USSOCOM

Optimizing SOF Military Construction (MILCON) Resources

MILCON Prioritization and Allocation Tool (MPAT)

J8, Strategic Studies
U.S. Special Operations Command

Military Construction (MILCON) Example

MILCON is an example of a resourcing problem that needs automation more than it needs AI/ML:

- Resource constrained.
- Extremely large number of potential solutions (e.g. 50 variables ~ 1.13×10^{15} solutions).
- Existing process is human resource (time & money) intensive.
- Problem can be constructed in an objective framework.
- Complex problem; optimal solution requires mathematical modeling.
  - Framed as a multi-knapsack problem (strongly NP-complete; unary NP-hard).
  - Can potentially be expanded for multiple objectives using metaheuristics.

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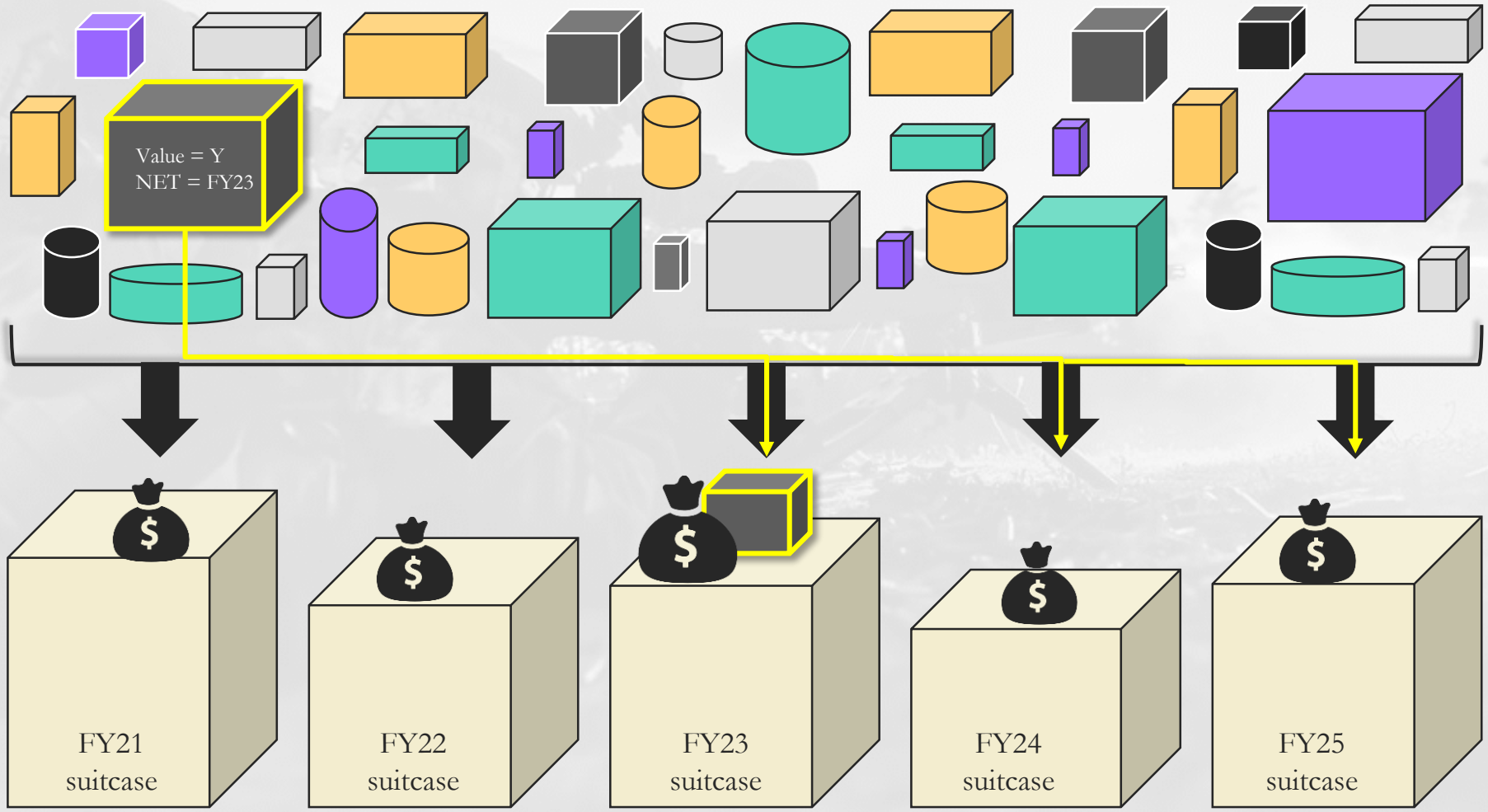
MILCON Mathematical Method:

Integer Programming

In the most basic format, the MILCON example is a multi-knapsack problem.
Which combination of projects provide the **most value** within our fiscal year **budget constraints**?

