationships for activity measures and the workload drivers can be done in a brainstorming session with system experts or with customers in a customer feedback session. Determining the nature of the these relationships requires more in depth study, data collection, and expert knowledge elicitation.

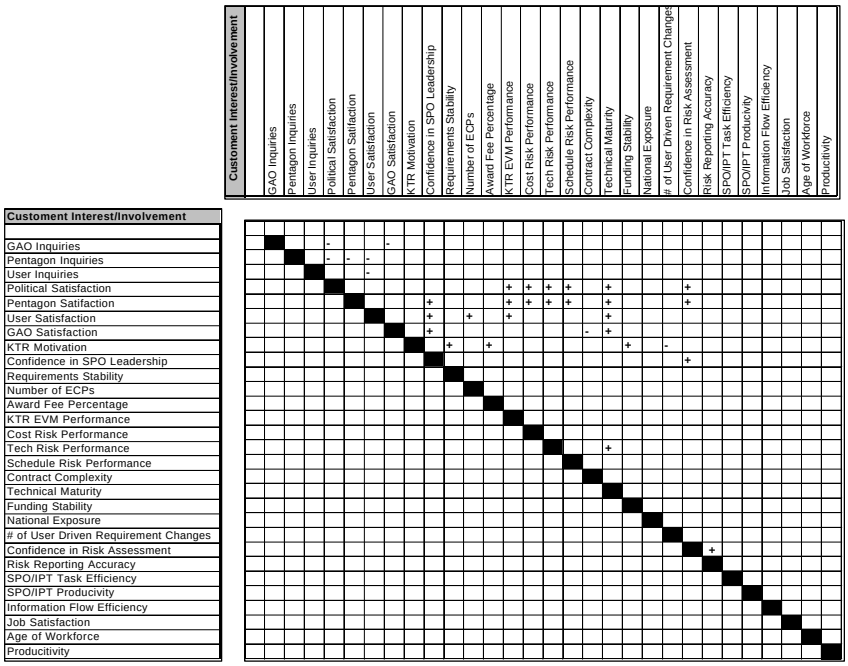
Customent Interest/Involvement	Performance/Requirements Gap	% Complete of Risk Mitigation Plans	% Complete of Technical Risk Assessm	% Complete of Cost Risk Assessment	% Complete of Schedule Risk Assessm	% Complete of Management Feedback	% Complete of CPAR	% Participation in Award Fee	% Timely formal r reporting	% of Timely ECP resolution	% of Timely DR resolution	% on time tasker Responses	% Tasker Rework	% of workweek spent communicating wi	% Complete for Recognition	% of Personnel Meeting Training Requir	% unplanned work
GAO Inquiries																	
Pentagon Inquiries																	
User Inquiries																	
Political Satisfaction	+								+			+					
Pentagon Satifaction	+								+			+					
User Satisfaction	+									+		+					
GAO Satisfaction										+	+	+					
KTR Motivation						+	+	+						-			
Confidence in SPO Leadership																	
Requirements Stability																	
Number of ECPs																	
Award Fee Percentage																	
KTR EVM Performance																	
Cost Risk Performance																	
Tech Risk Performance																	
Schedule Risk Performance																	
Contract Complexity																	
Technical Maturity																	
Funding Stability																	
National Exposure																	
# of User Driven Requirement Changes																	
Confidence in Risk Assessment			+	+	+	+											
Risk Reporting Accuracy																	
SPO/IPT Task Efficiency																	
SPO/IPT Producivity																	
Information Flow Efficiency																	
Job Satisfaction																	-
Age of Workforce																	
Producitivity																	
Turn Over Rate																	
Competency																+	
Morale															+	+	-

Matrix 8: Activity Performance Measures vs. Customer Interests/Involvement

Matrix 9 – Identifying the Workload Drivers (Customer Involvement/Interests) Causal Inter-relational Diagram:

Matrix 9 is a Causal Inter-relational Matrix (Cintergram). The matrix identifies the causal relationships intrinsic to the workload drivers that will affect the activities performed by the management system. For example, User Satisfaction is a workload driver that effects the number of program inquiries the User requires of a SPO. The

greater the User's Satisfaction, the less the number of inquires. Therefore, a "-" is placed in the box which relates the User Inquiries and User Satisfaction.



