OMS-RSC SEAMS STUDY: MARKET-TO-MARKET COORDINATION

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Executive Summary

This draft report presents our evaluation of the market-to-market coordination (M2M) processes that allow SPP and MISO to coordinate the management of congestion on transmission constraints that both RTOs affect. This effort is being undertaken at the request of the OMS Seams Committee and the SPP RSC. This report was produced by Potomac Economics as the MISO IMM in consultation with the SPP MMU.

Because SPP and MISO cause large power flows on each others' transmission networks, the M2M process is essential for coordinating the congestion caused by these flows. The total congestion on these constraints over the study period from June 2018 through May 2019 exceeded $150 million. Therefore, even modest improvements in the M2M coordination process can lead to large changes in congestion costs and efficiency savings. This study evaluates each of the key aspects of the M2M process:

- Testing rules and procedures that identify the constraints that should be defined as M2M constraints and coordinated;
- The relief request process that governs the amount of relief that is provided by the Non-Monitoring RTO; and
- Modeling of the external M2M constraints (those located in the other RTO's area) in the day-ahead and real-time markets.

In most respects, the M2M process operates efficiently and delivers sizable economic and reliability benefits. However, this study indicates some key areas that could be improved and we offer recommendations in these areas for the RTOs to consider. In particular, we find:

- The testing criteria : a) causes a number of constraints to be coordinated under the M2M procedures that produce very little value and b) prevents coordination on other constraints that would be valuable to coordinate.

  → We recommend the RTOs introduce a test based on the available flow relief that can be provided by the Non-Monitoring RTO (NMRTO) as a replacement for its current five percent shift factor test.

- The relief request process results in the Monitoring RTO (MRTO) asking for too much, too little, or a volatile quantity of relief. Therefore, we recommend:

  → Incremental improvements in the short term to base relief requests on the marginal costs of providing relief and an automated means to control for constraint "oscillations" or "power swings".

  → Utilizing dynamic transmission constraint demand curves in the long run to more accurately reflect the actual relief provided by the NMRTO in the dispatch of the MRTO.

- From an administrative perspective, we identify delays in testing constraints and activating the coordination process that increase costs and reduce the efficiency savings of the M2M process.

  → We recommend the RTOs improve the automation and procedures related to the testing and activation components of the M2M process.

- SPP appears to either not be modeling MISO's M2M constraints in their day-ahead market or modeling them in a manner that causes them not to bind.

  → This is likely a) resulting in less efficient generator commitments; and b) contributing to a material share of its very large balancing congestion uplift of almost $180 million over the past two years that is uplifted to its loads.

  → Therefore, we strongly recommend that SPP improve its modeling of MISO's M2M constraints, particularly those that have recently bound or are expected to bind in MISO's real-time market.

- MISO employs a generator shift factor cutoff that limits its relief on M2M constraints, resulting in: a) higher M2M settlement costs; and b) underfunding of its FTRs that flow over SPP's constraints.

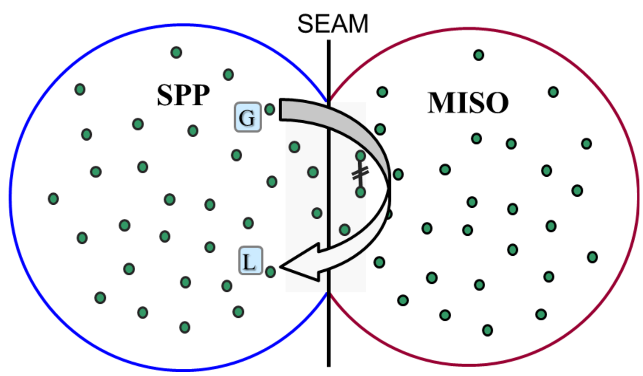
  → We recommend that MISO reduce or eliminate its GSF cutoff for low-voltage and M2M constraints.

Many of these recommendations represent incremental changes to the processes or the JOA that do not require substantial resources, but some require coordination between the two RTOs. We encourage the RTOs to take this opportunity to address these issues, which will produce sizable benefits by reducing congestion costs, reducing settlement costs for each RTO, and ultimately improving reliability.

I. Market-to-Market Study

A. Background and Approach

Due to the irregular and sometimes overlapping "seams" created with many of today's RTOs configurations, coordination of congestion management is imperative (and FERC requires it).[1] The following illustration shows when energy is produced at generation nodes and delivered to load nodes, the power flows over many different transmission paths. Some of this energy flows over the transmission facilities on the neighboring RTO's system and can contribute to substantial congestion. This results in a need to coordinate the congestion management of constraints affected by the dispatch of both RTOs' generation and load.



The Joint Operating Agreements (JOAs) between RTOs contain provisions for both Market-to-Market (M2M) and Market-to-non-Market coordination. Coordination occurs at a transmission facility level for facilities where a significant portion of the flows and the ability to reduce the flows is attributable to the generation and load in the external areas. Even prior to the formation of RTOs, the need to have regional coordination became apparent with Open Access. The initial solution directed by NERC was the Transmission Line Loading Relief (TLR) Procedures. Under TLR, the Reliability Coordinators (RCs) responsible for monitoring a facility send directives to change operations (redispatch) or reduce (curtail) physical transactions in neighboring regions to reduce flows on the overloaded facility. These TLR directives, however, ignore the economic value or costs of redispatch and of transactions curtailed.

The JOA defines a superior M2M coordination process that optimizes the relief that the Monitoring RTO (MRTO) requests from the neighboring Non-Monitoring RTO (NMRTO) to reduce flows on an overloaded facility. M2M coordination should reduce the overall costs of congestion management to the benefit of both JOA parties. The M2M processes include the following steps:

i. Identifying constraints that are affected by both RTOs by performing tests specified in the JOA – these are designated as M2M constraints.

ii. Coordinating the congestion management of any M2M constraint that is binding on a 5-minute basis. The RTOs coordinate by:

[1] A Joint Operating Agreement (JOA) between the MISO and PJM in operation since April 2005. A JOA between MISO and SPP was implemented in March 2015. The NYISO and PJM also have had a JOA in place since January 15, 2013. Other entities have non-M2M JOAs to describe TLR procedures including the allocation of physical rights and curtailment procedures.

a. The MRTO providing its cost of managing the constraint (a.k.a., the "shadow price") and a requested quantity of flow relief from the NMRTO.

b. The NMRTO activates the constraint in its 5-minute dispatch to provide the requested relief up to the MRTO's shadow price.

c. Information is updated and exchanged every 5 minutes.

iii. The RTOs settle with each other based on whether the NMRTO's flows are higher or lower than its Firm Flow Entitlement (FFE) level.

If these processes are not optimal, the savings are reduced, and congestion costs will be higher than necessary. Since the inception of M2M coordination in 2005 by MISO (originally with PJM), very few changes or innovations have been implemented to improve the performance of the M2M coordination processes. This report will evaluate four key elements of the M2M process that may point to potential improvements that could be implemented by SPP and MISO:

- The calculation of the amount of relief the MRTO requests from the NMRTO for an active M2M constraint; and
- The criteria employed to test non-M2M constraints to determine whether they should be designated as M2M constraints;
- The administration of the M2M processes by the RTOs to test potential M2M constraints and to activate the M2M coordination when a M2M constraint is binding; and
- Issues related to how M2M constraints are modeled in the RTOs' market models.

The following three sections contain our evaluations in each of the areas and a summary of recommended improvements based on our findings.

B. Evaluation of Relief Request Software

When a market-to-market (M2M) constraint binds, the coordination is initiated by the MRTO that is responsible for managing the constraint. The MRTO coordinates management of the constraint with the NMRTO by sending its marginal cost of providing relief on the constraint (i.e., the "shadow price") and a the quantity of relief it would like the NMRTO to provide (at a cost not to exceed the shadow price).

Hence, a key component of successful M2M coordination is optimizing the amount of relief that the MRTO requests from the NMRTO. If the request is too low, then the NMRTO will not provide all its economic relief, resulting in higher congestion costs and potentially higher settlement costs for the NMRTO. If the request is too high, it can result in congestion oscillation that can raise costs. This section of the study describes and evaluates the effectiveness of the relief request software.

Description and Evaluation of the Current M2M Relief Request Software

The relief request software calculates the amount of relief to request based on three factors:

1. The amount by which the flow exceeds the constraint's limit if it is in violation; plus
2. The relief provided by the NMRTO since activation; and
3. A discretionary amount up to 20 percent of the limit of the constraint, based on two parameter values.

The technical details pertaining to the relief request methodology and these factors are provided in Appendix A. The first two factors tend to be very small unless the constraint is in severe violation, while the third factor is a pre-determined amount that does not vary to bring about the desired shadow price convergence between the two RTOs. We have three concerns with this methodology that are described below.