MILCON Projects



Key Variables

i = Project number $\{1, 2, \cdots, n\}$.

j = Fiscal Year $\{18, 19, \cdots, 24\}$

$$x_{i,j} = \begin{cases} 0, & \text{Project } i \text{ is programmed in year } j \\ 1, & \text{Project } i \text{ is not programmed in year } j \end{cases}$$

u_i = POM sponsor of project i.

c_i = Cost of project i per year.

$v_{i,j}$ = Value of project i in year j.

$CBPL_i$ = Capabilities Based Program List score for project.

$r_{i,p}$ = Rank assigned to project i by POM sponsor (p).

w_r = Weight applied to Rank Score in the value function.

w_c = Weight applied to CPBL Score in the value function.

MF_i = Must fund Fiscal Year project i must be funded.

NET_i = No earlier Fiscal Year that project i can be funded.

PDS_i = Prospectus development study cost of project i.

$PND1_i$ = First planning and design cost of project i.

$PND2_i$ = Second planning and design cost of project i.

$CEQOM_i$ = Collateral equipment operations and maintenance cost of project i.

$CEQPROC_i$ = Collateral equipment procurement cost of project i.

$C4IOM_i$ = Command, control, communications, computing and information (C4I) cost of project i.

$C4IPROC_i$ = C4I procurement cost of project i.

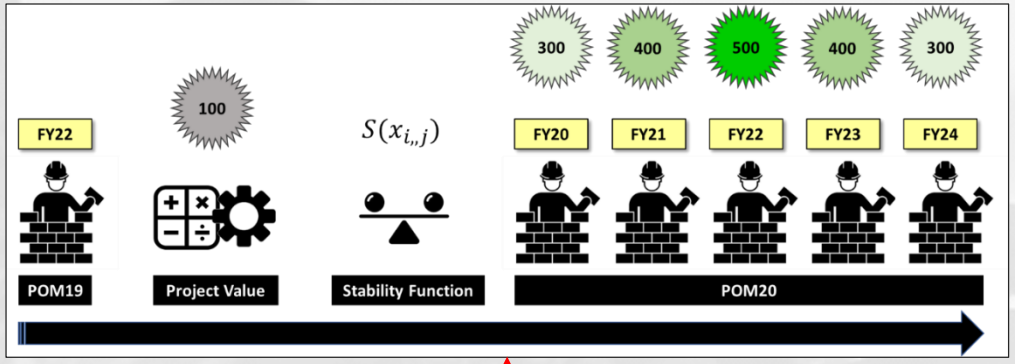
Each cost has an associated lead or lag time.

How are value scores calculated?

$$v_{i,j} = s(x_{i,j}) * \left[w_c\left(f(CBPL_i)\right) + w_r\left(f\left(R(r_{i,p})\right)\right)\right]$$

Stability Function

$$s(x_{i,j}) = \begin{cases} 5 - |k - j|, & k > 0 \quad \forall\, k \in \{1,2,3,4\} \\ 1, & k = 0 \end{cases}$$



- The stability function accounts for the relationship between the current program and the previous program. This function provides a reward for minimizing the number of year-to-year project shifts between POM cycles.
- Regardless of when a project was programmed in the previous POM, it has a higher likelihood of being included in the current solution, and it is more likely to be programmed in the same FY as in the previous POM.
- Example: If a project was programmed for FY22 in POM19, it will receive and increase to its entire value based on its location in POM20.

Rank Score (Normalized and Weighted by TOA)

$$R(r_{i,p}) = \begin{cases} 99 * \left(\frac{r_{i,p} - 1}{n_p - 1}\right) + 1, & r_{i,p} \geq 1 \\ 0, & r_{i,p} < 1 \end{cases}$$

$$\mathrm{f}\left(R(r_{i,p})\right) = \begin{cases} R(r_{i,p}) * \left(\frac{TOA_p / TOA}{n_p / N}\right) + 1, & R(r_{i,p}) \geq 1 \\ 1, & R(r_{i,p}) < 1 \end{cases}$$

- The rank score for each project is calculated by normalizing the ranks and weighting the normalized ranks based on the proportion of projects submitted compared the historical TOA percentage for each POM Sponsor.
- n_p = number of projects submitted by POM Sponsor p
- N = number of projects by all POM Sponsors
- The normalized rank $R(x_i)$ all POM Sponsor ranks to a scale of 1 to 100
- The weighted rank score $\mathrm{f}\left(R(x_i)\right)$ adjusts the ranks to account for POM sponsors that submit a number of projects that is not proportional to historical TOA percentages.