Matrix 9: Customer Interests/Involvement Cintragram

MCM Aggregation:

Once the original MCM was completed, it was obvious that many of the variables to could be pooled together and others were relatively insignificant to the engineering workload. Based on further interviews, the MCM was simplified to the highest meaningful level of aggregation. Below are the revised matrices.

Revised MCM

After completing the MCM, the two objectives the engineering workforce primarily supported was Broker Information and Manage Risk. Engineers supported other objectives, but an interview revealed that over 90% of the effort engineers expend was in these two areas.

Previously, the team identified 24 activities that engineers performed. These Activities were simplified into 3 areas of activities; Identify Risk, Mitigate Risk, and Broker Information.

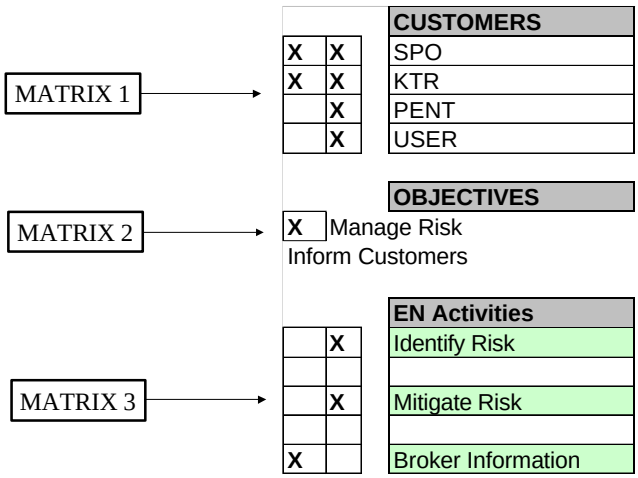


Figure 1. Revised Matrices 1, 2, and 3

Matrices 4, 5 and 6 were also simplified to address the high yield areas for engineering manning. The workload drivers, or Customer Interest/Involvement, were reduced from 33 to 13.

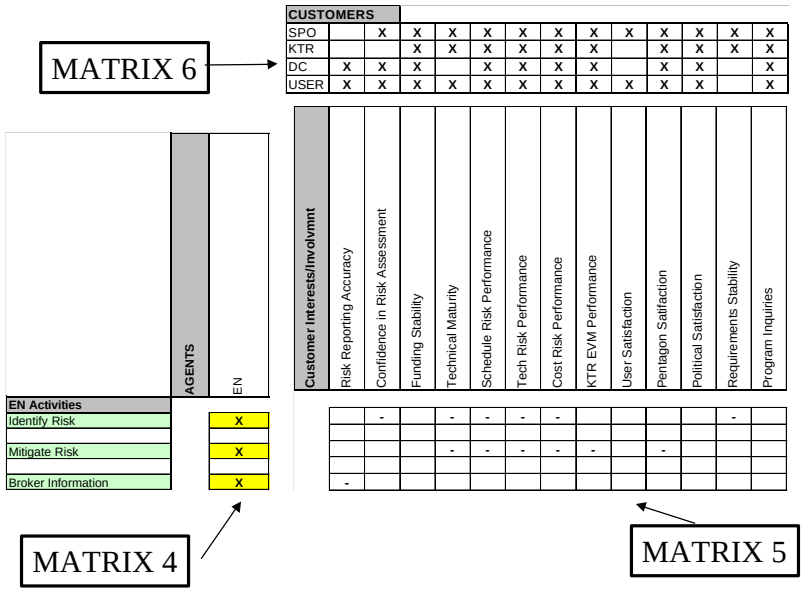


Figure 2. Matrices 4, 5, and 6 Revised

Figures 3 and 4 show the remaining revised matrices used for generating the initial stock and flow structure.

