

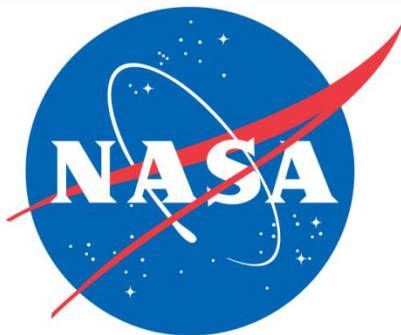


# FLIGHT PROJECTS DIRECTORATE

## A VALIDATION STUDY OF THE PERFORMANCE PREDICTION METHODOLOGY OF THE EARLY WARNING METRICS

NASA COST & SCHEDULE SYMPOSIUM  
AUGUST 2019

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# Agenda

1

## Background

State of Business Development Process,  
Organization, and Structure

2

## Early Warning Metrics Overview

3

## Forecast Assessment

4

## Conclusion

# Background

The **State of Business** is one of many by-products derived from a Business Change Initiative. This is a joint effort between **The Aerospace Corporation** and **NASA Goddard Space Flight Center (GSFC)**.

*Current Sponsor*

Dr. Wanda Peters, Deputy Director for Planning and Business Management

*Charter*

Provide **internal independent cost and schedule assessments to the GSFC Flight Projects Directorate (FPD) leadership** with additional insight through:

- ✓ *An integrated view of schedule, cost, EVM and risk data across the entire FPD project portfolio*
- ✓ *Focus on projects in need of additional management attention due to unfavorable schedule and cost trends and variances.*
- ✓ *Objective, data performance-based indicators collected by an independent team of project management subject matter experts assessing and advising whether projects based on that data can reasonably meet their schedule and budget commitments.*
- ✓ *Discussing the significance and implications of performance metrics, trends and forecasts in a monthly meeting with FPD management*
- ✓ *A basis for assisting FPD management in making informed decisions for mission success.*

# State of Business Process

1

## Monthly inputs derived from Projects data

(via monthly status reports, emails, Empower, etc.)

Input from Projects includes, but not limited to:

- Critical paths
- Current period performance metrics (e.g. HMI, CEI)
- Cumulative performance metrics (e.g. BEI, SPI, CPI)
- Cumulative milestones
- Budget and schedule margins
- Threats, liens and encumbrances
- Risks and Issues

2

## Team members generate respective reports and run independent analysis

 **Risks & Issues Report**

 **Cost Report**

 **Schedule Report**

 **EVM Report**

 **Early Warning Metrics Report**

3

## Team meets internally to discuss and integrate reports



A Brief is generated for the FPD with the goal of aiding decisions and supplying recommendations

### Risks & Issues Report

Examines top risks and new issues; determines if issues are being anticipated/preceded by risk(s)

### Schedule Report

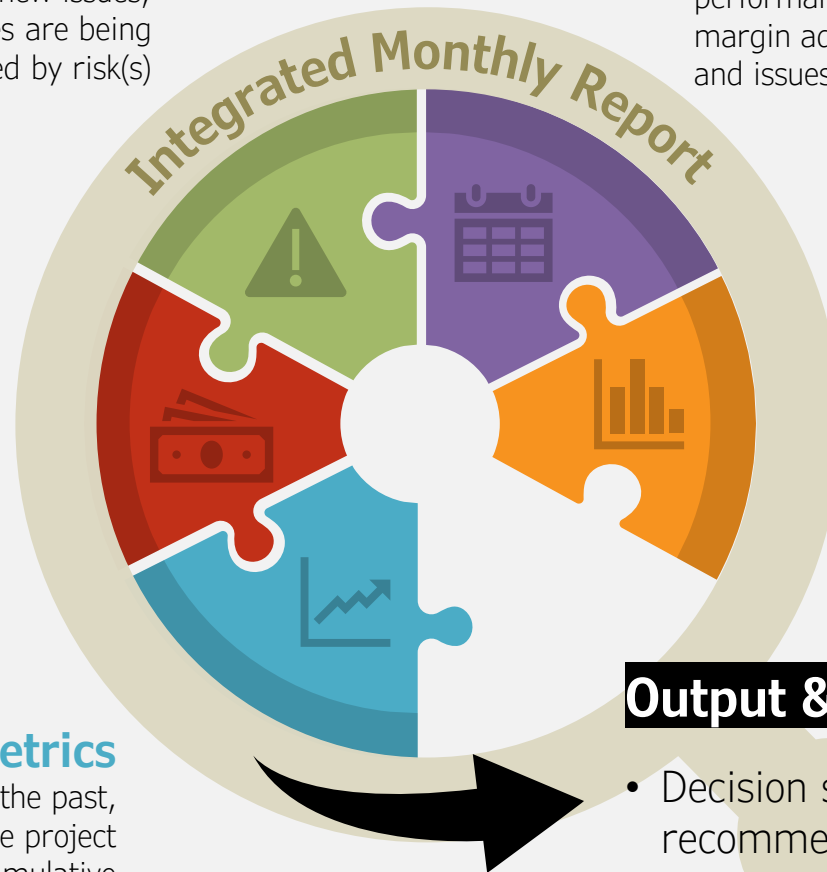
Examines project schedule performance trends, variances, margin adequacy, critical path, risks and issues

### Cost Report

Examines project cost performance trends; commitment, obligation, and cost variances; budget reserves/UFE adequacy; liens, threats, and encumbrances

### EVM Report

Examines project performance trends for cumulative to date and short term performance (CPI3, CPI6); cumulative performance trends and IEAC projections; SPI along with schedule data to evaluate if driving costs



### Early Warning Metrics

Provides at-a-glance view of the past, present, and future state of the project relative to its planned and actual cumulative milestones

### Output & Added Support

- Decision support & recommendations
- Performance trends and projections

# Integration, Decision Support & Recommendations

Tie the performance stories together to help management understand:

- 💡 **Are State of Business assessments in agreement with PM assessments** as reported in monthly status reports? Why different?
- 💡 Based upon current performance metrics, **will projects meet schedule commitments? Cost commitments?** Are budget & schedule margins adequate given risks, threats, and upcoming funding gaps?
- 💡 **Additional insight** to management on performance not reported to management
- 💡 Identify projects that may require further analysis
- 💡 **Conduct “deep dive” analyses** and/or face-to-face meetings with at-risk projects as needed