CBPL Score (Normalized)

$$f(CBPL_i) = 100 * \left(\frac{CBPL_i^{-1} - min(CBPL^{-1})}{max(CBPL^{-1}) - min(CBPL^{-1})}\right)$$

- The CBPL score for each project is calculated by normalizing the CBPL values on a scale of 0 to 100 using the maximum and minimum CBPL values.

Multi-Knapsack Problem: **Strongly NP-Complete**

Objective Function

$$\text{maximize } Z = \sum_{i=1}^{n}\sum_{j=1}^{5} v_{i,j}$$

Value function

$$v_{i,j} = s(x_{i,j}) * \left[w_c\left(f(CBPL_i)\right) + w_r\left(f\left(R(r_{i,p})\right)\right)\right]$$

Constraints

s.t.

$$\sum_{i=1}^{n} c_i x_{i,j} + \sum_{i=1}^{n} C_i x_{i,(j-L_i)} \leq TOA_j, \forall \text{j} ,\text{k} \neq \text{j}$$

Budget Constraints The sum of the costs for all projects programmed in each FY cannot exceed the TOA for that FY.

$$x_{i,MF_i} = 1;$$

Must Fund Constraints A project cannot be programmed prior to the must fund FY (if a must fund FY exists).*

$$x_{i,j} = 0, \forall\, j < NET_i;$$

No Earlier Than Constraint A project cannot programmed prior to its NET FY.

$$\sum_{j=1}^{5} x_{i,j} \leq 1;$$

Limiting Constraints A project cannot programmed in more than one FY.

$$\sum_{j=1}^{5} x_{i,j} \geq BR;$$

Business Rule Constraint A project programmed in prior POM must be included in the current solution. **(Removed for POM21)**

$$x_{i,j} = binary$$

Whole Projects Constraint A project cannot be partially programmed.

$$C_i \ni \{PDS_i, PND_i, CEQ_i, C4I_i, \dots\} \quad L_i \ni \{l_{PDS,i}, l_{PND,i}, l_{CEQ,i}, \dots\}$$

* Component #1 priorities were assigned as Must Fund in the Desired FY for POM21.

The model requires one input file of requested MILCON projects.

Project	POM Sponsor	Cost	CBPL Score	Rank Score	NET	Must Fund	Previous POM	PDS Lead	PDS Cost	PND Lead	PND Cost	CEQ Lag	CEQ Cost	C4I Lag	C4I Cost
Project 1	USASOC	$108,000	192.44	54	FY21		0	-3	125	-1	$4,320	2	$795	2	$135
Project 2	NSW	$100,000	192.44	0		FY22	20	-3	125	-1	$4,000	2	$,4800	2	$368
Project 3	HQ	$97,000	108.28	50		FY21	0	0	125	-1	$3,880	2	$0	2	$398
Project 4	MARSOC	$80,000	192.44	44	FY22		0	-3	125	-1	$3,200	2	$9,000	2	900
Project 223	NSW	$77,000	104.86	373			23	-3	125	-1	$3,080	2	$4,786	1	$1,436
Project 224	AFSOC	$75,000	136.73	373			20	-3	125	-1	$3,000	2	$1,870	2	$368

The input data is used to construct a integer program in matrix format.
For POM20, there were 1,170 decision variables for an analysis of 234 projects.

$$\begin{pmatrix} Ax \\ 941 \times 1{,}170 \end{pmatrix} \leq \begin{pmatrix} b \\ 941 \times 1 \end{pmatrix}$$

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MILCON Optimization

Integer Programming

R Shiny

MPAT is uses R programming and is hosted with an R Shiny Server for a internet browser user interface.

MILCON Prioritization and Allocation Tool

- Instructions
- Optimization
- Project Statistics
- Table: MPAT Solution
- Table: Capability Sponsor Costs
- Chart: Capability Sponsors
- Chart: MIS Programs
- Chart: Project Counts
- Chart: Cost-Value
- Summary Statistics
- Glossary of Input Data Fields

SOCOM J8-S
Version 2.6.3

SOCOM MILCON Prioritization and Allocation Tool (MPAT) Overview

MPAT is a tool designed to inform budget resource allocation decisions. The tool incorporates optimization to maximize the total value of Military Construction (MILCON) projects subject to numerous constraints. MPAT is built using R and Shiny. The imbedded optimization component uses a linear programming API called lpSolveAPI to solve integer programs.