Use of the Relative Costs of Providing Relief. The principal concern with this methodology is that it does not consider the RTOs' current marginal costs of providing additional relief. When one RTO can provide relief that is much less costly than the other, the relief request software should produce incremental changes that cause that RTO to provide its lower-cost relief.

Use of Physical Flow Exceedances. A secondary concern is the usage of physical flow to calculate MRTO exceedance in the first component of the relief request formula. If the MRTO dispatches its resources to eliminate some or all the current exceedance, this modeled MRTO relief should not be requested of the NMRTO as well. Conversely, if the physical flow is currently below the limit but modeled to increase, the relief request should reflect the tightening conditions. Replacing the physical flow input with the real-time modeled flow output would improve the relief request formula.

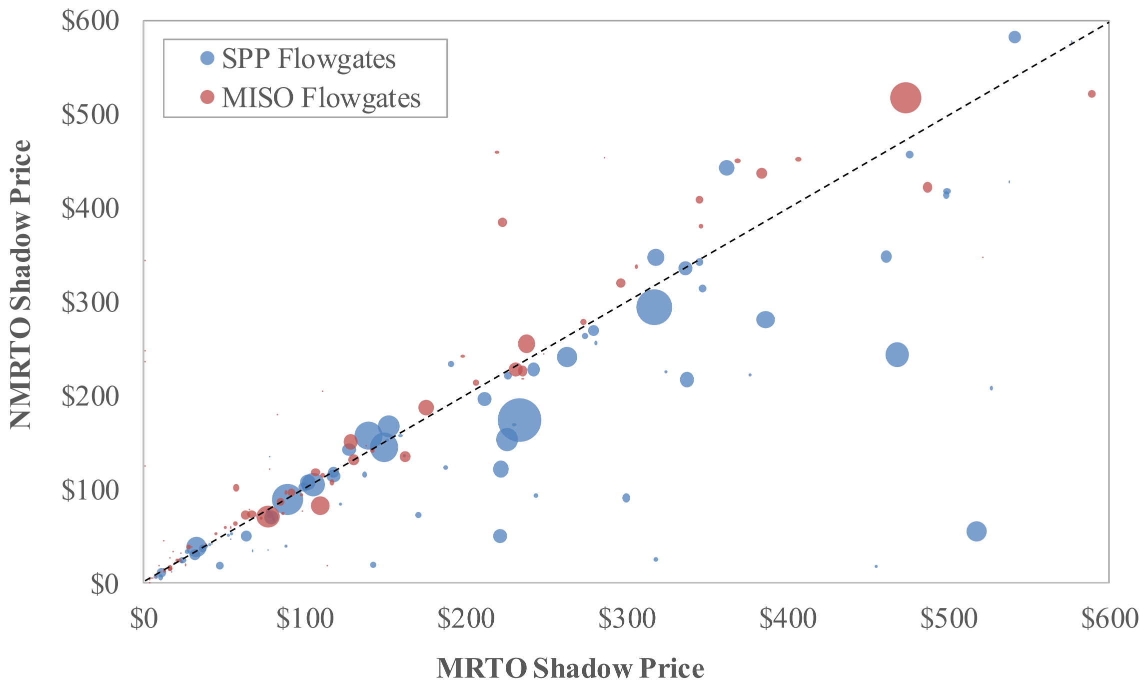
Discretionary Relief Amounts. We also have the following concerns about the third factor:

- The discretionary amounts are only applied when the MRTO is managing the constraint at its limit – the most common factors for each of the discretionary amounts is five percent (for a total of 10 percent)
- Based on historical constraint violation data, the MRTO's request for relief based on the first factor (the violation amount) averages *three* percent of the constraint limit when the constraint is in violation.
- Once the constraint is managed at its limit, the third factor (discretionary relief amount) replaces the first (violation amount) and the MRTO will *increase* its relief request to five or ten percent of the constraint limit.

This is counter-intuitive because the relief request should be *greater* when a constraint is violated. The can cause very bad outcomes, including relief requests moving in the wrong direction as constraints go into violation.

Our analysis in Figure 1 below evaluates the effectiveness of the coordination process by showing the shadow price convergence on individual constraints. This figure shows the MRTO's average shadow price on the x-axis and the NMRTO's average shadow price on the y-axis. The size of the bubbles indicates the amount of congestion associated with each constraint, and the colors separately identify MISO and SPP constraints. Perfect convergence would cause the data points to lie on the dashed 45-degree line. However, even if the observations fall on this line, convergence may still be poor during some events or periods.

Figure 1: Shadow Price Convergence



This figure shows that, in general, convergence could be improved. Convergence is reasonably good at lower shadow prices but tends to be worse at higher shadow price levels where the benefits of improved relief requests would be the largest. This is particularly true for several SPP M2M constraints. Many SPP constraints are below the dotted line indicating a lower shadow price in MISO and an opportunity to improve convergence by increasing the relief request. The figure also shows that there are some constraints for which the NMRTO's shadow price is higher than the MRTO's. The results of this high-level analysis, coupled with our constraint-specific monitoring of the process, raises three concerns regarding the relief software:

- It does not always request enough relief from the NMRTO because the current software does not consider the shadow price differences between the RTOs.
- The relief requests are sometimes *larger* than optimal, which can cause the constraint to oscillate. This occurs when the NMRTO provides sufficient relief in the next interval to unbind the constraint (i.e., causing the shadow price to drop to zero), which will cause the

MRTO's relief request to be zero. When the NMRTO then stops providing the relief, the constraint will bind again and the shadow price will spike.

- The current methodology also can result in highly volatile relief requests. This can undermine the effectiveness of the M2M coordination process.

Table 1 screens each of the intervals in which M2M coordination is active and categorizes the intervals when the relief request methodology produces requests that are unreasonably low, causing oscillation, or are excessively volatile. We identify relief requests as "undersized" if the MRTO's shadow price exceeds the NMRTO's shadow price by more than $100 over multiple intervals. Oscillation periods meet one of two conditions: a) a constraint unbinding after being violated in the prior ten minutes or b) the shadow price fluctuating from greater than $100 to $0 to greater than $100 over three consecutive intervals. Volatile relief request periods show a 5-minute request change that exceeds the greater of 10 MW and 3 percent of the transmission limit. This analysis excludes constraint intervals when coordination was switched to the NMRTO.

Table 1: Frequency of Substantial Relief Request Issues

	MISO Flowgates		**SPP Flowgates**		**All Flowgates**	
	Intervals	**Share**	**Intervals**	**Share**	**Intervals**	**Share**
Total Coordinated Intervals	**13,857**	**100%**	**32,201**	**100%**	**46,058**	**100%**
Undersized Relief Request	149	1.1%	1,315	4.1%	1,464	3.2%
Oscillation	75	0.5%	1,590	4.9%	1,665	3.6%
Volatile Relief Request	2,529	18.3%	7,523	23.4%	10,052	21.8%
Intervals Exceeding Limit	**317**	**2.3%**	**6,133**	**19.0%**	**6,450**	**14.0%**

The current methodology results in one or more of these three flawed or inefficient relief request outcomes in 26 percent of intervals.

Volatile relief requests. Volatile requests impact about 22 percent of coordinated intervals. Some volatile requests occur when the NMRTO cannot satisfy the requested relief. There is little efficiency loss in these cases because the NMRTO is providing all its available economic relief.

Undersized relief requests. SPP constraints accounted for about 90 percent of these intervals during the study period. We attribute this result to the much greater frequency that flows exceeded the limits of SPP's constraints, 19 percent versus 2 percent of MISO's constraints. Due to the "Discretionary Relief Amount" flaw, exceedances often result in understated relief requests. Poor price convergence and higher costs is the result of requesting too little relief.