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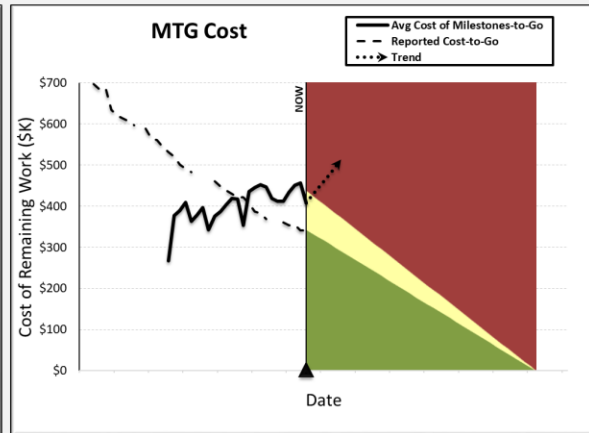
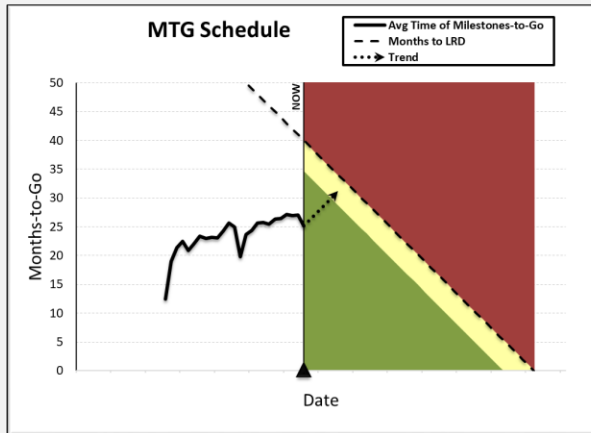
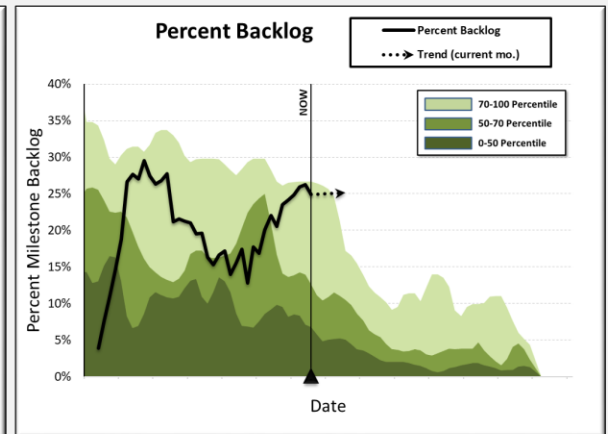
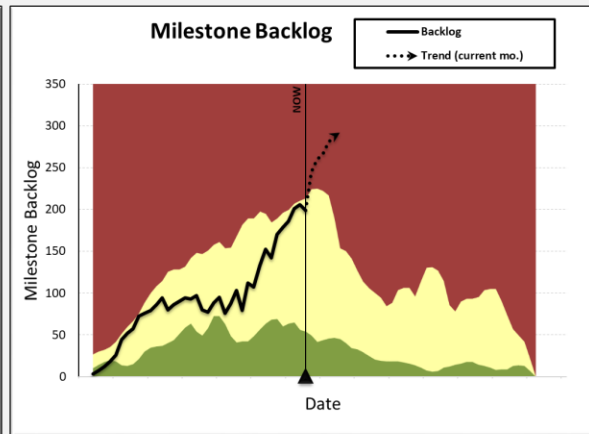
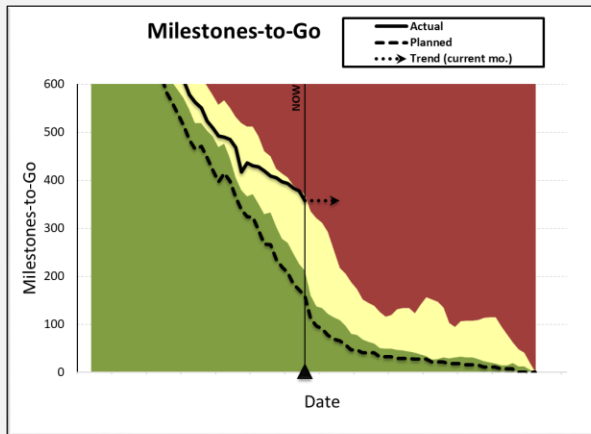
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# Early Warning Metrics

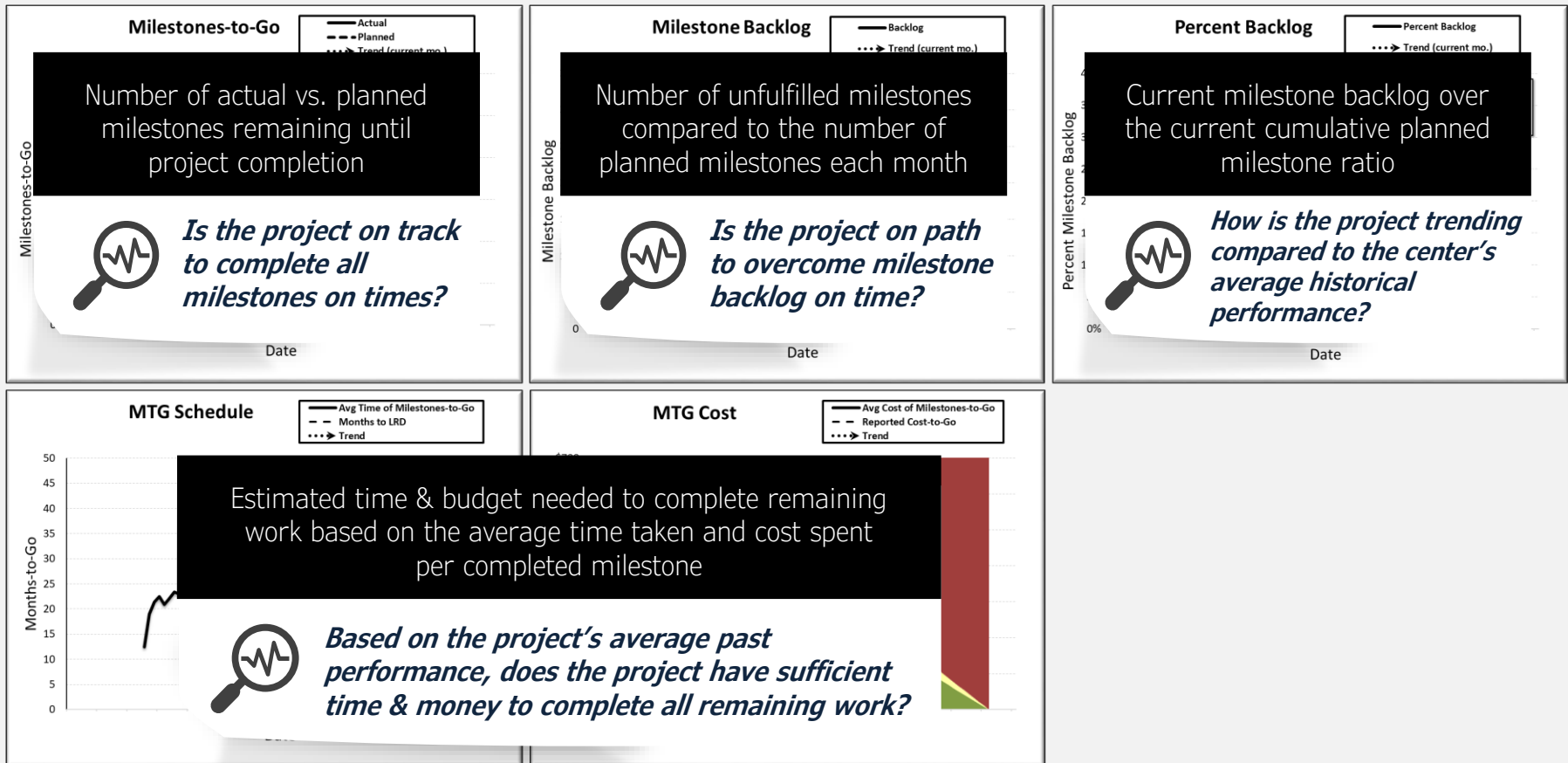
Provides at-a-glance view of the past, present, and future state of the project relative to its planned and actual cumulative milestones