Optimization Instructions

1. Download the CSV template (*Input_Data_Template.csv*) for required fields and formatting. See **Glossary** in the sidebar menu for data field descriptions. **Do not delete any template columns!**
2. Import the MILCON raw data (CSV file) using the **Import** button.
3. Adjust parameters and budget constraints. Use the slider bars to set the budget constraints for each Fiscal Year (FY). Use the numeric input boxes to set the CBPL and Rank weights (0 to 1) for the value function. The sum of the weights must equal 1. The run time determines how long the optimization will search for a most optimal solution. *It is recommended to use 60 seconds or less for demonstations and ~1,000 seconds for decision-making with the current data.*
4. Click the **Load Parameters** button to set the contraints and parameters for solving. The **Solve** button will appear when complete. Click the **Reset Model** button before subsequent parameter loads.
5. Click the **Solve** button to begin solving the optimzation. When finished, a green message box with the number of projects funded will appear in the Status Report box.
6. View reports and summary statistics from the sidebar menu.

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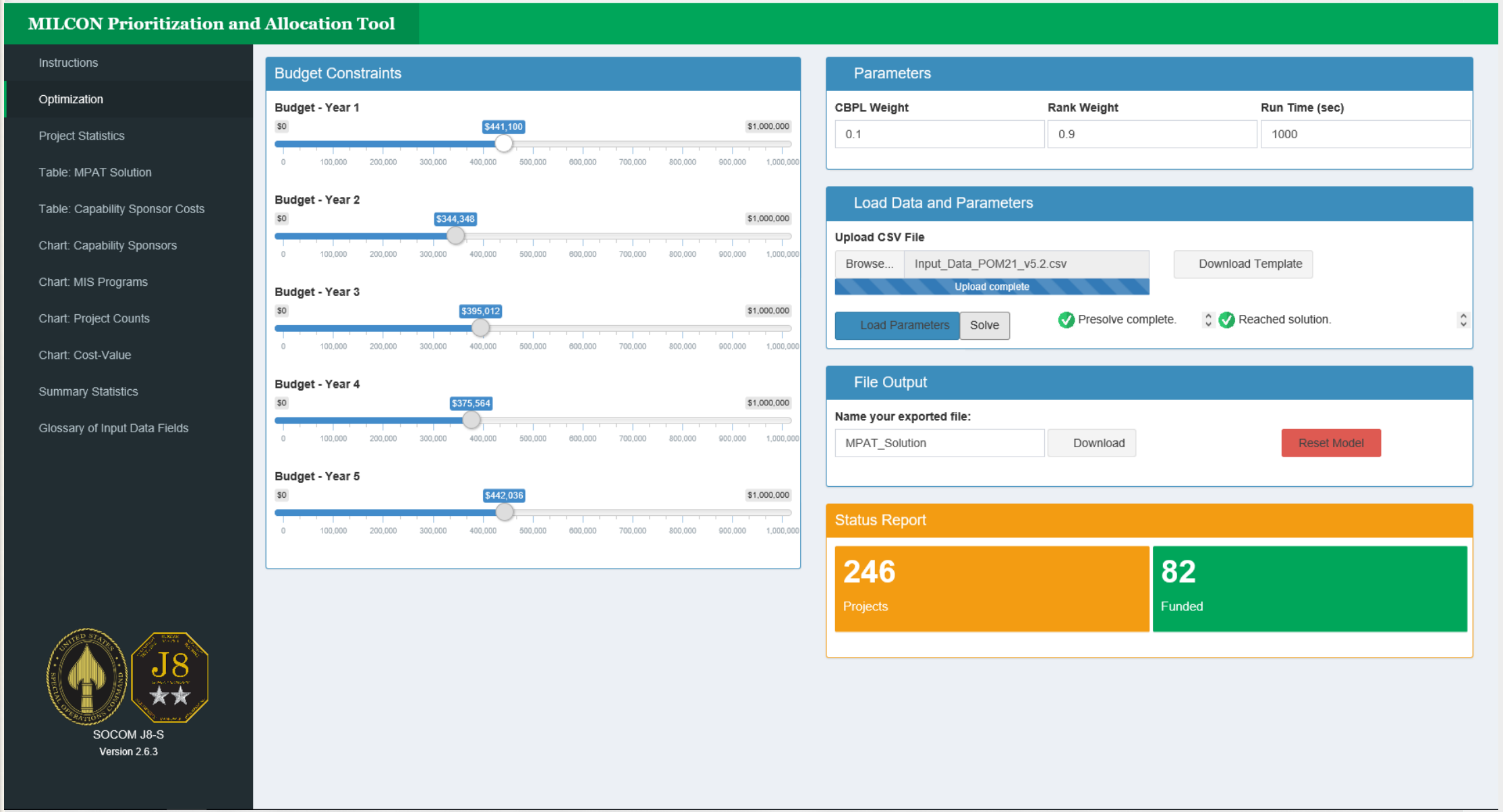
Users import data, adjust parameters, and solve the integer programming model to produce an optimal solution.



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The solution table displays the recommended funding year for each project. The example below is sorted by cost.