Oscillation. SPP-monitored constraints were more subject to oscillation than MISO constraints, accounting for 95 percent of all oscillation intervals. The worst oscillation occurred on facilities where the MRTO has almost no redispatch capability. Similar outcomes are common when the NMRTO has a relatively high proportion of the fast-ramping, inexpensive relief capability. This has occurred on SPP constraints heavily impacted by MISO wind generation. The RTOs activate

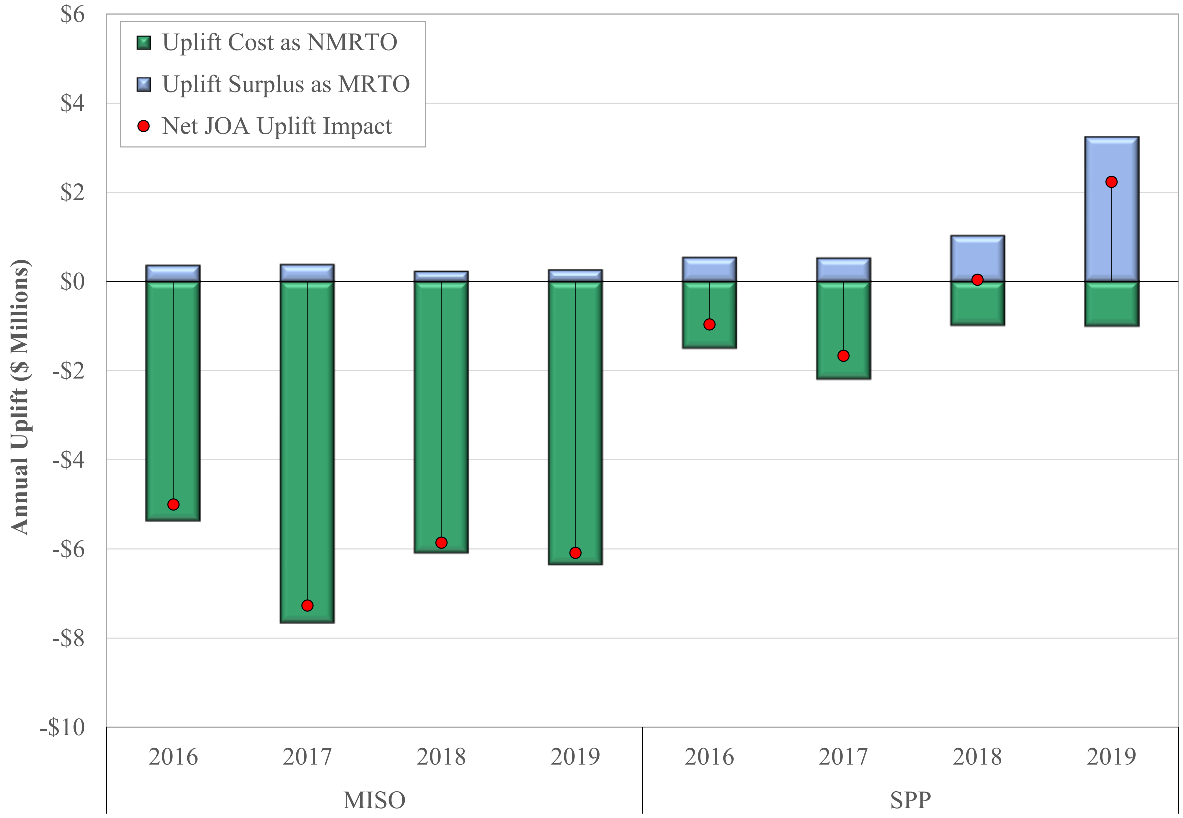
"Power Swing" software as needed to reduce or dampen the oscillation power swings. This software holds the shadow price used by the NMRTO constant based on the average shadow price of the MRTO for prior intervals. Although an improvement, it is not a long-term solution.

While the incidence of these flaws is greatest on SPP's constraints, both RTOs are impacted:

- SPP faces degraded reliability from oscillation and greater congestion management costs from the failure to converge shadow prices.
- Poor convergence has a material settlement effect on MISO as well. When shadow prices converge, the JOA settlement is a transfer of congestion collected in one RTO to the other RTO. When shadow prices fail to converge, the amount an RTO owes or receives in the JOA settlement may differ from the amount the RTO collected through its shadow price. This results in "JOA uplift" that must be collected from loads.

Figure 2 summarizes the JOA uplift impact of poor shadow price convergence. The green bar in the figure shows the portion of the JOA settlement attributable to shadow price differences on excess market flows as the NMRTO. Because there is a shortfall in the congestion revenues, these JOA payments must be uplifted via Revenue Neutrality Uplift (RNU). The blue bar represents the opposite case: the MRTO collects net congestion revenue when the NMRTO is under its FFE and providing relief at a lower shadow price. In this case, the MRTO is paying for congestion relief at a lower cost than it charges to market participants loading the constraint.

Figure 2: JOA Uplift Impact of Shadow Price Non-Convergence



The funding impacts of SPP flowgate non-convergence are materially worse for MISO than SPP:

- MISO averaged about $6 million per year in JOA uplift resulting from poor shadow price convergence in its coordination with SPP.
- In 2019, these uplift costs accounted for 28 percent of all balancing congestion costs in MISO and 9 percent of all RNU charged to market loads.

Across the time period, the JOA uplift in SPP associated with non-convergence averaged less than $0.1 million per year with MRTO surpluses offsetting the costs when MISO constraints converged poorly. The increasing trend in the JOA surplus in SPP is a concern because net funding surpluses indicate inefficient coordination and a clear opportunity for improvement.

As MISO and SPP explore improvements in the relief request software, they should strive to address each of these issues. Ultimately, the goal should be to request optimal relief quantities. The benefits of requesting an optimal quantity of relief are estimated in the next subsection.

Benefits Available from Optimizing the Relief Requested

An important means to evaluate the performance of the current process and quantify the maximum available benefits of making improvements is to estimate the savings that would accrue if the MRTO's relief request were optimal. To estimate this, we determined the optimal relief request and shadow price by:

- Building ramp-constrained transmission constraint relief supply curves for SPP and MISO;
- Determining the aggregated constraint relief demand curve for each constraint, including the relief that would be released if the shadow price were to decline;
- Finding the intersection of the demand and supply curves.

Based on this optimal relief quantity for each constraint in each interval, we then estimated the reduction in congestion that would result from requesting this quantity. Because we lacked SPP participant offer data, we had to estimate SPP generator costs and physical parameters (dispatch limits and ramp rates). Physical parameter estimates were inferred using data from MISO's state estimation cases. Cost estimates used class average heat rates and index prices of liquid fuel delivery points within the SPP footprint.

The following figure shows the effects of optimizing the relief requested from the NMRTO on the 20 individual constraints with the greatest congestion value during the study period. Optimal relief requests allow the RTOs to utilize the lowest-cost relief available from both RTOs.

Figure 3: Benefits of Requesting Optimal Relief

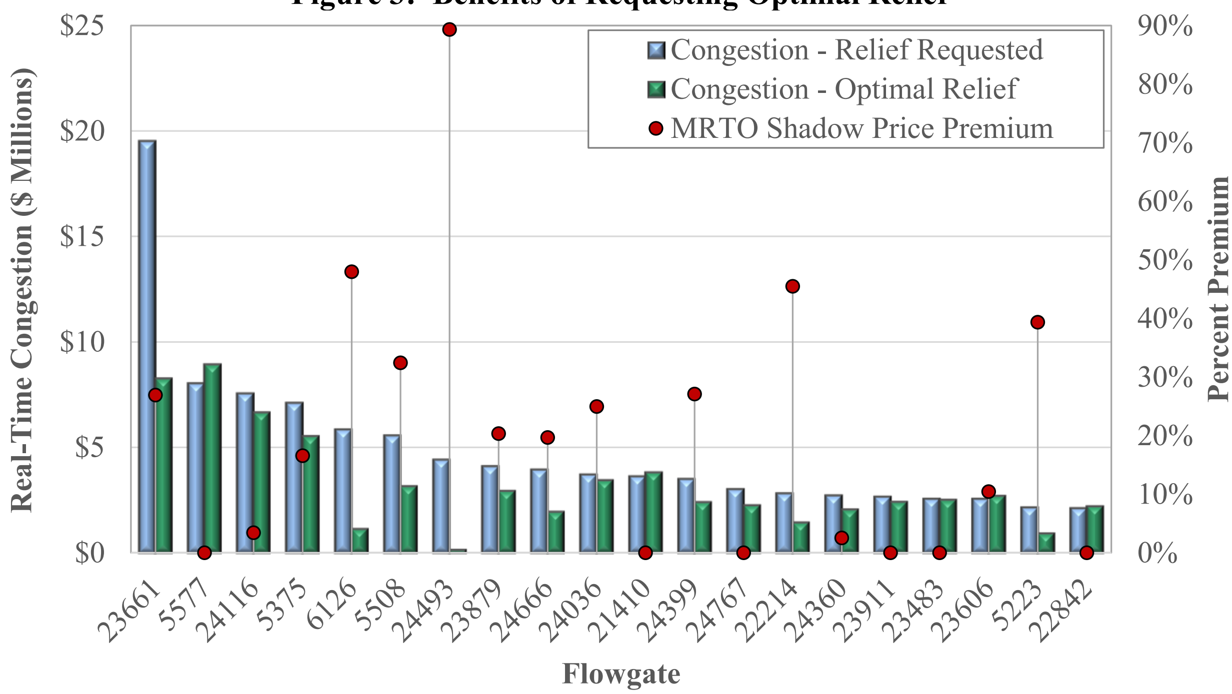
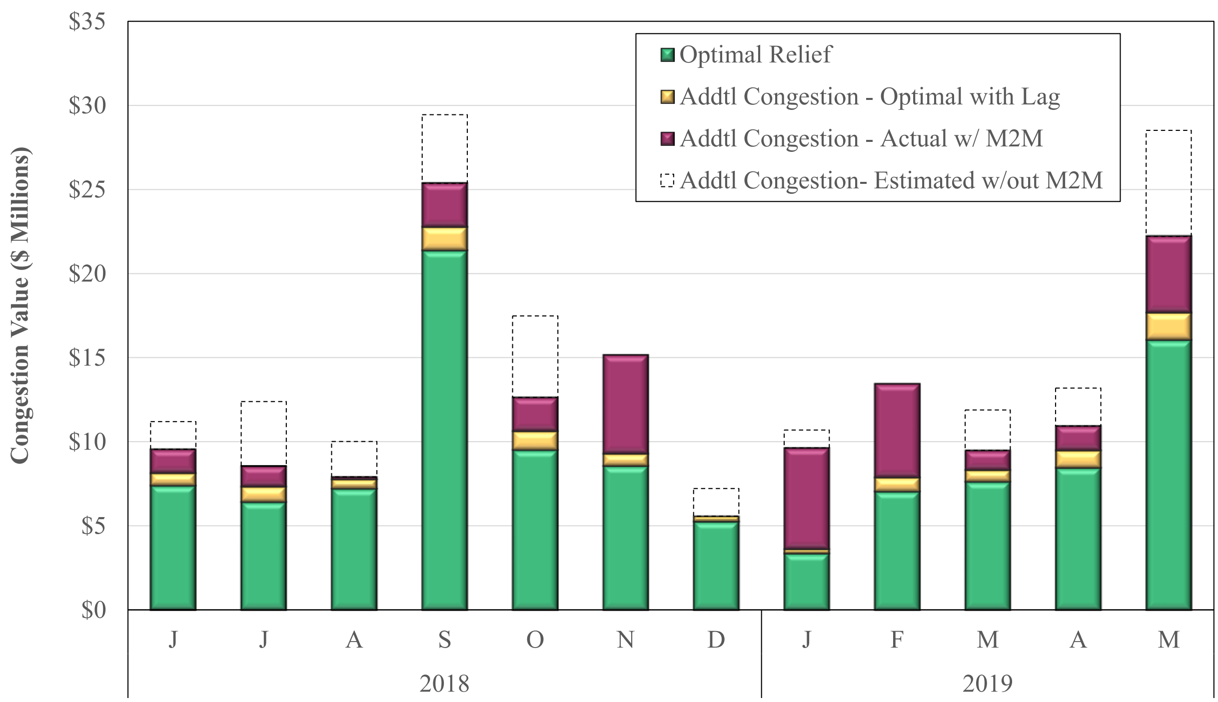