# Early Warning Metrics

Provides at-a-glance view of the past, present, and future state of the project relative to its planned and actual cumulative milestones



# Early Warning Metrics Performance Thresholds

	Green Performance Threshold	Yellow Performance Threshold	Red Performance Threshold
<p><b>Milestones-to-Go (MTG), Milestone Backlog, &amp; Pct. Milestone Backlog</b></p> <p><i>Performance thresholds formulated from historical project performances.</i></p>	<p><i>Backlog <math>\leq</math> 50<sup>th</sup> Percentile of historical GSFC missions at this time in its schedule</i></p> <p>Backlog is comparable to or better than previous, healthy GSFC projects.</p>	<p><i>Backlog is <math>\leq</math> 70<sup>th</sup> Percentile of historical GSFC missions at this time in its schedule</i></p> <p>Backlog is within the average performance range of historical GSFC projects but may require attention.</p>	<p><i>Backlog is <math>&gt;</math> 70<sup>th</sup> Percentile of historical GSFC missions at this time in its schedule</i></p> <p>Backlog is worse than unhealthy historical GSFC projects and requires attention as it may threaten the baseline plan.</p>
<p><b>MTG Schedule</b></p> <p><i>Performance compared to remaining months until Launch Readiness Date (LRD)/Delivery and Funded Schedule Margin (FSM).</i></p>	<p><i>MTG Schedule <math>\leq</math> (Months to LRD/Delivery – GPR 7120.7 FSM Requirement)</i></p> <p>Program is achieving milestones at a fast pace and may complete the remaining work without using FSM.</p>	<p><i>MTG Schedule <math>\leq</math> Months to LRD/Delivery</i></p> <p>Program is completing milestones at an expected pace to meet LRD on time but may use some or all of the FSM.</p>	<p><i>MTG Schedule <math>&gt;</math> Months to LRD/Delivery</i></p> <p>Program is completing milestones at a slower pace than planned, and if maintained, has the potential to not meet the LRD/Delivery date.</p>
<p><b>MTG Cost</b></p> <p><i>Performance compared to remaining Cost-to-Go and Cost Reserves.</i></p>	<p><i>MTG Cost <math>\leq</math> Reported Cost-to-Go</i></p> <p>Cost per milestone to date is less costly than planned and may complete the remaining work well within the reported budget without the use of cost reserves.</p>	<p><i>MTG Cost <math>\leq</math> Reported Cost-to-Go + Contingency thru Liens</i></p> <p>Cost per milestone to date is expected and the program is on track to complete the remaining work within the reported budget and cost reserves.</p>	<p><i>MTG Cost <math>&gt;</math> Reported Cost-to-Go + Contingency thru Liens</i></p> <p>Cost per milestone is more expensive than planned and has a potential to exceed the budget.</p>

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## Current Prediction Method

The current method is based on how well the program is expected to continue completing milestones with respect to its cumulative milestone completion performance to date. The demonstrated milestone completion rate to date, or work efficiency factor  $\eta_{work}$ , is defined as:

$$\eta_{work} = 1 - \left( \frac{\text{Cum. Milestone Backlog}}{\text{Actual Cum. Milestones Completed}} \right)$$

$\eta_{work} > 100\%$  or 1 completed more than planned

$\eta_{work} = 100\%$  or 1 no backlog, on plan

$\eta_{work} < 100\%$  or 1 behind plan

The projected milestone completion rate for future months **Projected  $\eta_{work}$** , based on a the average  $\Delta\eta_{work}$  from the past three months, is used to project the **Milestone Backlog** for the next three month.

$$\text{Proj. Milestone Backlog} = (1 - \text{Proj. } \eta_{work}) * \text{Planned Cum. Milestones}$$

## Current Prediction Method

The **Projected Milestone Backlog** is then used to calculate the **Projected Cumulative Actual Milestone**. The 1 to 3-month projections for the rest of the metrics can then be calculated from there.