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Show 20 entries Search:

MILCON Projects

	Project Title	MIS Program	Location	POM Sponsor	Must Fund	No Earlier	POM 19	Current	Cost
P090	Operations Facility	PG0022	Location 8	POM Sponsor C	FY 22	FY 20	FY 20	FY 22	$100,000
P158	Headquarters	PG0027	Location 9	POM Sponsor E	-----	FY 23	FY 23	FY 23	$77,000
P109	AMU & Weapons Hangar	PG0006	Location 28	POM Sponsor A	-----	FY 20	FY 20	FY 20	$75,000
P023	Battalion Complex	PG0020	Location 8	POM Sponsor C	-----	FY 20	FY 20	FY 20	$72,400
P091	Command and Control Facility	PG0034	Location 19	POM Sponsor F	FY 22	FY 20	FY 22	FY 22	$58,811
P092	Joint Intelligence Center	PG0034	Location 19	POM Sponsor F	FY 22	FY 20	FY 22	FY 22	$56,100
P073	USASOC HQ Secure Operations	PG0042	Location 19	POM Sponsor F	-----	FY 21	FY 22	FY 22	$49,000
P143	Undersea Operational Training Facility	PG0026	Location 43	POM Sponsor E	FY 20	FY 20	FY 20	FY 20	$48,009
P051	Group Headquarters	PG0010	Location 19	POM Sponsor F	-----	FY 20	FY 20	FY 22	$48,000
P175	Combat Service & Support Facility	PG0031	Location 32	POM Sponsor E	FY 21	FY 20	FY 21	FY 21	$48,000
P038	Military Free Fall Advanced Training Complex	PG0041	Location 46	POM Sponsor F	-----	FY 20	FY 20	FY 20	$44,800
P178	Operations Facility	PG0007	Location 31	POM Sponsor A	FY 20	FY 20	FY 20	FY 20	$44,523
P105	Special Tactics Operations Facility	PG0007	Location 28	POM Sponsor A	-----	FY 21	FY 21	FY 22	$43,000
P022	Battalion Operations Facility	PG0010	Location 19	POM Sponsor F	-----	FY 21	FY 21	FY 21	$41,000
P050	Battalion Operations Facility	PG0005	Location 31	POM Sponsor F	-----	FY 21	FY 22	FY 23	$41,000
P062	Operations Faciltiy	PG0019	Location 19	POM Sponsor C	-----	FY 21	FY 21	FY 21	$40,000
P111	Combat Aircraft Parking Apron-North	PG0006	Location 28	POM Sponsor A	-----	FY 21	FY 21	FY 21	$37,038
P095	Operations and Maintenance Facilities	PG0018	Location 11	POM Sponsor A	FY 22	FY 20	FY 22	FY 22	$36,748
P166	Operations Facility & Command Center	PG0032	Location 32	POM Sponsor E	-----	FY 21	FY 21	FY 21	$36,700
P135	Training Facility	PG0026	Location 16	POM Sponsor E	-----	FY 20	FY 21	FY 21	$35,700

Showing 1 to 20 of 234 entries Previous 1 2 3 4 5 … 12 Next

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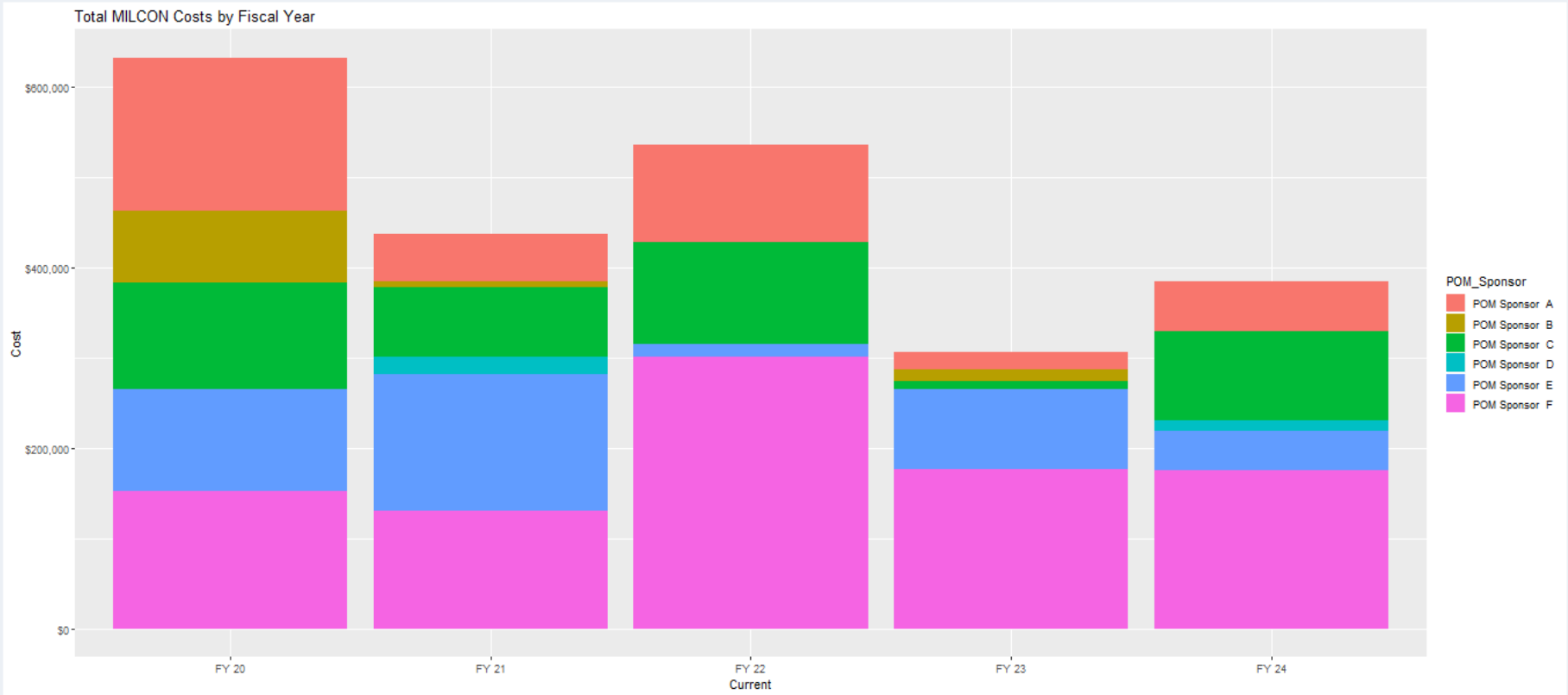