Figure 3 shows large reductions in congestion are possible on many constraints by improving the relief requested. Consistent with intuition, the largest reductions accrue on constraints where the shadow price spreads are the greatest. We found that the RTOs could reduce the value of congestion on their systems by $41.3 million during the study period by optimizing the amount of relief requested by the MRTO. This corresponds to approximately 20 percent of all congestion on these constraints. Our results show reductions for almost all constraints.[2]

The prior analysis assumed the MRTO had access to full information about the status, costs and physical parameters of the NMRTO's generators, plus the ability to simultaneously coordinate dispatch of both RTO's resources. Barring a joint dispatch, realizing all these benefits is not possible. In this section, we present a modified version of the prior analysis in order to quantify the benefits that could be realized by improving the relief requests, but accounting for the 5-minute lag that will continue to exist as the RTOs exchange information.

In this case, the NMRTO would only provide its relief up to the shadow price of the MRTO from the prior interval. The MRTO would be aware of the coordination lag and be able to forecast the amount of relief that would be provided by the NMRTO given the lagged shadow price. Figure 4 shows the total congestion costs incurred on M2M constraints during the study period.

Figure 4: Congestion Value Estimates



2 Those that show an increase are likely due to inaccuracy in the estimated costs and physical parameters of SPP generators. Additionally, we have found that the MRTO shadow price and resulting congestion value is often understated in periods when the prior shadow price sent to the NMRTO is low and results in the NMRTO releasing some or all of the relief it had previously provided. This condition results in actual flow exceedances with the current relief request software.

The green bar shows the congestion costs we estimate would prevail with optimal relief requests, consistent with the prior analysis. The other bars reflect the incremental increases in congestion caused by other issues that reduce the efficiency of the coordination:

a) the five-minute coordination lag (shown in yellow);

b) Suboptimal relief requests occurring currently (maroon); and

c) No M2M coordination (transparent bar).

Figure 4 shows a total congestion reduction benefit of roughly $41 million transitioning from the current process to an optimal process. However, the lag to exchange information is unavoidable, and we found that this causes roughly $10 million or 25 percent of the congestion benefits to be unachievable. Nonetheless, the remaining congestion benefits of $32 million remains significant and would result in production costs savings of almost $4 million over this period. These savings provide substantial support for improving the relief request software.

Recommendations for Improving Relief Requests

We recommend long-term improvements that would efficiently address each of the issues described above. However, these long-term improvements will require significant software changes. Given the benefits described above, we recommend a set of short-term improvements that should be feasible to address in the near term. We also describe a long-term improvement that could capture the remaining benefits.

Short-Term Improvements. We recommend that the RTOs consider three modifications to the current software to improve its performance:

i. Eliminate the toggling between the violation amount (factor 1) when a constraint is in violation and the discretionary relief amounts when a constraint is not in violation (factor 3).

ii. Add a factor to increase the relief requested when the shadow prices or relief costs of each RTO are not converging over multiple intervals.

iii. Add an automated provision to dampen oscillation when it occurs by limiting the downward movement in shadow prices and relief quantities.

Long-Term Improvements. In the long-term, it would be more efficient to determine the relief quantities and control power swings by utilizing the relief supply curves from each RTO. This could be implemented through more dynamic modeling of Transmission Constraint Demand Curves (TCDCs). The RTOs could supplement their current data exchange to include the quantities and costs of the relief from the NMRTO, which would allow the MRTO to develop TCDCs that reflect the NMRTO's cost of relief. Including the current and expected relief from the NMRTO in the MRTO's dispatch will reduce the adverse effects of the lag in the coordination process, prevent oscillation, and improve the overall efficiency of the coordination.

For example, if the NMRTO had provided 8 MW of relief at a cost of $50 per MWh on a 100 MW constraint, the MRTO could modify its TCDC to $50 at 92 MW and $1000 (the default value) at 100 MW. The MRTO would only release the NMRTO relief if it could provide an extra 8 MW for less than $50 per MWh. In this case, the MRTO would be prepared for the NMRTO to release 8 MW of flow back on the constraint without causing a violation.

C. Evaluation of M2M Constraint Testing Criteria

Like the Relief Request software, the rules for determining constraints that qualify as coordinated constraints have not been significantly revised since market-to-market inception in 2005. Identifying the constraints to coordinate is important to ensure both efficient and reliable coordination, to establish equitable settlements, and to improve the price signals in the NMRTO market. Currently, a constraint will be identified as a M2M constraint when the NMRTO has:

- a generator with a shift factor greater than 5 percent; or
- Market Flows over the MRTO's constraint of greater than 25 percent of the total flows (SPP JOA) or 35 percent of the total flows (PJM JOA).