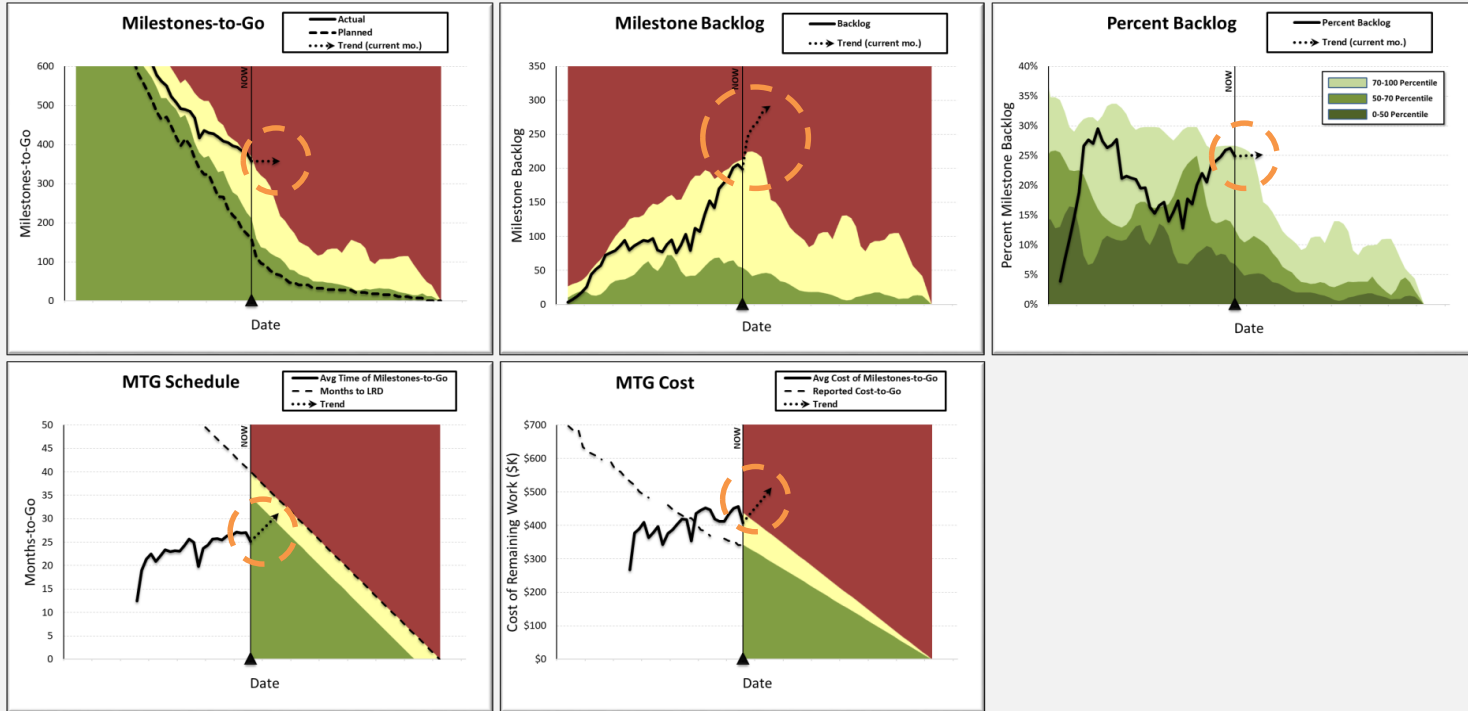
$$\text{Proj. Actual Cum. Milestones} = \text{Planned Cum. Milestones} - \text{Proj. Milestone Backlog}$$

$$\text{Proj. Milestones} - \text{to} - \text{Go} = \text{Planned Cum. Milestones} - \text{Proj. Milestone Backlog}$$

$$\text{Proj. MTG Schedule} = \frac{\text{\# of months since Phase B}}{\text{Actual Cum. Milestones Completed}} * \text{Proj. Milestones} - \text{to} - \text{Go}$$

$$\text{Proj. MTG Cost} = \frac{\text{Cum. Development Cost to Date}}{\text{Actual Cum. Milestones Completed}} * \text{Proj. Milestones} - \text{to} - \text{Go}$$

# Current Prediction Method & Limitations



- **Lagging Indicator** – This model does not take account or predict possible future replans. These sudden events can skew projections for upcoming months.
- Since all the projections are reliant on the Projected Milestones, they are all **volatile to changes in the Planned Milestones** due to schedule shifts.

**Due to these limitations, we introduced the following prediction improvements:**

# ARIMA Overview and Methodology

## Purpose

**Validate and improve predictions for Early Warning Metrics by utilizing the AutoRegressive Integrated Moving Average (ARIMA) Model.**

ARIMA is defined by three parameters

- ***p*** is the order, or number of time lags, of the autoregressive model
- ***d*** is the integrative part of the model that ensures the time series is stationary
- ***q*** is the order of the moving average model

For each metric AND at each time step AND for each prediction length of 1 to 3 months, **2/3 of the data** (at least 6 months) **was used for training** and the **remaining 1/3 of data was used to test.**

1

Using grid search with the training data set, errors for dozens of ARIMA parameter combinations were calculated.

2

With the best parameter combination from the grid search, the projection was calculated on the test set.

3

The Normalize Root Mean Square Error (NRMSE) was calculated and saved for comparison.

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (X_{obs,i} - X_{model,i})^2}{n}}$$

$$NRMSE = \frac{RMSE}{X_{obs,max} - X_{obs,min}}$$

*X* = actual observation (model output)

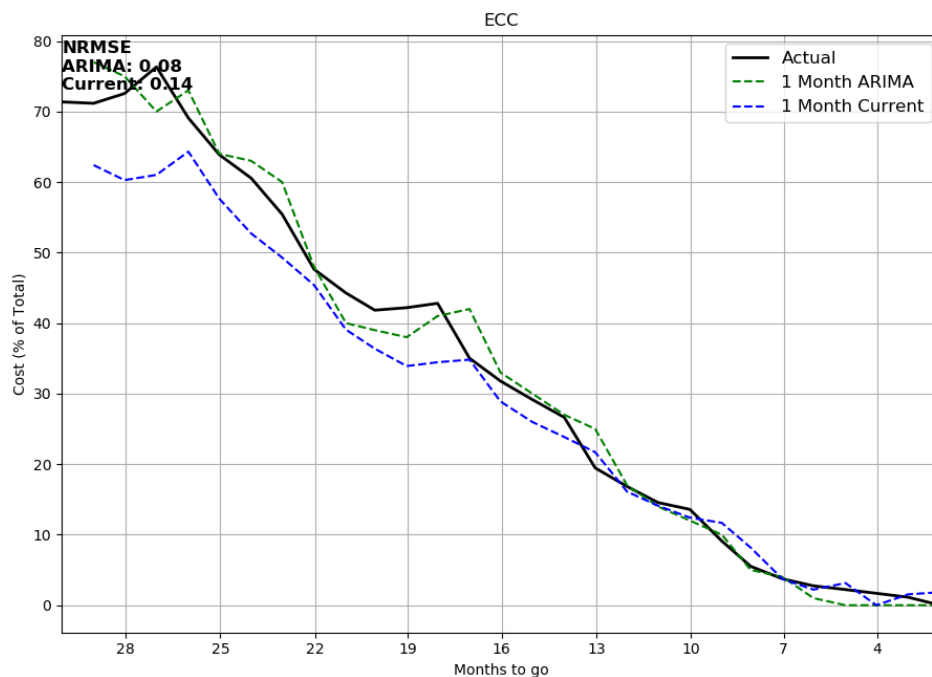
*n* = of observations

# Example Analysis

The NRMSE for ARIMA predictions were compared against the NRMSE of current method for 5 missions:

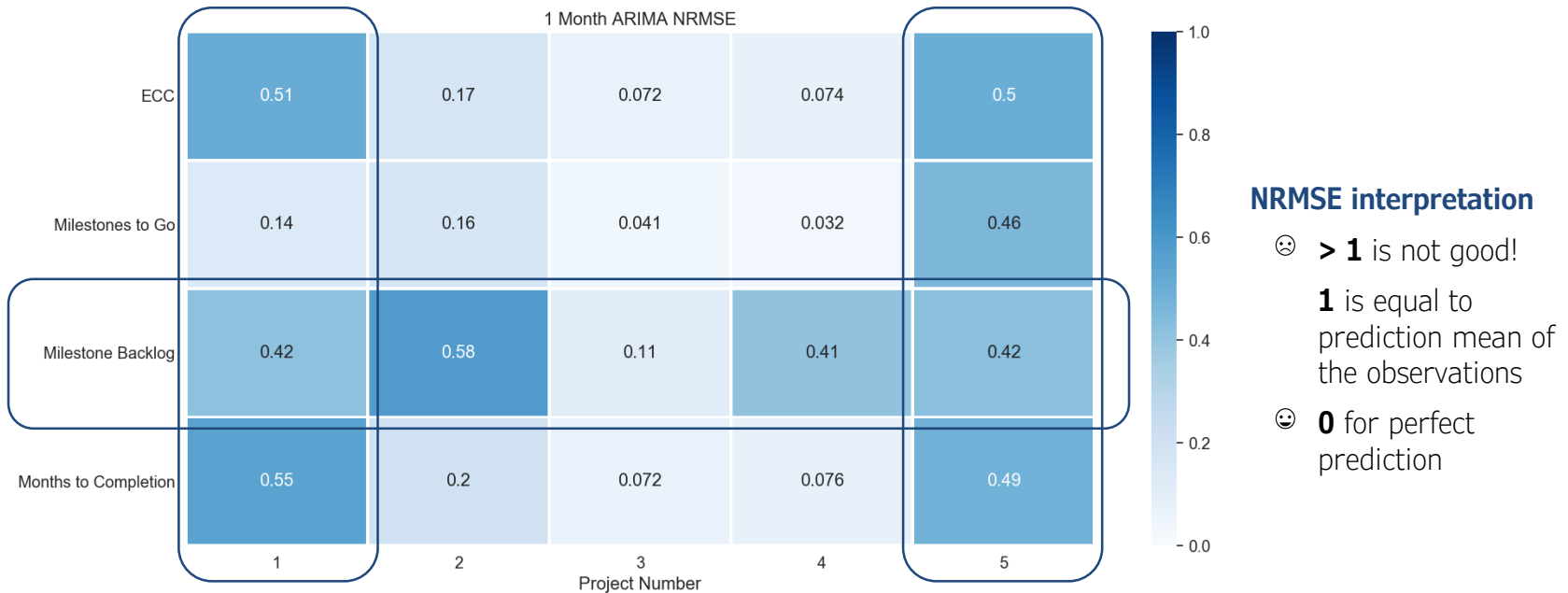
- A laser-based instrument
- A multi-build environmental satellite
- A space observatory
- A laser communications satellite
- A ground station

An example comparison for a 1-month prediction of the MTG Cost or Estimated Cost to Completion (ECC) for Project 4 is shown here.





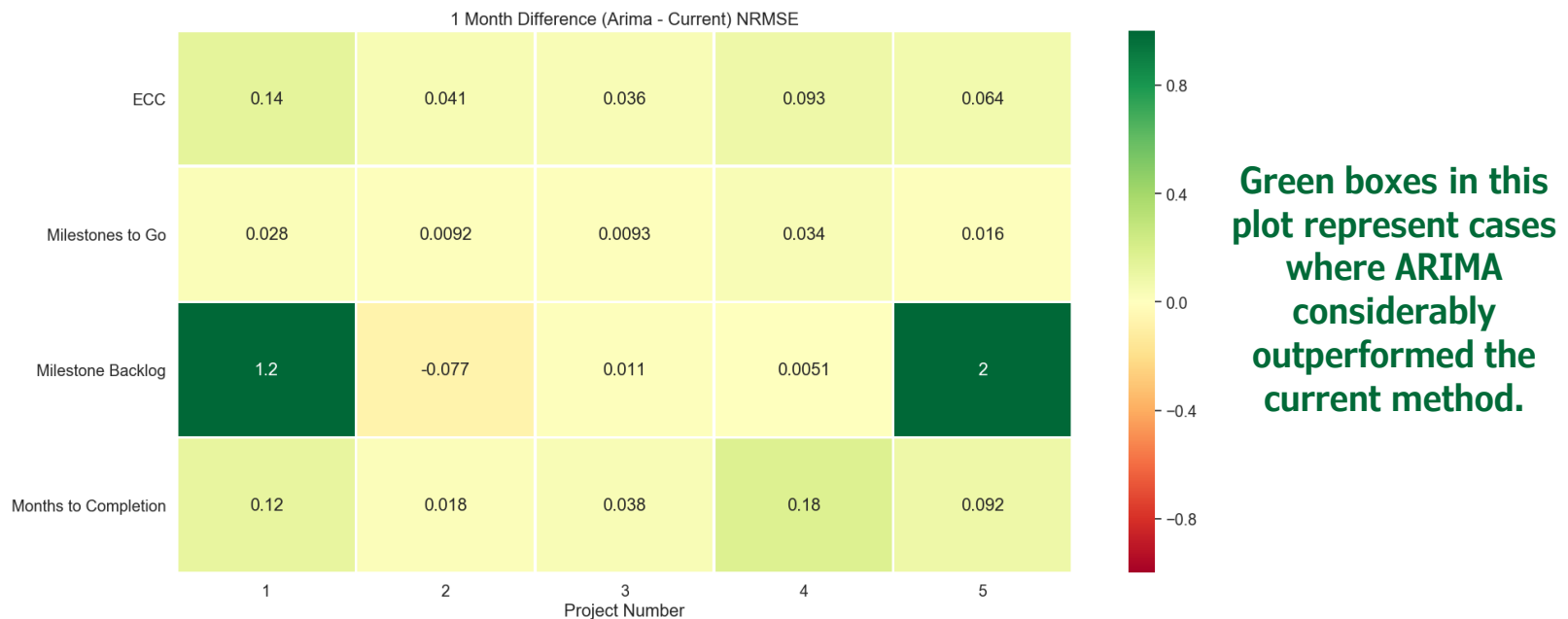
# ARIMA Results



- 🔍 **Milestone Backlog had the greatest error with an average of 0.39**, which resulted from higher volatility of the actual data.
- 🔍 **Project 1 and Project 5 also had high errors (0.41 and 0.47 respectively)** due to these projects having considerable changes and “black swan” events that the time series analysis could not predicted. It is similar to the current method in that it is a **lagging indicator**.
- 🔍 In general, for metrics and projects that went according to plan, **the ARIMA method performed with an NRMSE of under 0.2.**