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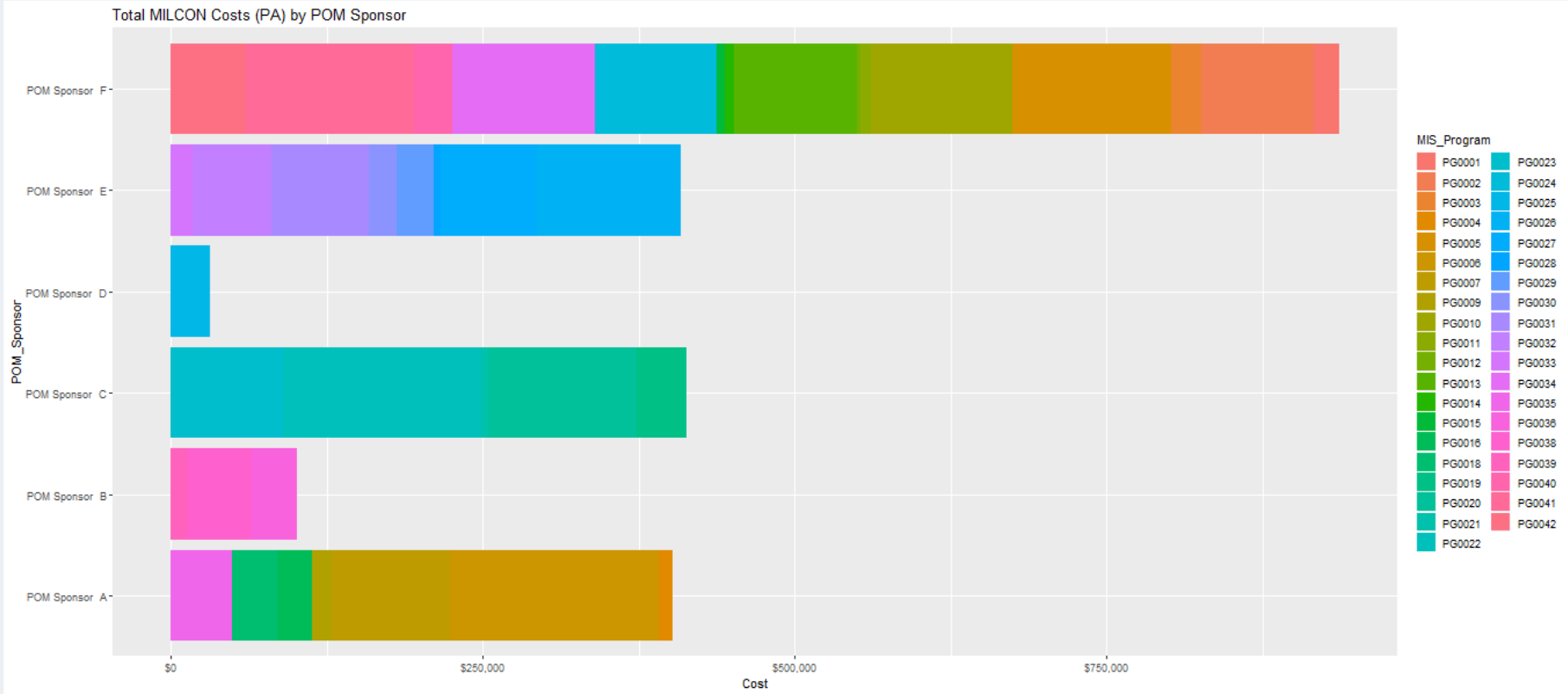