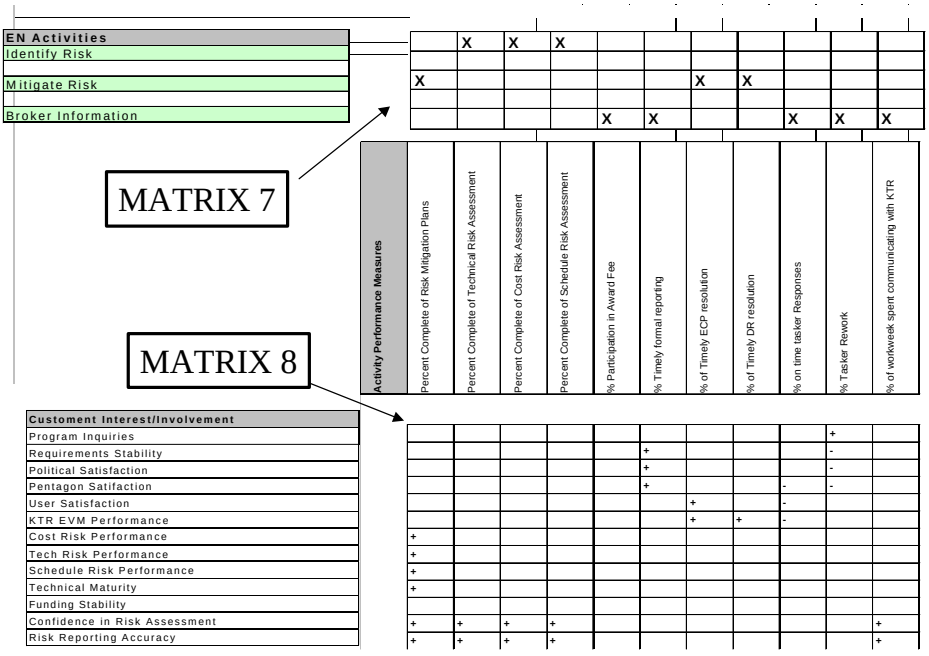


Figure 3. Matrices 7 and 8 Revised

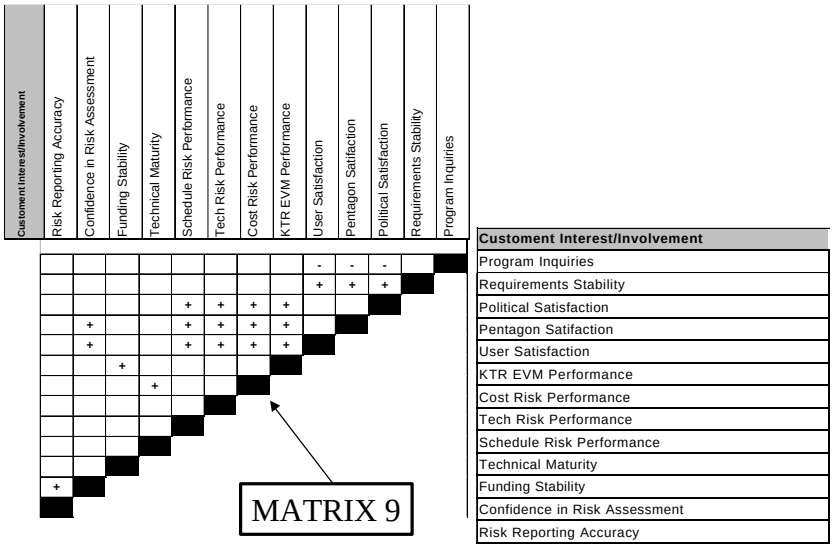


Figure 4. Revised Matrix 9

Example:

In this section I will present an example that walks through the entire MCM. I selected to trace dynamic behavior for **Identify Risk**. This activity supports the objective **Manage Risk** highlighted by Matrix 1. The function **Manage Risk** is a valued engineering function by all of the system customers and this is represented in the highlighted section of Matrix 1.

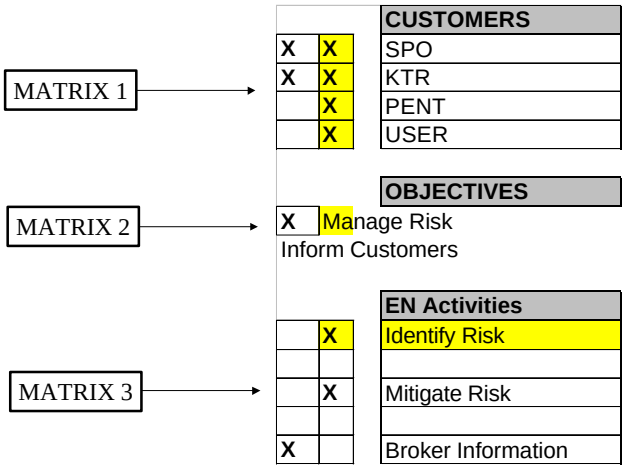


Figure 5. Matrices 1, 2, and 3 Revised

In figure 6, Matrix 4, highlights the casual relationships that interact with the Identify Risk Activities. Matrix 5 reveals causal relation is identified between **Technical Maturity** and **Identify Risk.** The higher the level of **Technical Maturity**, the less effort required for engineers to identify risk.