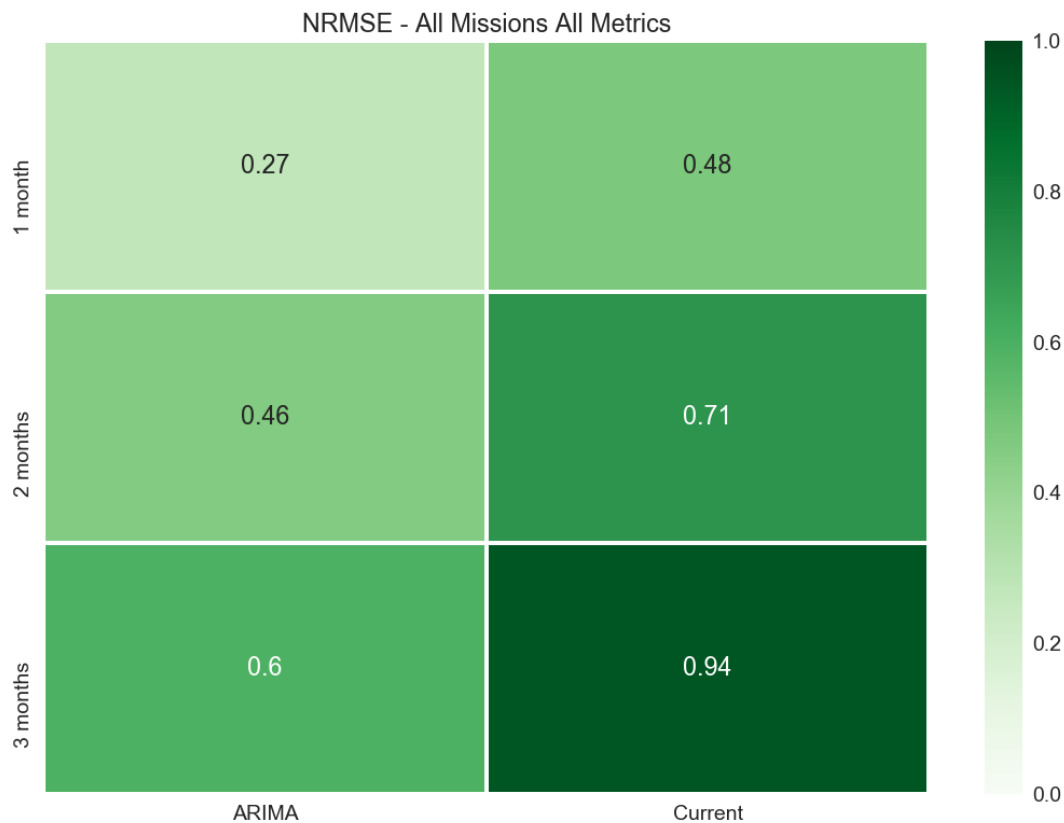
# ARIMA vs. Current Method

The NRMSE's for the current method were also calculated and subtracted from the ARIMA results for comparison.



- 🔍 ***ARIMA significantly improved the Milestone Backlog prediction for the two replanned projects.***
- 🔍 *The only case where ARIMA did not improve the predictions was for Milestone Backlog for Project 2.*

# ARIMA vs. Current Method



*ARIMA outperformed the current method by 0.21 for 1-month predictions, 0.25 for 2-month, and 0.34 for 3-month.*

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## Conclusion

- Like the current forecasting method, **the ARIMA method is a lagging indicator**. They both use only time series data they are predicting from. When a large, unexpected replan occurs for a project or metric, neither method performs well.
- While both methods face the same systematic shortcomings, **the ARIMA method showed less error in unexpected replan cases** since it incorporates more of the historical data in its predictions. Integrating the ARIMA model to the Early Warning Metrics forecasting cushions the volatility of the metrics to **produce more accurate projections**.
- ▶ Further improvements to the Early Warning Metric projections need to **focus on identifying indicators that a replan may occur** and work that information into the predictions.

# Conclusion

- To continually improve the State of Business team's insight into the future performance of projects, the **forecasting method for Early Warning Metrics was revisited and validated.**
- The State of Business provides **internal independent assessments to the FPD leadership** by integrating schedule, cost, Early Warning Metrics, EVM and risk data across the entire FPD project portfolio.
- By providing a **unique and holistic insight of the FPD project portfolio**, the State of Business team has grown to become a trusted advisor to the FPD ensuring the success of all space flight projects.

# Contributors

## State of Business

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## Forecast Assessment

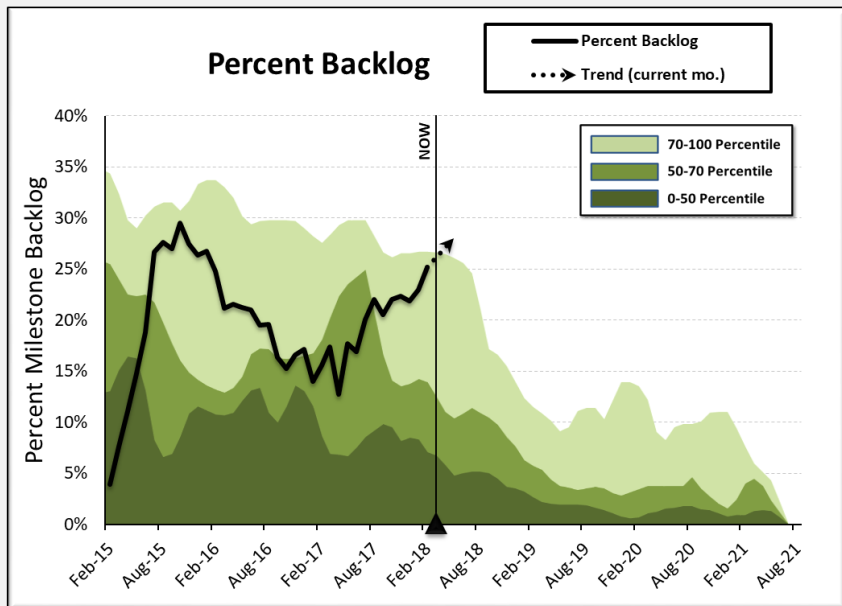
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# Questions?