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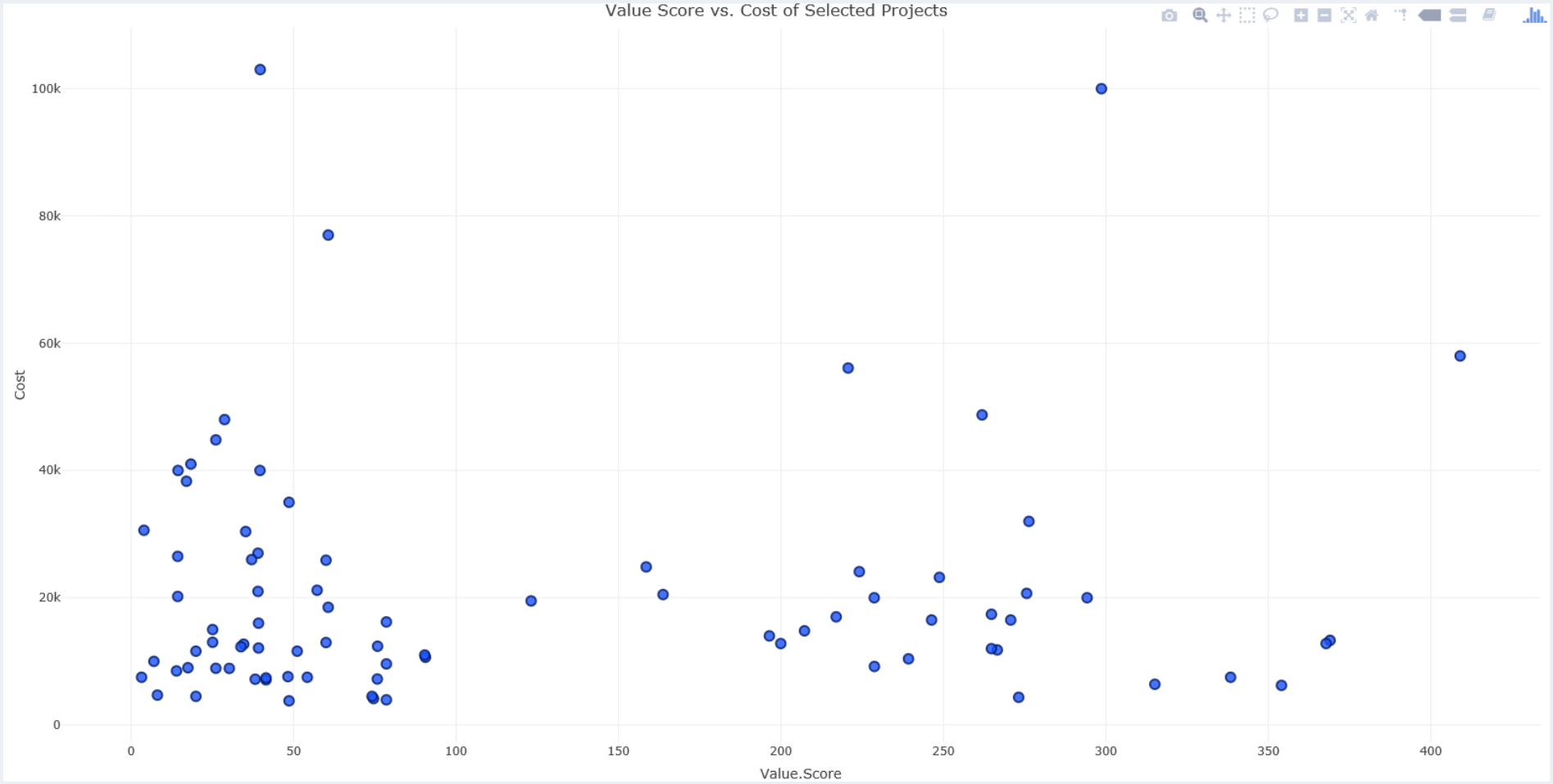