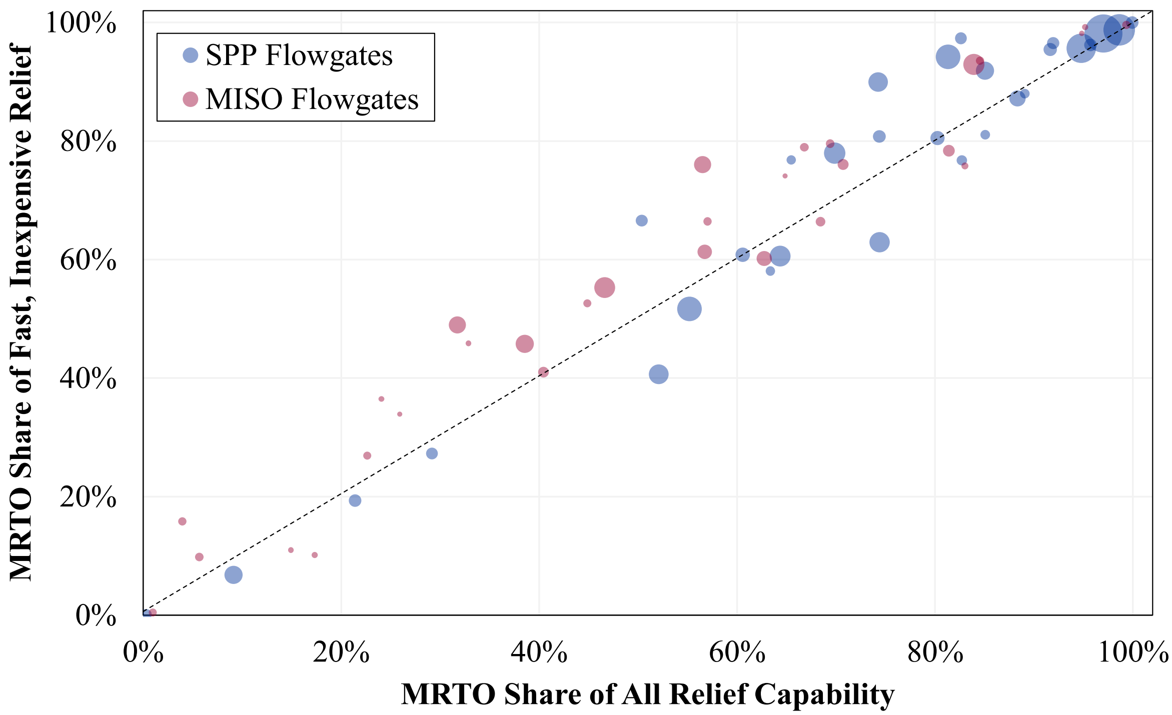
These two tests are not optimal in identifying constraints that would benefit from coordination because they do not consider the economic relief the NMRTO will likely have available. The single generator test is particularly questionable because it ignores the size and economics of the unit – this test does not ensure that the NMRTO has any economic relief. Alternative tests may do a better job of identifying the most valuable constraints to define as M2M constraints, which is the focus of this section.

Evaluation of Relief Available from Both RTOs on M2M Constraints

Figure 6 shows the share of economic relief from each RTO for the M2M constraints binding during the study period. This figure shows the portion of the total relief on the x-axis and the available economic relief on the y-axis that is held by the MRTO.[3] When both percentages are very high, the expected value of coordinating the congestion management of the constraint is limited because the NMRTO has a very small share of the relief capability.

3 Economic relief is categorized as any redispatch relief that could be provided within five-minutes time with a shadow price less than or equal to $200.

Figure 5: Share of the Relief from the MRTO

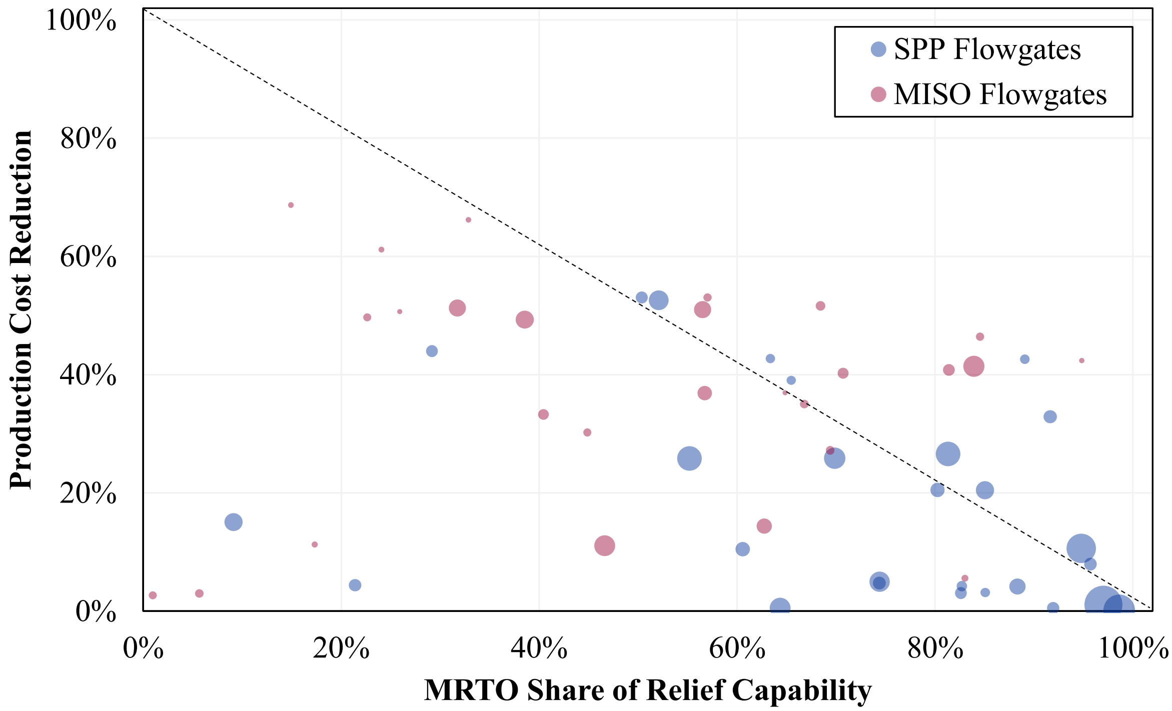


This figure allows us to make the following observations about the current set of M2M constraints:

- SPP has a greater share of relief on its own constraints than MISO does on the MISO constraints. This may be due to the GSF cutoff issue described in the next section.
- There are several M2M constraints for which the NMRTO has a very small portion of the economic relief – those in the extreme upper-right portion of the figure. These are constraints for which the NMRTO has very little ability to assist in managing the congestion.
- If the NMRTO's market flows are also low on these constraints, then they are likely constraints that should not be designated as M2M constraints because the production cost savings of coordination may not exceed the administrative burden.

To evaluate the value of these constraints being coordinated, Figure 6 shows the relationship between the MRTO's relief capability (as it rises to 100%, the NMRTO relief falls to 0%) and the production cost savings of coordinating the constraint.

Figure 6: Production Cost Savings and Relief Distribution



This figure shows that there is a strong relationship between production cost savings through coordination and the share of relief available from the NMRTO. We found several coordinated constraints where the NMRTO had very little effective relief and coordination yielded minimal production cost benefits during the study period. Although most of these were SPP constraints, it is likely that MISO's 1.5 percent GSF cutoff, discussed later in the report, skews the relief distribution and decreases the production costs savings potential on SPP constraints. We are recommending that MISO address this issue.

We also found some other constraints that were not coordinated where in aggregate the NMRTO did have significant market flow and/or effective relief. Accordingly, we recommend that MISO work with PJM and SPP in evaluating this recommendation and consider these results in improving the M2M Coordination tests.

Analysis of Current and Alternative Tests

In this section, we evaluate the current five percent GSF test (i.e., the NMRTO has at least one generator that significantly effects the constraint) and market flow test (>25 percent of the flows on the constraint are caused by the NMRTO). To evaluate these tests, as well as alternative tests that may be superior, we processed historical test information for MISO's constraints.[4] This includes both constraints defined as M2M and those that were not. We then estimated the relief capability from SPP and other external control areas on MISO's non-M2M constraints based on MISO's state estimator data. Finally, we combined the information with constraint limits to assess the relative magnitude of flows and relief capability.

Based on this analysis we find that the current tests, particularly the five percent GSF test, could be significantly improved. We find that:

- The five percent test is not reliable and has identified several constraints for which the benefits of coordinating are very small. Since GSFs are higher on high-voltage facilities, they tend to pass this test more often than they would based on available relief.
- Three-quarters of coordinated constraints have *more than half* the total relief capability provided by resources with less than a five percent shift factor.

The five percent test only exists as a proxy that indicates the NMRTO may be able to provide relief from at least one generator. A better test would be based on the *actual* available relief. Hence, we recommend the five percent test be replaced by two potential discrete tests based on the available relief controlled by the NMRTO:

- The share of relief capability from the NMRTO; and/or
- The NMRTO relief as a percentage of the transmission limit.

Using threshold values for these tests of 10 percent would be reasonable because it correlates well with coordination benefits. Our analysis shows that implementing this recommendation would likely reduce the total number of M2M constraints. In other words, we find that the five percent test is identifying more constraints that are not highly beneficial to coordinate (i.e., false positives) and should be undefined than the number of new constraints that would warrant coordination under our improved relief-based tests. Although this analysis only included MISO's M2M and non-M2M constraints because of SPP data limitations, we believe the results in SPP would be comparable.

Finally, in addition to changing the fundamental basis for one of the two M2M tests, our evaluation revealed one other aspect of the tests that could be improved. "Raise help" wind resources should only be considered in the market flow test. Raise-help wind resources cannot generally increase output to provide relief because they are usually producing as much output as they are able. Most wind resources have zero or negative marginal costs, so they operate to their

4 This analysis is one-sided, as SPP was not able to provide shift factor data for MISO generators on its non-M2M constraints.

maximum capability under almost all conditions. Therefore, they generally cannot increase output to provide relief.