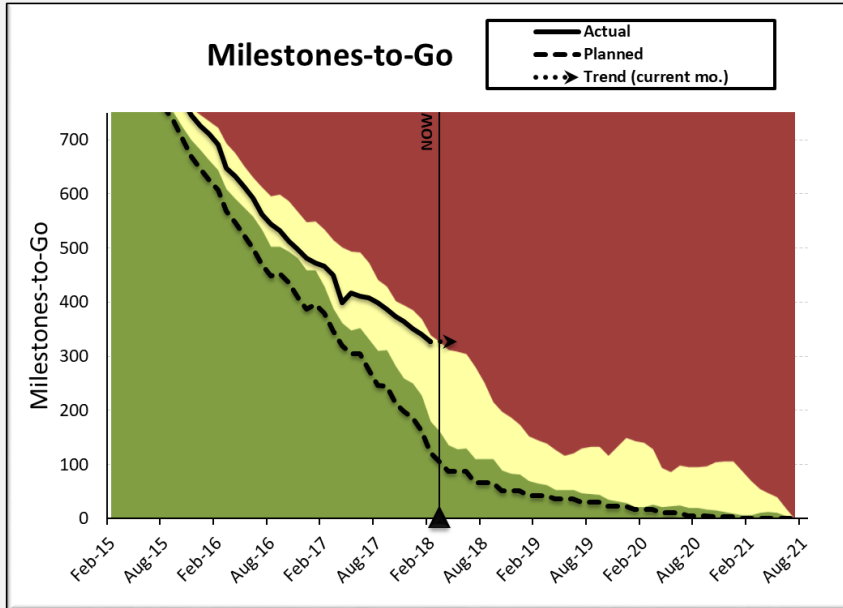
# Backup



Milestone performance regions are based on **historical backlog data** (PDR to LRD/Delivery) from launched and delivered GSFC projects. The historical backlog data is further categorized into instrument and mission development type projects.

$$Pct\ Milestone\ Backlog(t) = \frac{Milestone\ Backlog(t)}{Cum\ Plan(t)}$$

The **current milestone backlog over the current cumulative planned milestone ratio** to serve as a comparison to similar flight programs



Total raw number of **actual versus planned milestones remaining** until project completion

$$\begin{aligned}
 \text{Milestones to Go or } MTG(t) &= \\
 \text{Total Cum Plan(LRD or Delivery)} & \\
 - \text{Cum Actual}(t) &
 \end{aligned}$$

Performance compared to historical data

**Green**

- Backlog is  $\leq 50^{\text{th}}$  percentile of historical GSFC projects at this time in its schedule after PDR
- Indicative of healthy progress

$$\begin{aligned}
 & \text{Green Performance}(t) \\
 & \leq MTG_{planned}(t) + \text{Cum Plan}(t) * (50^{\text{th}} \text{ Pct Historical Backlog})
 \end{aligned}$$

**Yellow**

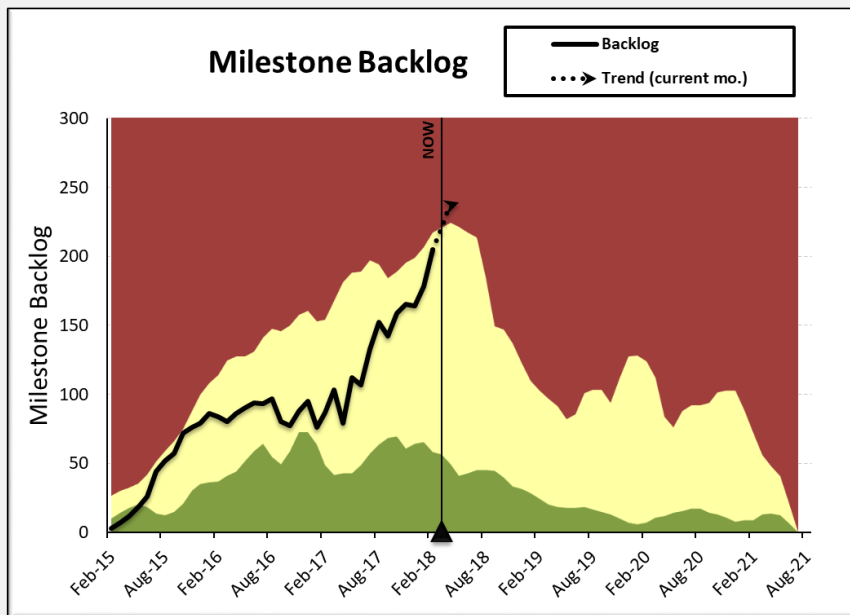
- Backlog between the  $50^{\text{th}}$  and  $70^{\text{th}}$  percentile of Historical GSFC projects at this time in its schedule after PDR
- Indicative of nominal performance at this time.

$$\begin{aligned}
 & \text{Yellow Performance}(t) \\
 & > MTG_{planned}(t) + \text{Cum Plan}(t) * (50^{\text{th}} \text{ Pct Historical Backlog}) \\
 & \leq MTG_{planned}(t) + \text{Cum Plan}(t) * (70^{\text{th}} \text{ Pct Historical Backlog})
 \end{aligned}$$

**Red**

- Backlog is  $> 70^{\text{th}}$  percentile of historical GSFC missions at this time in its schedule after PDR
- Requires attention as it may threaten the baseline plan at this time

$$\begin{aligned}
 & \text{Red Performance}(t) \\
 & > MTG_{planned}(t) + \text{Cum Plan}(t) * (70^{\text{th}} \text{ Pct Historical Backlog})
 \end{aligned}$$



Total raw number of **unfulfilled milestones** compared to the number of milestones planned for completion each month

$$\text{Milestones Backlog}(t) = \text{Cum Plan}(t) - \text{Cum Actual}(t)$$

Performance compared to historical data

**Green**

- Backlog is  $\leq 50^{\text{th}}$  percentile of historical GSFC projects at this time in its schedule after PDR
- Indicative of healthy progress

$$\text{Green Performance}(t) \leq \text{Cum Plan}(t) * 50^{\text{th}} \text{ Pct Historical Backlog}$$

