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Scaling Detailed High-Resolution Data Split Performance Measures to Statewide System Level Management

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Scaling Detailed High-Resolution Data Split Performance Measures to Statewide System Level Management

by

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ABSTRACT

Recent advancements in high-resolution signal controller data logging and acquisition technologies have enabled development of fundamental performance measures that are effective at identifying split failures and rebalancing green times. However, from a system operator perspective it is important to scale these metrics system-wide for monitoring, triaging, and decision-making uses. This paper articulates the questions that concern a typical system operator, and the associated performance measures and tools that can be used to actively manage such systems macroscopically. To illustrate this methodology, the paper examines 70 signals across seven corridors over a six-month period. Approximately three billion high-resolution signal events including 217 million phase occurrences are analyzed, with 126 million of those phases occurring during the 0600–1900 time period. This paper proposes a scalable method to identify phase occurrences with insufficient green. Applying a previously-developed split failure performance measure for this purpose, over 106,000 split failures (0.08% percent) of the phase occurrences are estimated to have failures for the time of day period. These are displayed using a graphical visualization we called the Purdue Split Failure Ticker (PSFT). Subsequent sections of the paper recommend Pareto ranking, drill-down analysis by movement and hour, and corridor movement split summaries to identify where to prioritize resources for signal re-timing activities and geometric improvements.

Keywords: Traffic, high-resolution, signal, controller, data, split failure, occupancy, events, timing.
INTRODUCTION

Operators of traffic signal systems often lack adequate resources to sustain a comprehensive active traffic management program (1). In current practice, many agencies rely on public complaint calls and anecdotal knowledge of system performance to manage systems outside of regularly scheduled retiming activities (1,2). While some tools have been developed over the years to monitor systems, it has been challenging to deploy these in a scalable manner because those tools have relied on additional hardware installation, “always-on” low-latency communication that is costly to deploy and maintain, or both.

Two recent developments have made performance monitoring of traffic signal systems in a scalable manner possible. One is the development of a data collection capability within the traffic signal controller itself (3). The other is the introduction of a means of remotely retrieving that data that can tolerate intermittent breaks in communication (4). Of these, the latter has been particularly important in Indiana, whose signal systems are dispersed throughout the state. In Utah, where previous investments in a high-quality communications system allowed all of the state-operated signals being previously connected, it has been possible to begin collecting data from hundreds of signalized intersections very rapidly (5).

Over the past decade, collaboration between the Indiana Department of Transportation, Purdue University, and a consortium of controller manufacturers has led to a set of data specifications (6) that are now supported in at least six different controller models from five different manufacturers in North America. The data objects, called high-resolution event data, include signal phase change and detector activation states that are recorded at the smallest possible time resolution (0.1 seconds in most controllers). This type of data has been the subject of an extensive amount of research, with applications in a variety of areas (7–16). Many of these performance measures have been implemented in several different traffic management centers across the US (8), with some agencies growing to a large number of intersections. However, much of the research to date has focused on development of performance measures for individual intersections or studies over a relatively small time period. This paper focuses on the problem of scaling the data methodology to a system-wide scale, and a longitudinal analysis covering an extended time period, to understand where recurring capacity deficiencies exist in the system.
WHAT CONSTITUTES A ‘SPLIT FAILURE’ AND SCALABILITY CONSIDERATIONS

This paper defines a split failure as an occurrence where the duration of green for a movement at a signalized intersection is insufficient to serve the amount of demand present. The measurement of split failures has been considered from the high-resolution data perspective in several previous studies (8,11,15). One performance measure that has been used extensively in Indiana considers an analysis of occupancy during the green interval in combination with the beginning of the subsequent red interval (15). The advantage of an occupancy-based measurement is that it can be deployed at any location featuring stop bar detection. Count detection is less widely available. The pilot study on this performance measure recommended that vehicle occupancy exceeding 80% of green coupled with 80% or higher occupancy during the first five seconds of the subsequent red interval (on any lane at the stopbar) could accurately indicate a split failure. To mitigate the influence of stochastic spikes in demand, three consecutive occurrences of this pattern have proven useful for reducing the noise in the data. This performance measure has proven effective at the intersection level, but has been challenging to scale up to systems with dozens if not hundreds or thousands of intersections. This paper proposes a methodology to aggregate and visualize large volumes of split failure data necessary for performance monitoring system-wide, with subsequent drill down capability.

