

Mission Process Calculator

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Preface

This document is the user manual for an Excel-based tool, the Mission Process Calculator. The tool itself is available from the authors on request. This tool was created for ACC/A2.

This research was sponsored by ACC/A2 and was conducted within the Force Modernization and Employment Program of RAND Project AIR FORCE as part of a fiscal year 2016 study, “New Effects-Based Targeting Methodology.” The tool was developed as an exemplar tool to assist with a system-of-systems network analysis as a part of a target systems analysis.

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Mission Process Calculator User Manual

Introduction

The Mission Process (MP) Calculator is a Microsoft Excel workbook with NodeXL,¹ an Excel add-in, for network visualization. The workbook handles the data entry and network calculations for the key components of a system-of-systems network approach. The following information is needed to define the network:

- a functional flow diagram of the targeted adversary mission
- a mapping of adversary functions to systems
- a mapping of the dependencies between adversary systems, including but not limited to physical dependencies and information flow.

Installation Instructions for NodeXL

The MP Calculator with NodeXL has been tested on Windows machines with Excel 2010, and there appears to be no reason it would not work with more recent versions of Excel on Windows (2013 and 2016), provided the NodeXL add-in is installed and macros are enabled for the calculations to work. Because there is no Mac OS version of the NodeXL add-in, a Mac user should use Parallels and the Windows version of Excel. If the computer on which MP Calculator will be used has an internet connection, the most recent version of NodeXL Basic will provide the necessary network visualization tools used in MP Calculator. The most recent version with an offline installer for NodeXL Pro is available for \$749/year. An earlier version of the offline NodeXL Basic installer is available from the lead author upon request.

Worksheet Descriptions

The MP Calculator workbook has four different worksheet classes, each with a different tab color: The *License Agreement* and *Start Page* sheets are orange;² the network input sheets are green; the network calculation sheets are red; and the network visualization sheets are blue. The first class of sheets is self-explanatory; the workbook opens on the *Start Page* sheet. The other classes of worksheets will be explained in the next sections.

¹ NodeXL, a free Excel template developed by the Social Media Research Foundation, is available at Social Media Research Foundation, NodeXL: Network Overview, Discovery and Exploration for Excel website, September 27, 2016.

² As a convention, worksheet names will be *in italics*, any action button names will be **bold**.

Network Input Sheets (Green Tabs)

Setup

This sheet has three columns of values: “Systems,” “Tasks,” and “Attacks.” When beginning to develop a new network system-of-systems (SoS) framework, the names of the systems involved, the tasks, and attacks should be put here. At least one of each type of object is required. When the objects are entered, the **Setup Worksheets** button should be clicked. After confirmation that the user wants to generate a new framework, all existing data are deleted from the input sheets, and the new objects are populated in the proper places on the various sheets. To work on several different SoS frameworks, the user should save them in separate Excel workbooks. Systems and Tasks are to be enumerated using the codes (Si) and (Tj), respectively, where i and j are counters of the number of systems and tasks used in the mission framework. If a framework requires additional objects, the user can add them at the end of the list, then click **Append New Elements to Worksheets**, which will update all the worksheets but will not delete existing data.

The worksheet has four additional buttons:

- **Compute System Predecessors.** Once the *System Dependencies* sheets are filled out, this button calculates which systems have either physical or information dependencies on other systems. Dependencies are propagated from one system to the next, so if System A depends on System B, which depends on System C, then System C is a predecessor of both System A and System B. The results are displayed on the *System Predecessors* sheet.
- **Find Source-Sink Paths for Tasks.** Once the *Task Functional Flow* sheet is filled out, this button calculates the paths from all sources (tasks with no predecessors) to all sinks (tasks with no successors) and displays them on the *Source-Sink Routes* sheet along with their weights, which are the product of the edge weights of the component edges of the route.
- **Compute Attack Effects.** Once the *Attack Effects* sheets are filled out, this button calculates the probability that each system is disabled by the attacks on the *Attack Effects* sheets. Similarly, for each task, it computes the probability that the task is completed and, for each route, the probability that the route is operational (the product of the probabilities that all the tasks along the route are operational). The button also automatically executes the same calculations as the previous two buttons because the intermediate calculations are needed to calculate the attack effects. All intermediate and final results are shown on the *Attack Calculations* worksheet.
- **Generate Network.** Once all input sheets are filled out, clicking this button will populate the sheets that NodeXL uses to visualize the SoS network. The user must click the **Refresh Graph** button in the NodeXL window (which has the label “Document Actions” in the upper left corner) to see the network, as well as after any changes to the underlying network data. Additionally, if a layout option needs to be selected, the user should select that option and then hit **Refresh Graph** or **Lay Out Again**. The network shows both Tasks and Systems as nodes (blue circles and red squares, respectively), with directed links to show direct task predecessors (blue arcs), directed links to show system predecessors (red arcs, which are either dotted, dashed, or solid, depending on whether there are physical dependencies, information dependencies, or both, respectively), and directed links (green

arcs) from systems to tasks to denote that the system appears in the logical function that determines the probability that the task can be performed. Attack effects are shown on the graph, with affected systems and tasks represented by larger icons whose sizes are proportional to the probability of a set of attacks disabling the system and/or task.

System Dependencies—Physical; System Dependencies—Info

Physical and information system dependencies are noted on these sheets. If system (S_j) has a physical or information dependency on system (S_i), a 1 should be entered in row j, column i of the applicable table. These tables are used to determine the system predecessors described earlier.

Task Functional Flow

This sheet is where the functional flow of the targeted adversary mission is represented. If task (T_i) is an immediate predecessor of task (T_j) for some route to complete the adversary mission, a number between 0 and 1, inclusive, should be entered in row j, column i of the table. The numbers correspond to the effectiveness of an adversary mission when completed using that particular pair of tasks: When the routes are determined, the weight of a route is the product of the weights of all the edges along it.

Task Functional Definitions

This sheet is where the logical mappings of systems to adversary tasks are represented. For each task, a logical function describing the combinations of systems required for the task to occur should be given. The logical function should be in terms of the systems (represented by (S_i)) and can use the AND and OR logical operations. The function can be arbitrarily complex and use parenthetical logical clauses, subject to the rule that any set of clauses within a set of parentheses must be chained together by identical logical operations. The following logical functions are legal:

- (S₁)
- (S₁) AND (S₂)
- (S₁) OR (S₂) OR (S₃)
- (S₁) OR ((S₂) AND (S₃) AND (S₄))
- (S₁) AND ((S₂) OR ((S₃) AND (S₄))).

(S₁) AND (S₂) OR (S₃) is an example of an illegal logical function, although ((S₁) AND (S₂)) OR (S₃) or (S₁) AND ((S₂) OR (S₃)) are both allowable.

Attack Effects—Physical and Attack Effects—Info

The user can define one or more attacks on an adversary mission and have the tool evaluate their effectiveness. An attack can affect either the physical or information element of the system or both. Values in these tables should be between 0 and 1, inclusive, and represent the probability that the attack disables the system. At the top of each column is a 0/1 flag to turn attacks on and off from consideration.

Network Calculation Sheets (Red Tabs)

System Predecessors

The values on this sheet were explained earlier in the **Compute System Predecessors** button explanation.