**Yellow**

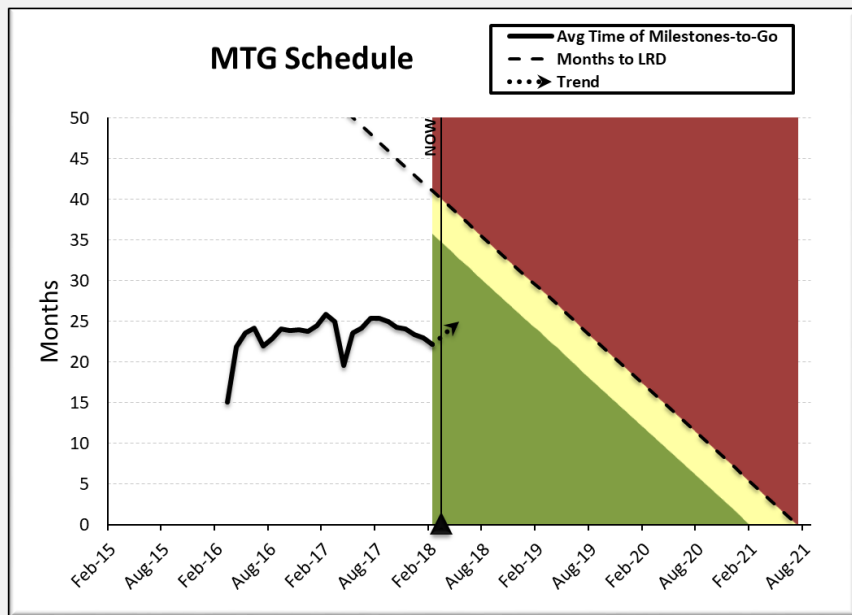
- Backlog between the  $50^{\text{th}}$  and  $70^{\text{th}}$  percentile of Historical GSFC projects at this time in its schedule after PDR
- Indicative of nominal performance at this time

$$\text{Yellow Performance}(t) > \text{Cum Plan}(t) * 50^{\text{th}} \text{ Pct Historical Backlog} \leq \text{Cum Plan}(t) * 70^{\text{th}} \text{ Pct Historical Backlog}$$

**Red**

- Backlog  $> 70^{\text{th}}$  percentile of historical GSFC missions at this time in its schedule after PDR
- Requires attention as it may threaten the baseline plan at this time

$$\text{Red Performance}(t) > \text{Cum Plan}(t) * 70^{\text{th}} \text{ Pct Historical Backlog}$$



Performance compared to remaining schedule and schedule reserves

**Green**

- Completing milestones at a fast pace and may complete the remaining work well within the GPR 7120.7 FSR

$$\begin{aligned} & \text{Green Performance}(t) \\ & \leq \text{Months to Planned LRD or Delivery} \\ & - \text{GPR 7120.7 Funded Schedule Reserve} \end{aligned}$$

**Yellow**

- Completing milestones at a typical pace to meet LRD/Delivery but may exceed the GPR 7120.7 FSR

$$\begin{aligned} & \text{Yellow Performance}(t) \\ & \leq \text{Months to Planned LRD or Delivery} \end{aligned}$$

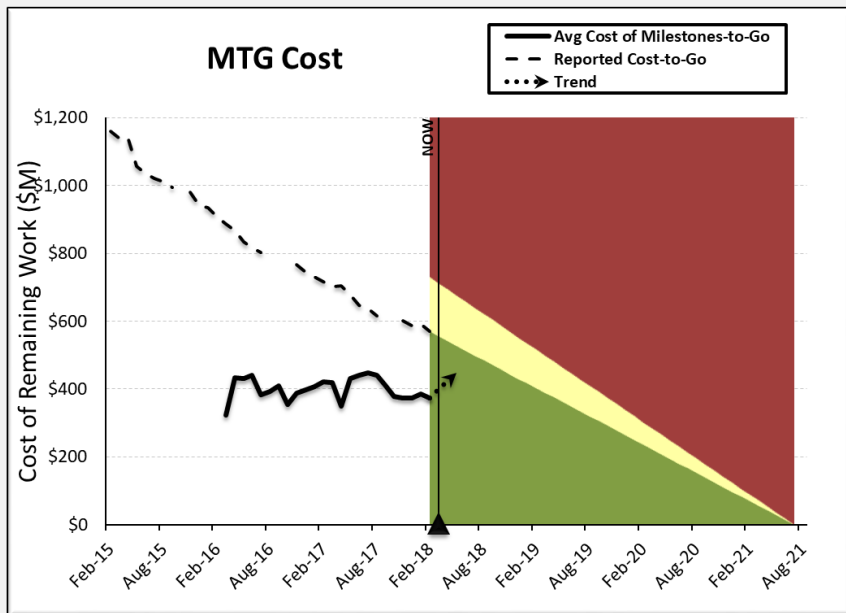
**Red**

- Completing milestones at a slower than planned pace and has the potential of delaying the schedule

$$\begin{aligned} & \text{Red Performance}(t) \\ & > \text{Months to Planned LRD or Delivery} \end{aligned}$$

The estimated **time needed to complete the remaining work** based on the average time per milestone completed to date

$$\text{MTG Schedule } (t) = \frac{MTG(t)}{\left( \frac{\text{Cum Actual}(t)}{\# \text{ of Months since start of Phase B}} \right)}$$



Performance compared to reported cost-to-go and budget reserves

**Green**

- Average cost per milestone to date is cheaper than planned and may complete the remaining work well within the reported budget without using reserves

$$\text{Green Performance}(t) \leq \text{Reported Cost to Go (Phase B thru D)}$$

**Yellow**

- Cost per milestone to date is typical and the program is on track to completing the remaining work within the reported budget plus reserves

$$\text{Yellow Performance}(t) \leq \text{Reported Cost to Go} + \text{Contingency thru Liens (Phase B thru D)}$$

**Red**

- Cost per milestone is more expensive than planned, and if maintained, may result in a budget overrun may

$$\text{Red Performance}(t) > \text{Reported Cost to Go} + \text{Contingency thru Liens (Phase B thru D)}$$

The estimated cost of the remaining work based on the average cost per milestone completed to date

$$\text{MTG Cost}(t) = \left( \frac{\text{Cum Development Cost}(t)}{\text{Cum Actual}(t)} \right) * \text{Actual MTG}(t)$$