D. Effectiveness of the Testing and Activation Processes

While the level of automation of the JOA has increased over time, a number of important JOA procedures remain as manual steps. The process of creating a M2M constraint involves identifying that a new constraint should be tested and coordinating with the NMRTO to test the constraint. Once the tests are completed and the M2M constraint is defined, the M2M coordination process must be activated each time the flow on the constraint nears its limit.

While RTOs have staff dedicated to M2M operations, these are not real-time 24/7 staff, and new constraints may bind at any time. We evaluate the effectiveness of the administration of the M2M processes in this section. While M2M processes improve efficiency overall, the efficiency and effectiveness of coordination can be limited by the three factors identified below.

1. Testing Failure - the failure to test constraints that might qualify as market-to-market;
2. Testing Delay - not defining constraints as market-to-market constraints until after the constraint begins binding in the market; and
3. Activation Delay - delays in coordination or failure to coordinate constraints previously classified as market-to-market.

Each of these issues is significant because when a market-to-market constraint is not identified or activated, it raises the following concerns:

- Efficiency concerns. The savings from coordinating with the NMRTO to relieve the constraint are not achieved and congestion costs are increased.
- Equity concerns. The NMRTO may vastly exceed its firm flow entitlements on the constraint with no compensation to the MRTO.

We developed a series of screens to identify constraints that should have been coordinated but were not because of the issues listed above. We were limited in our access to SPP transmission data, which we addressed by the following means:

- Given the lack of flow data for SPP non-M2M constraints, we assume historical shadow price and flow data when the constraints were binding as M2M constraints to evaluate the congestion effects of these issues on SPP's constraints.
- Given the lack of GSF data for MISO's generators on SPP's non-M2M constraints, we identified binding non-M2M SPP constraints with the same monitored element as an

existing M2M constraint, which should have similar shift factor distributions and thus be likely to pass one of the current coordination tests.[5]

Table 2 presents the results of this evaluation. The table has two panels that separately quantify a) the annualized congestion value, and b) potential congestion reduction associated with each inefficiency factor during periods when the constraints in question were not being coordinated. The potential congestion reduction is calculated as the product of congestion value and the historical percentage decrease in shadow price when binding through the M2M process. For the first two factors (never classified and testing delay), we account for the time needed to test a constraint by removing the first day a constraint was binding. The shares in this table show the share based on the total congestion on all M2M constraints.

Table 2: M2M Process Evaluation

	Testing Failure		Testing Delay		Activation Delay		Total	
	$	**Share**	**$**	**Share**	**$**	**Share**	**$**	**Share**
Congestion Value on M2M Monitored Elements ($millions/yr)								
MISO	$21.9	7.2%	$25.0	8.3%	$11.4	3.8%	$58.3	19.2%
SPP	$18.9	3.4%	$57.3	10.4%	$24.4	4.4%	$100.6	18.2%
Combined	**$40.8**	**4.8%**	**$82.3**	**9.6%**	**$35.8**	**4.2%**	**$158.9**	**18.6%**
Estimated Congestion Reduction with M2M Coordination ($millions/yr)								
MISO	$7.2	2.4%	$7.2	2.4%	$1.3	0.4%	$15.7	5.2%
SPP	$6.0	1.1%	$9.7	1.8%	$4.1	0.7%	$19.8	3.6%
Combined	**$13.2**	**1.5%**	**$16.9**	**2.0%**	**$5.4**	**0.6%**	**$35.5**	**4.2%**

The largest category of potential savings is reducing the delays associated with testing potential new M2M constraints. We recommend the both RTOs explore means to reduce these delays, including increasing the automation of the process and identifying constraints prospectively that are likely to bind due to outages or other factors. Increasing the automation of the testing process would also likely reduce the number of constraints that the RTOs have failed to test in the past.

Finally, the activation delay-related congestion and estimated reduction opportunity is substantial. While the process to identify and test M2M constraints is involved, activation should be relatively quick when a constraint begins to bind. Therefore we recommend that both RTOs consider tightening their procedures to eliminate this activation delay inefficiency.

5 To benchmark the accuracy of this process, we performed an identical analysis on the MISO data and found it to be reasonably accurate. In limited cases, a different contingency may cause different post-contingent flows and overstate the testing failure result, but this would be offset by cases where non-M2M constraints would pass the tests that do not have a M2M constraint "cousin" that shares the same monitored element

Benefits in this area could be readily obtainable because software changes may not be required. Activating existing M2M constraints can be effectuated by existing real-time operations staff.

E. Modeling Issues Affecting M2M Coordination

In this section, we address two other significant issues that can lead to suboptimal coordination or increased costs under the M2M processes. The first is how the RTOs model their neighbor's M2M constraints in the Day-Ahead markets and the second is the use of "GSF Cutoffs" that determine whether generators with small effects on M2M constraints are included in the dispatch to manage the flows on the constraints.

Day-Ahead Modeling of M2M Constraints

The JOA between MISO and SPP calls for each RTO to model the other's M2M constraints in their Day-Ahead Markets. This is valuable because the Day-Ahead Markets coordinate the generation that will be committed and dispatched, and establish financially-binding schedules (generation infections, load withdrawals, and resulting network flows). When a constraint is not modeled, market participants can effectively purchase flow over the constraint that far exceeds its limit, which can result in sizable costs in real time to buy back the excess flows.

To determine the extent to which each RTO is effectively modeling the other's M2M constraints, we calculated the average day-ahead and real-time shadow prices of the constraints most frequently coordinated in real time. We show the information separately in Figure 7 and Figure 8 for SPP constraints and MISO constraints, respectively. The MRTO data is shown with a square marker while the NMRTO is a circle. The colors of the markers differentiate the RTOs: red for MISO and blue for SPP.

In a well-functioning day-ahead market, constraints should bind more frequently but with a lower shadow price when binding than in real time. The shadow prices shown in the figures below are an average of all hours, so hours when the constraint is not binding are included as $0 observations. Good market performance would result in average shadow prices that converge between day ahead and real time markets, close to the 45-degree line that represents "perfect" convergence.