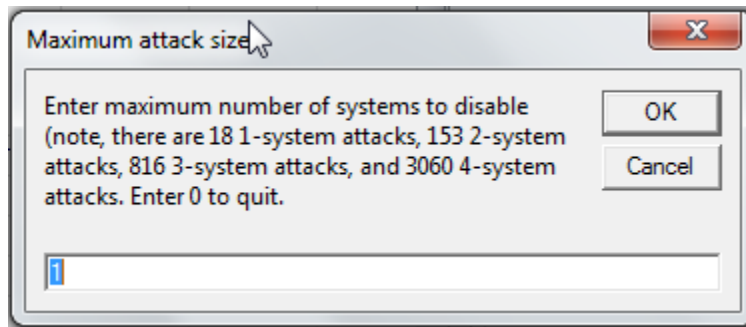
Source-Sink Routes

The values on this sheet were explained earlier in the **Find Source-Sink Paths for Tasks** button explanation. In addition to the table showing the tasks in each route and the route weights, there is a column in which users can optionally name the routes (otherwise, the system defaults to numbering the routes (Rk)).

Critical Systems

When the **Determine Critical Systems** button on this sheet is pressed, an input box like the one in Figure 1 appears.

Figure 1. Input Box



This value sets the size of the largest subset of systems to attack simultaneously in the critical system analysis. A separate table is given for each subset size from 1 up to the maximum given in this input box. For each subset of systems and each route, the calculator determines whether disabling the subset of systems disrupts the route (that is, whether any task along the route fails to be completed). Then, the calculator determines the weighted fraction of the routes that are disrupted, where the weights are those calculated and shown on the *Source-Sink Routes* sheet. The subsets are then sorted from largest to smallest fraction to determine promising candidates for systems to maximally disrupt the overall adversary mission.

Attack Calculations

This sheet presents the step-by-step determination of the effectiveness of the attacks given on the *Attack Effects* page. Table 1 explains each column.

Table 1. Description: Attack Calculations

Column	Explanation
System [Predecessors]	Contains all the systems and their predecessors, when applicable.
Pr(System Disabled—Physical)	Gives the probability that an attack will directly physically disrupt a system.
Pr(System Disabled—Information)	Gives the probability that an attack will directly disrupt the information flow for a system.
Pr(Predecessors Disabled—Physical)	Gives the probability that an attack physically will disrupt any predecessor of the system.
Pr(Predecessors Disabled—Information)	Gives the probability that an attack will disrupt the information flow for any predecessor of the system.
Pr(System Operable—Physical)	Gives the probability that a system will be physically operable. The value given is $1 - (1 - \text{Pr}(\text{System Disabled}))(1 - \text{Pr}(\text{Predecessors Disabled}))$.
Pr(System Operable—Information)	Gives the probability that the information flow for the system will be operable. The value given is $1 - (1 - \text{Pr}(\text{System Disabled}))(1 - \text{Pr}(\text{Predecessors Disabled}))$.
Pr(System Operable)	Gives the probability that the system will be operable. The value given is $\text{Pr}(\text{System Operable - Physical}) * \text{Pr}(\text{System Operable - Information})$
Task	Lists all tasks that are a part of the adversary mission.
System Logic	Gives the logical function of system operability that determines whether the task is completed.
Pr(Task Disrupted Physical)	Gives the probability that the attacks physically disrupt the task.
Pr(Task Disrupted Info)	Gives the probability that the attacks disrupt the information flow necessary for the task to be completed.
Pr(Task Completed)	Gives the probability that the task is completed. It is equal to $1 - (1 - \text{Pr}(\text{Task Disrupted Physical}))(1 - \text{Pr}(\text{Task Disrupted Info}))$
Route	Lists all routes for mission completion.
Task Components	Lists the tasks that are components of each route.
Pr(Route Disabled Physical)	Gives the probability that any task along the route is physically disrupted.
Pr(Route Disabled Info)	Gives the probability that the information flow necessary for any task along the route is disrupted.
Pr(Route Completed)	Gives the probability that the route is completed. It is equal to $1 - (1 - \text{Pr}(\text{Route Disabled Physical}))(1 - \text{Pr}(\text{Route Disabled Info}))$

Network Visualization Sheets (Blue Tabs)

The tool populates these sheets automatically, so the user generally does not need to change information on them. Indeed, doing so risks disrupting proper display of the network.