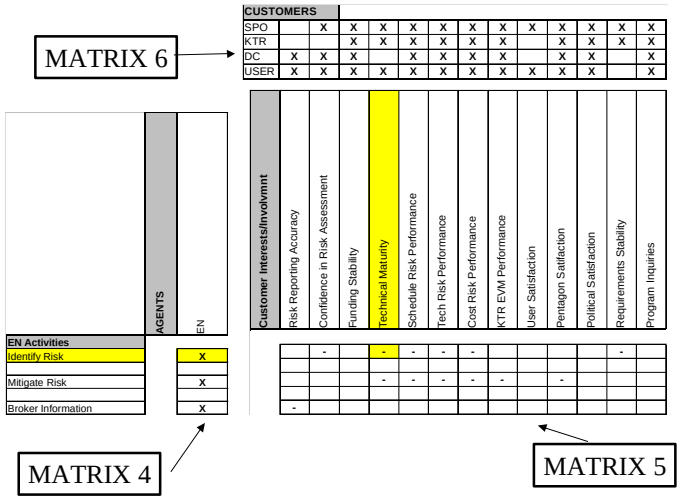


Figure 6. Matrices 4, 5, and 6 Revised

In figure 6, matrices 7 and 8 show several relationships. **% complete of Technical Risk Assessment** is function of number of engineers to **Identify Risk**. If the proper number of engineering staff are allocated to **Identify Risk** then the **% complete of Technical Risk Assessment** performance is good. If this activity performance measure is high, then the variable, **Confidence in Risk Assessment**, is also high. This is represented by the "+".

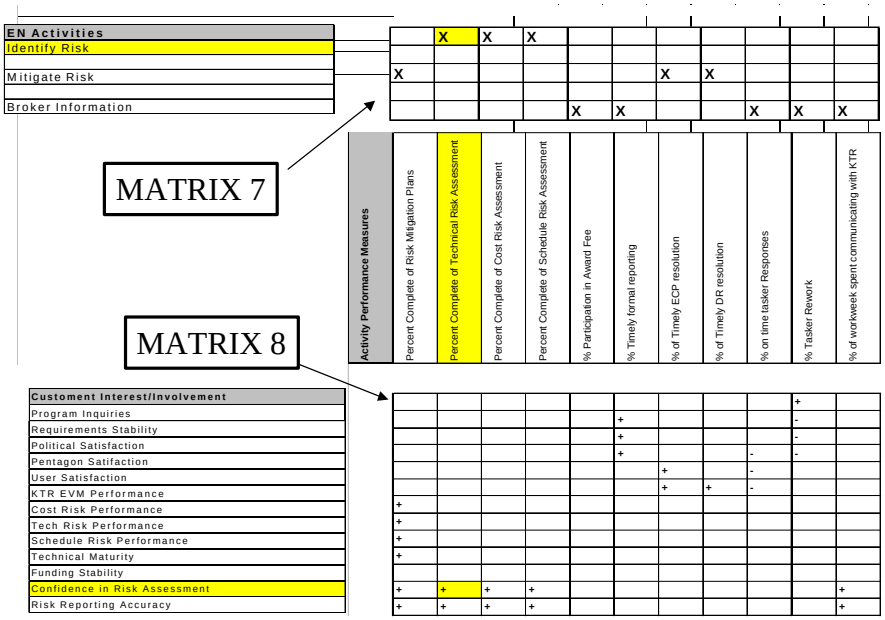


Figure 7. Matrices 7 and 8 Revised

In the revised matrix 9, the previously complex Cintragram is greatly simplified by changing the model boundaries. Figure 8 highlights the relationship between **Confidence in Risk Assessment** and **Risk Reporting Accuracy**. The "+" indicates that the greater the **Confidence in the Risk Assessment** the higher the **Risk Reporting Accuracy**. We can follow the matrix to show that the feedback to the **Customer's Satisfaction** is positive the higher **Risk Reporting Accuracy**. Then in turn affects the **Number of Inquiries** engineers will be required to answer.