Figure 7: Day-Ahead Shadow Price Convergence on SPP Constraints

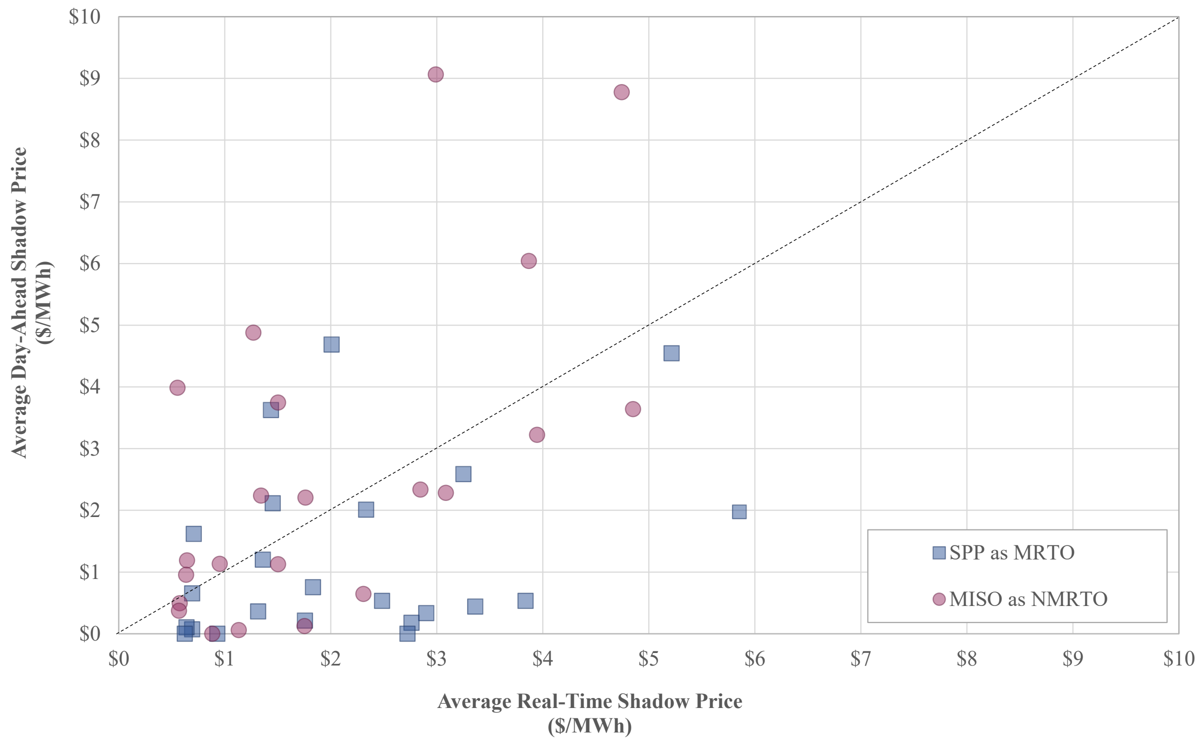


Figure 8: Day-Ahead Shadow Price Convergence on MISO Constraints

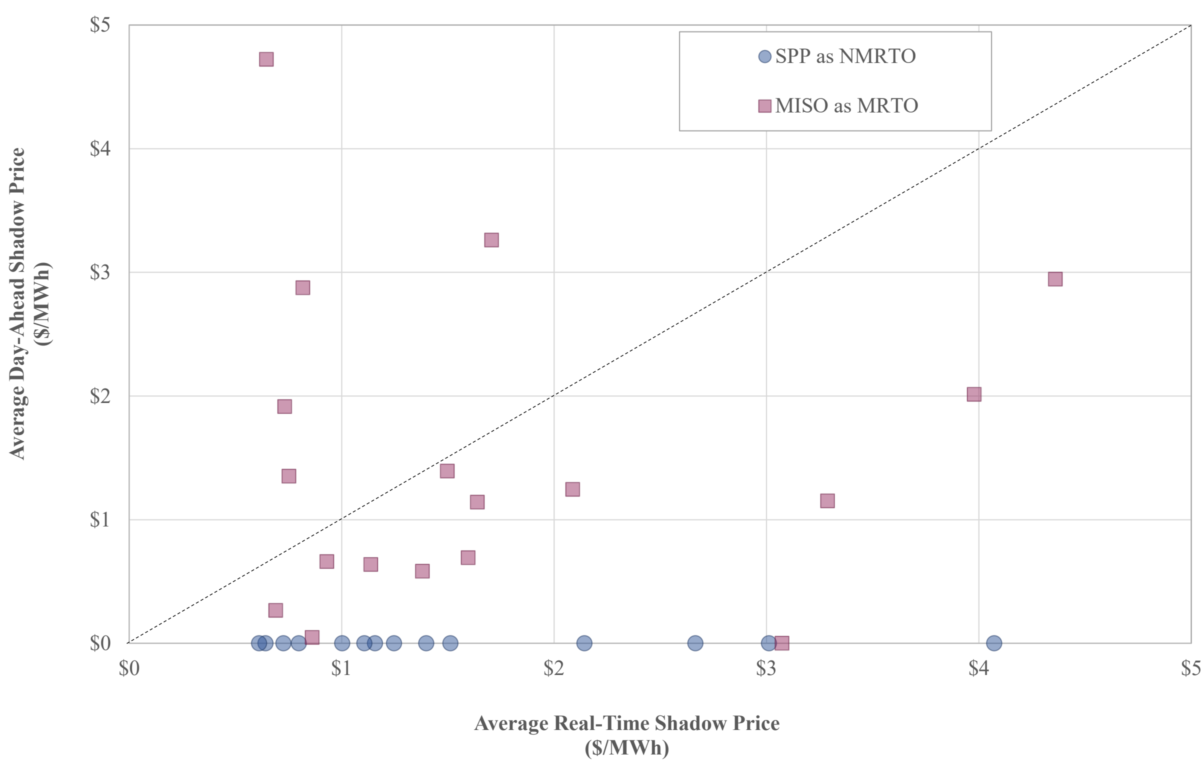


Figure 7 shows that the day-ahead markets in both MISO and SPP have performed well in reflecting the congestion on SPP's M2M constraints. MISO's market exhibits a slightly less-biased set of results, while SPP has a more prominent bias toward higher real-time shadow prices. MISO generally pays SPP for using more than its FFE in real time. This usage pattern would explain a real-time shadow price premium for SPP as the MRTO.

Figure 8, in contrast, shows poor results in SPP for MISO's M2M constraints. SPP appears to either not be modeling MISO's M2M constraints in their day-ahead market or modeling them in a manner that causes them not to bind. This raises substantial concerns, not only because it may not be consistent with the JOA requirements, but also because it is likely causing SPP to commit resources inefficiently in its day-ahead market. If SPP is committing resources that load MISO's M2M constraints, it may be more costly for both SPP and MISO to manage the constraints in real time. Most of this additional cost would be borne by SPP through the M2M settlements.

Additionally, if virtual traders in SPP recognize that congestion on these constraints is not modeled consistently in SPP's day-ahead market, they can schedule flow over these constraints at no cost that SPP will have to pay to buy back at the real-time shadow price. This could result in millions of dollars of balancing congestion allocated to load-serving entities. Balancing congestion occurs when the flows scheduled in the day-ahead market over a constraint exceed the flows that can be accommodated in the real-time market. This can occur when the limit for the constraint falls due to an outage or other factor, but it can also happen if the constraint is not modeled entirely in the day-ahead market. Although we do not have the data needed to quantify these amounts specific to MISO constraints, Figure 9 shows the total balancing congestion in SPP and MISO over the past two years.

Figure 9: Monthly Balancing Congestion Costs

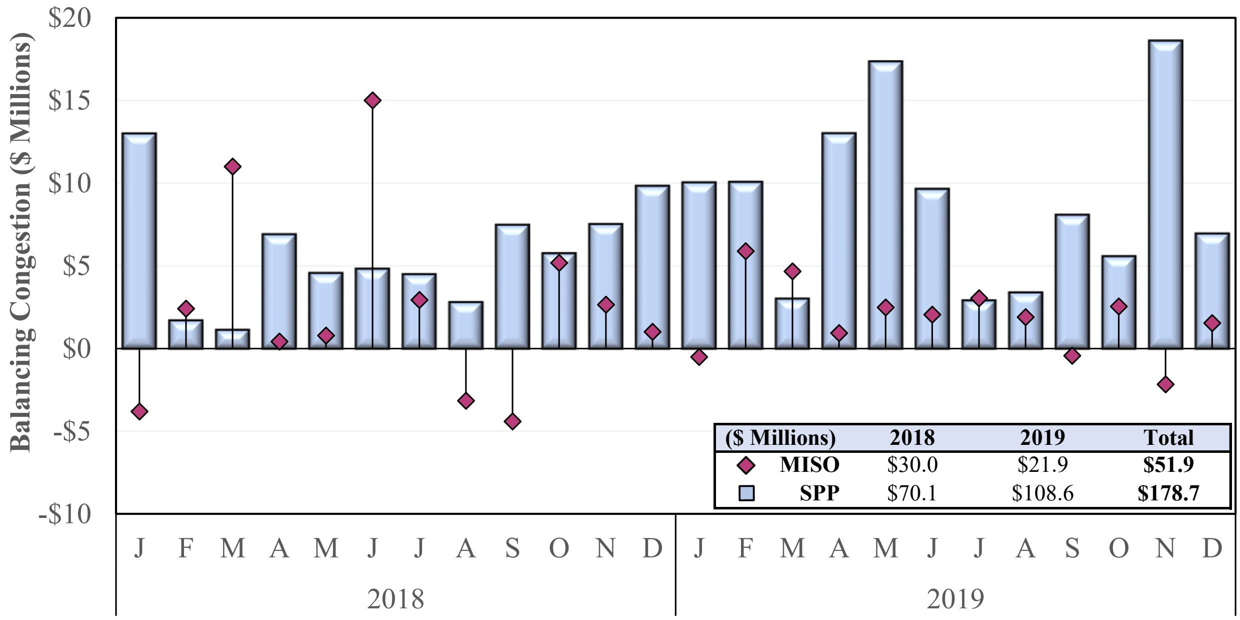


Figure 9 shows that balancing congestion in SPP is consistently positive and more than three times greater than in MISO, totaling almost $180 million over the past two years. This indicates very poor consistency between SPP's day-ahead and real-time network modeling. It is likely that the failure to model MISO's M2M constraints is a significant source of this inconsistency. The future exposure to these costs could grow as participants find these inconsistencies and take advantage of them. Therefore, we strongly recommend that SPP improve its modeling of MISO's M2M constraints, particularly those that have recently bound or are expected to bind in MISO's real-time market.

Generation Shift Factor Cutoff in MISO

SPP's market software applies the same shift factor methodology in its day-ahead and real-time energy markets as the RTOs use for market flow settlements under the JOA. Namely, SPP includes all generators that affect a constraint it its market models (i.e., all generators with a non-zero GSF). This means that pricing, dispatch and JOA settlement are in alignment. Because GSFs are calculated down to zero without any cutoff, no flow effects are ignored or socialized, which is very desirable.