Documentation for NodeXL, the various network layouts, and features of the NodeXL add-in is available, both via the **Help** button on the NodeXL ribbon and online.³ As an example of a change users may wish to make to this worksheet (with the previous caveats in mind), users can fix the locations of the nodes in the network by setting the **Layout** option in the NodeXL window to None, unhiding columns L–Z on the *Vertices* sheet, modifying the coordinates of the nodes in columns M and N, and clicking **Refresh Graph** in the NodeXL window, modifying node coordinates until the desired layout is achieved. Selecting a different layout (e.g., Sugiyama, Random), will replace the values the user has entered into these columns.

If the NodeXL window is ever closed, it can be displayed again by clicking the **Refresh Graph** button on the upper left in the NodeXL ribbon. Similarly, if the network does not appear in the window, clicking **Show Graph** will cause the graph to reappear. If the graph appears to be too small, the Zoom and Scale parameters should help. Additionally, to view one portion of the network (either the Systems or Tasks side), the user clicks the **Dynamic Filters** button and restricts the X- or Y-coordinates on the Vertex Filters boxes until only the desired subnetwork is shown.

³ The documentation for NodeXL can be found at Social Media Research Foundation, “Getting Started,” NodeXL: Network Overview, Discovery and Exploration for Excel website, October 20, 2015.

Appendix. Targets to Effects Modeling to Disrupt Mission Processes

Variables

S_1, \dots, S_K	The systems entities require to perform tasks.
S_j^i, S_j^p	If there are system dependencies (information flow or physical linkages) of system S_j on system S_i , then s_{ij} is 1, 0 otherwise.
$o(S_j)$	The probability that system S_j is operational.
$o_0(S_j)$	The probability that system S_j is operational in the absence of any attacks (baseline).
T_1, \dots, T_N	The tasks that make up a mission process.
t_{ij}	In the mission process map functional flow diagram, if T_i is an immediate predecessor to T_j , then t_{ij} is 1, 0 otherwise.
$f_i(o(S_1), \dots, o(S_K))$	For each task T_i , the function describing the probability it can be performed as a function of the probabilities of the operability of the underlying systems. As examples, if S_2 and S_3 must both be operational for task T_1 , then $f_1 = o(S_2)o(S_3).$ If either can be operational, then $f_1 = 1 - [1 - o(S_2)][1 - o(S_3)].$
A_1, \dots, A_L	The set of attacks against systems.
X_1, \dots, X_L	Binary variables denoting whether attack A_i is selected.
$p_{i,j}$	The probability that attack A_i directly disrupts system S_j .
R_1, \dots, R_D	The set of source-to-sink routes (along edges with $t_{ij} = 1$) in the process flow diagram.
e_{ij}	Is equal to 1 if route R_i contains task T_j , 0 otherwise.
$\Omega(X_1, \dots, X_L)$	The probability that the mission process is successful.

Equations of Interest

$$o(S_j) = 1 - [1 - o(S_k)] \prod_{i=1}^L (1 - X_i p_{i,k})$$

where k is a predecessor of S_j or $S_k = S_j$. Note that these equations assume independence of attack effects against a system.

$$\Pr(\text{Route } R_i \text{ is operational}) = 1 - \prod_{j=1}^N (1 - e_{ij} f_j)$$

If attack effects on routes are independent of one another, then

$$\Omega = 1 - \prod_{i=1}^D [1 - \Pr(\text{Route } R_i \text{ is operational})].$$

References

Social Media Research Foundation, “Getting Started,” NodeXL: Network Overview, Discovery and Exploration for Excel website, October 20, 2015. As of October 14, 2016:
<http://nodexl.codeplex.com/documentation>

Social Media Research Foundation, NodeXL: Network Overview, Discovery and Exploration for Excel website, September 27, 2016. As of October 14, 2016:
<http://nodexl.codeplex.com/>