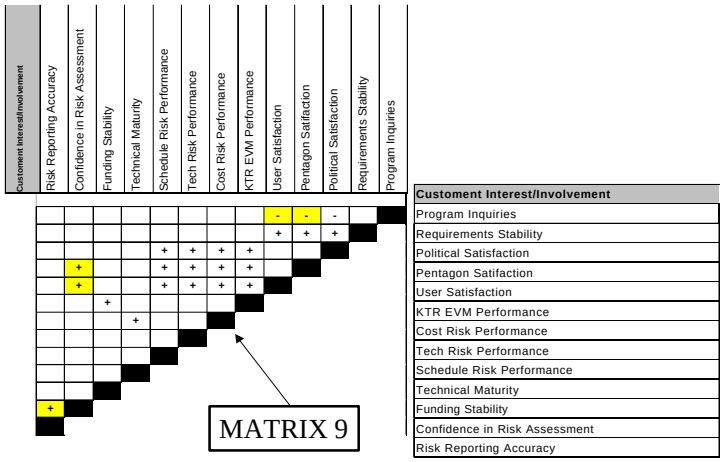


Figure 8. Matrix 9 Revised

Stocks and Flows Example:

This section describes a stock and flow diagram used to model a portion of the information generated by the MCM, which was described in the section above. **Technical Maturity** is a variable that determines the **Required Effort to Identify Risk**. The more mature the program, the less engineering manpower is required to identify risk. **Confidence in Risk Assessment** compares the **Required Effort to Identify Risk** with **Available Manpower to Identify Risk**. If the **Available Manpower to Identify Risk** meets the defined threshold, the engineers will achieve an acceptable **Rate of Risk Discovery**. **Rate of Risk Discovery** determines the amount of **Discovered Risk** for each time interval. If the **Discovered Risk** matches the **Discovery Profile** it increases the **Risk Reporting Accuracy**.

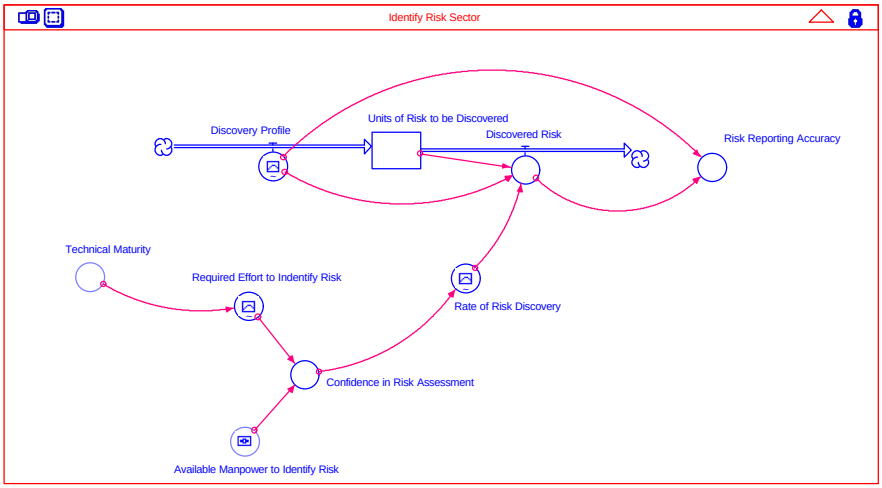


Diagram 1. Identify Risk Sector

The sector displayed above is one portion of a larger stock and flow model of the entire the engineering manpower system defined by the MCM. A more complete description of the model is found in Bartolomei and Smith's paper titled, "A System Dynamics Model of Government Engineering Support During the Development Phase of a Military Acquisition Program." (Bartolomei and Smith:2001)

Conclusions:

MCM provide a rigorous process of gathering information during the information-gathering phase of model development. In addition, the organized structure gives users a greater insight to the many interrelationships and interdependencies found within an extremely complex system. The process of defining a MCM cultivates a strong intuitive appreciation for the entire system. Through a better understanding of the entire system, a modeler can simplify the process boundary definition and the degree of aggregation.

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