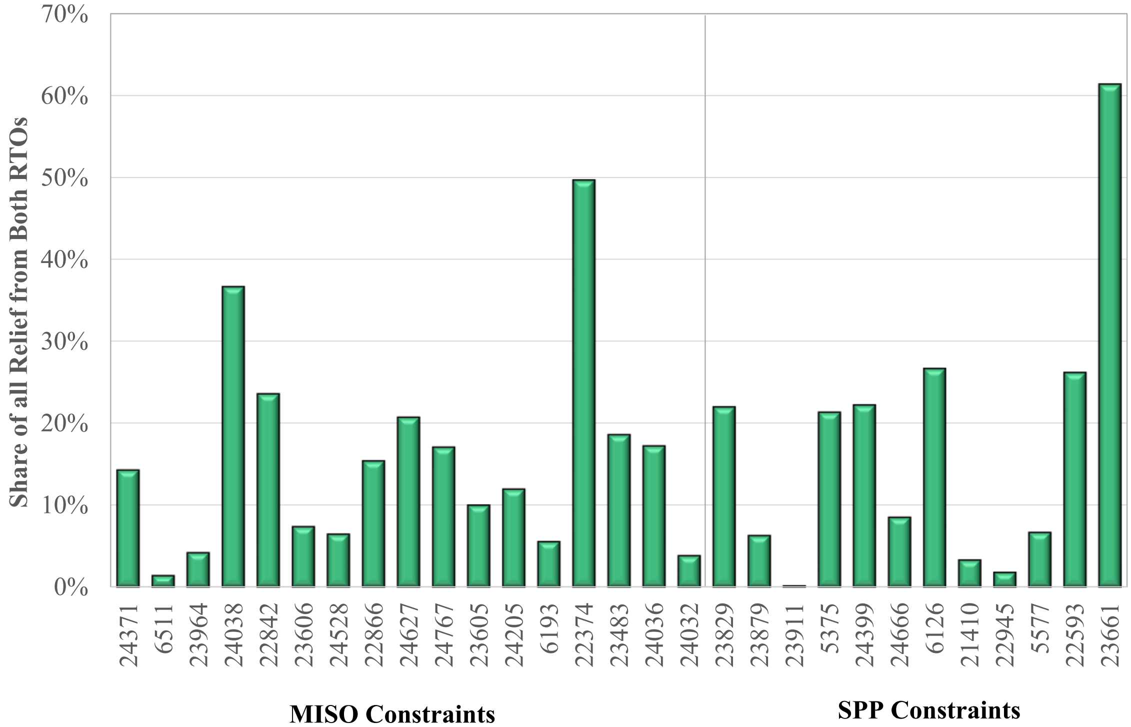
Unfortunately, the MISO's markets are not aligned in a similar fashion. As a result of software performance concerns, MISO adopted a shift factor cutoff. The cutoff has declined over time and is now set at 1.5 percent. In other words, generators with a GSF between -1.5 percent and 1.5 percent are assumed to have no effect on a constraint. Therefore, shifting the output between two generators that could create as much as a 3 percent change in flow over a constraint is ignored (ramping up the -1.5 percent generator and down the 1.5 percent generator).

The effects of applying a GSF cutoff are minimal on internal, high-voltage constraints because many generators are available with GSFs larger than 1.5 percent. However, this cutoff has substantial implications on the manageability and funding of lower voltage constraints and M2M constraints. We lack the data to calculate MISO's relief on M2M constraints that is lost due to the cutoff, but we have data for SPP since it does not employ such a cutoff.

Figure 10 shows the significance of SPP's low shift factor relief on the transmission constraints most frequently coordinated under the MISO-SPP JOA. The blue bars indicate the share of the total relief capability in MISO and SPP combined that is provided by SPP resources with a shift factor less than 1.5 percent in absolute terms.

This figure shows that the share of relief from low-impact SPP resources exceeds 20 percent on several constraints and accounts for half the relief capability on two constraints. Given the larger size and number of generating units in MISO, we would expect an equal or greater contribution from low impact MISO resources if the current cutoff was reduced or eliminated.

Figure 10: SPP Relief Capability below MISO's GSF Cutoff



In addition to improving the efficiency of the management of congestion on the M2M constraints, lowering this GSF cutoff would have important effects on both M2M settlements and FTR funding.

M2M Settlements. The market flows calculated for M2M settlements include all flows, not only those resulting from locations with a shift factor exceeding 1.5 percent. Congestion associated with the flows that are "cut-off" in MISO's market models total roughly $11 million per year on SPP M2M constraints. MISO must pay for these flows, but the GSF cutoff prevents MISO from reducing these flows through its dispatch or collecting the congestion to support the M2M settlements from the participants causing the flows. This results in uplift costs in MISO that much be charged to support the settlements.

FTR Funding Implications. MISO's FTR market operates with no GSF cutoff, creating a disconnect between energy market outcomes and financial settlements with FTR holders. MISO's day-ahead market often generates shortfalls on low-voltage constraints and M2M constraints because it does not collect congestion from the low-impact locations. Instead these low impact flows are treated as "loop flows" and result in downward adjustments to day-ahead transmission limits. In 2019, we estimate that the GSF cutoff produced FTR shortfalls totaling approximately $21 million, of which $8.5 million was attributed to three SPP constraints.

Hence, we recommend that MISO reduce or eliminate its GSF cutoff for low-voltage and M2M constraints.

II. Conclusions

The M2M process continues to be essential for coordinating the congestion management on constraints that are loaded by the generation and load of both SPP and MISO. The total congestion on these constraints over the study period exceeded $150 million, which we estimate could be reduced by as much as $32 million by making the recommended improvements. The study identifies other improvements that are unquantifiable that would further reduce these congestion costs.

To achieve these benefits, we make the following recommendations to improve key aspects of the M2M process:

> *Testing Criteria.* Introduce a test based on the available flow relief that can be provided by the Non-Monitoring RTO as a replacement for its current five percent shift factor test.
>
> *Administration of Testing and Activation.* Improve the automation and procedures related to the testing and activation components of the M2M process.
>
> *Short-Term Relief Request Improvements.* Base relief requests on the marginal costs of providing relief and an automated means to control for constraint “oscillations” or “power swings”.
>
> *Long-Term Relief Request Improvement*. Utilize dynamic transmission constraint demand curves to more accurately reflect the actual and expected relief provided by the Non-Monitoring RTO in the dispatch of the Monitoring RTO.
>
> *SPP Day-Ahead Modeling of MISO M2M Constraints*. SPP should improve its modeling of MISO’s M2M constraints, particularly those that have recently bound or are expected to bind in MISO’s real-time market.
>
> *MISO Modeling of SPP Constraints*. MISO should reduce or eliminate its GSF cutoff for low-voltage and M2M constraints to improve its ability to provide relief on these constraints. This should lower its M2M settlement costs and improve its FTR funding.

Many of these recommendations represent incremental changes to the processes or the JOA that do not require substantial resources, but some require coordination between the two RTOs. We encourage the RTOs to take this opportunity to address these issues, which will produce sizable benefits by reducing congestion costs, reducing settlement costs for each RTO, and ultimately improving reliability.

APPENDIX A

Technical Description of the Current Relief Request Software

The Relief Request Software currently calculates a relief request as follows:

Relief Request = (Physical Flow - Effective Limit) + (Initial Market Flow - Current Market Flow) + Adjustable Adder

The first term (Physical Flow – Effective Limit) is a calculation of the difference between physical flow on the constraint and the Effective Limit for the constraint. If the physical flow is greater than the Effective Limit, it means the MRTO in the next five-minute interval is unable to control the constraint to its limit. It represents the minimum physical relief required on the equipment from the reliability perspective.

The second term (Initial Market Flow – Current Market Flow) calculates the change in the NMRTO's market flow on the constraint comparing the initial market flow (at the time of activation) to the current market flow (from the most current information). It has an effect of netting-out the initial market flow from the calculation and providing an amount equal to relief that has been provided up to now.

The last term, the Adjustable Adder, is the additional relief requested from the NMRTO when the MRTO has the flowgate under control but would like the NMRTO to provide additional relief. This parameter represents the status of relief on the constraint in the two RTOs and is used to converge the difference between the shadow prices between the two monitoring RTOs by increasing the relief request MW.

The Adjustable Adder is calculated as follows:

(Effective Parameter 1 + Effective Parameter 2) * Facility limit

Where the Effective Parameter 1 and Effective Parameter 2 are zero if the RTOs do not want any additional relief other than what is needed from the reliability perspective. This are discretionary amounts determined by the RTOs.

The Effective Parameter 1, or Convergence Maintenance Factor, is dependent on the MRTO. If the MRTO wants additional relief from the NMRTO apart from the relief required from the reliability perspective, then Effective Parameter 1 is non-zero; otherwise it is zero. Its non-zero default value is 5 percent.

The Effective Parameter 2, or Convergence Acceleration factor, is dependent on the NMRTO. If the NMRTO could provide an additional relief which is higher than the relief requested from the MRTO then it is non-zero; otherwise it is zero. Its non-zero default value is 5 percent.