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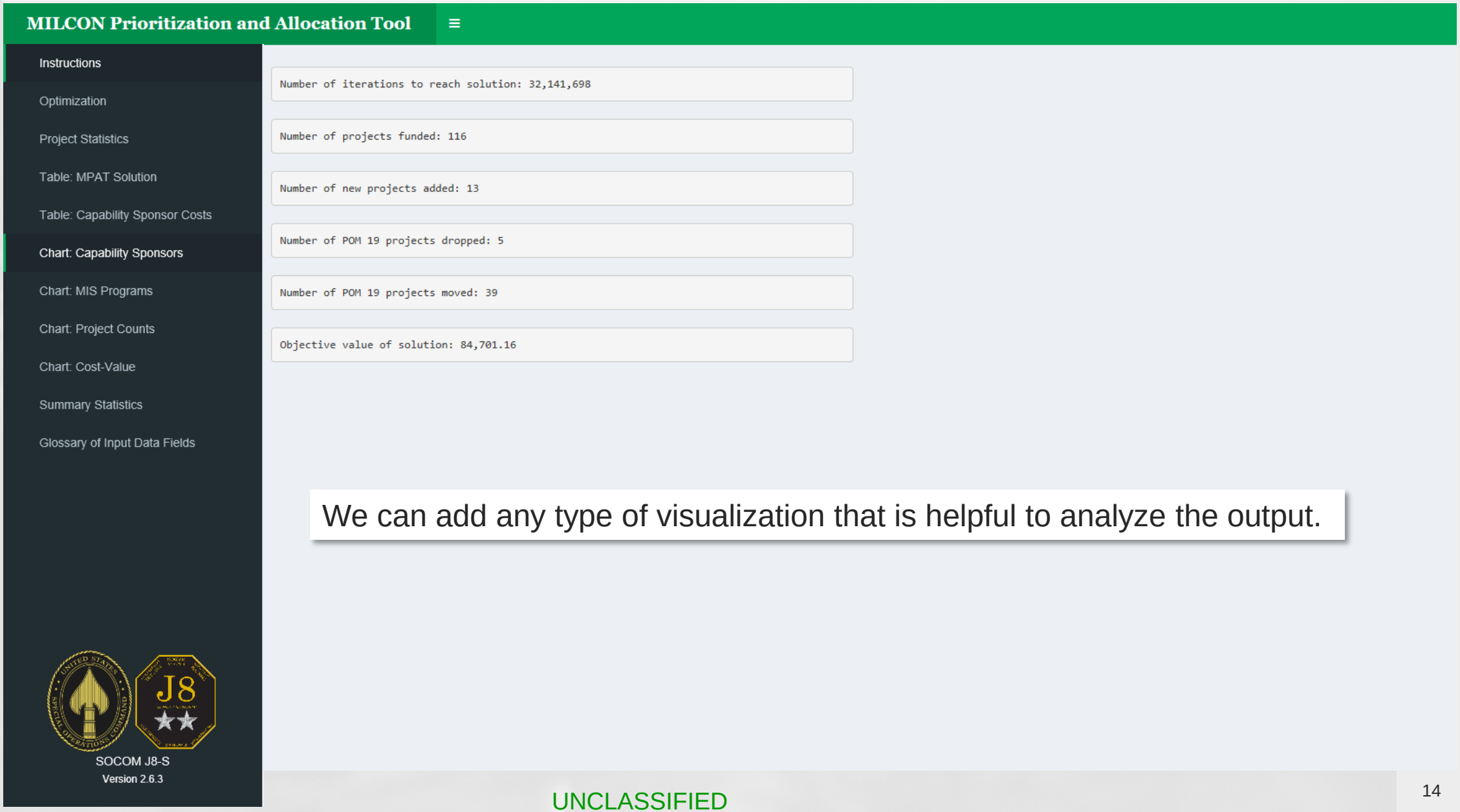

We can add any type of visualization that is helpful to analyze the output.

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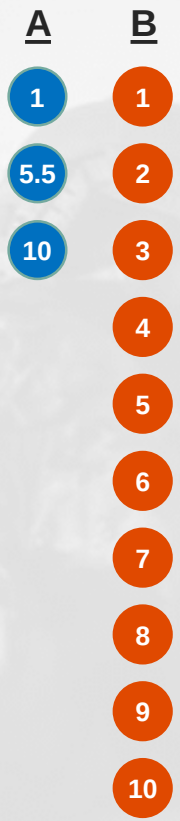
Backup

How do we make a composite ranking of mutually exclusive ranks?

Sponsor A ranks 3 projects
Sponsor B ranks 10 projects

Number of projects (N) = 13
Number of A projects (n_A) = 3
Number of B projects (n_B) = 10

Step 1:
Put rakings on the same scale.



Step 2
Merge to a combined indexed list.

Assume
TOA_A % for A is 3/8
TOA_B % for B is 5/8

Example

$$R(r_{i,p}) * \left(\frac{TOA_p\%}{n_p/N}\right)$$

$$5.5 * \left(\frac{3/8}{3/13}\right) = 6.2$$

Step 3
Scale based on TOA proportions.