METHODOLOGY

STUDY AREA

The study area consists of seven corridors located in Central Indiana, totaling 70 intersections (Figure 1). There are a combined 637 phases, 907 lanes, and 973 detectors in the study scope (Table 1). Each of these corridors generally run semi-actuated coordination from morning into the evening starting at 6 am, seven days a week, with varying number of plans and end times across corridors and different plans for weekdays and weekends. This study analyses the split failure performance of the seven corridors for 180 days from January 1 to June 30, 2015. Three generic time-of-day (TOD) analysis periods are used to provide consistent windows for comparison between the corridors: 1) 0600 to 0900 AM period, 2) 0900 to 1600 midday period, and 3) 1600 to 1900 PM period.
Figure 1. Locations of seven corridors in Central Indiana.
Table 1. Detailed information on study corridors in Indiana.

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Intersections</th>
<th>Phases</th>
<th>Lanes</th>
<th>Detectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pendleton Pike</td>
<td>14</td>
<td>133</td>
<td>192</td>
<td>208</td>
</tr>
<tr>
<td>US-31 Greenwood</td>
<td>11</td>
<td>93</td>
<td>141</td>
<td>139</td>
</tr>
<tr>
<td>US-31 Columbus</td>
<td>10</td>
<td>95</td>
<td>132</td>
<td>133</td>
</tr>
<tr>
<td>SR-37 Martinsville</td>
<td>5</td>
<td>39</td>
<td>53</td>
<td>75</td>
</tr>
<tr>
<td>SR-37 Noblesville</td>
<td>10</td>
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<td>137</td>
<td>139</td>
</tr>
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<td>SR-37 Indianapolis South</td>
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<td>99</td>
<td>151</td>
<td>162</td>
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<tr>
<td>US-421 Zionsville</td>
<td>7</td>
<td>79</td>
<td>101</td>
<td>117</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>70</strong></td>
<td><strong>637</strong></td>
<td><strong>907</strong></td>
<td><strong>973</strong></td>
</tr>
</tbody>
</table>

**DATA AGGREGATION**

The raw, stateless data acquired is comprised of over three billion records for all seven corridors across the six-month analysis period. Each record requires a minimum of 10 bytes per event, with additional storage overhead needed to index the data for database performance considerations (6). To develop useful performance measures, substantial processing of the stateless data is required. To determine whether a phase has split-failed, the duration of each phase occurrence, detector presence, and their overlapping time periods are distilled from the stateless events into ‘interval’ records. These intervals are defined by starting and ending time references, and an identifier. The identifier can reference either 1) a signal output channel, such as a phase number (indicating green, yellow, and red intervals) or 2) a detection channel (indicating occupied and unoccupied intervals). Occupancy information can be computed by analyzing these interval objects using detector-phase mapping information provided by the agency. This initial aggregation reduces the number of records by 77% from the original, stateless event data, and provides a spatial-temporal layer of information for the next level of analysis. In total, 217 million phase intervals and over 470 million occupancy intervals occurred over the six month study of the 70 intersections. For just the 0600 to 1900 period, 126 million phase intervals and over 365 million occupancy intervals occurred.

Applying the split failure performance measures (15) to this data set, and aggregating the number of split failures into 15 minute bins, reduces the number of records by 99.3% compared to the stateless event data. The three tiers of data and their cumulative quantities over the six months are illustrated in Figure 2.
MAKING SENSE OF MANY SPLIT FAILURES

SPLIT FAILURE TICKER

The Purdue Split Failure Ticker (PSFT) is a stacked-area graph that plots the total number split failures in each category over a user defined time scale. The categories can isolate corridors, intersections, phases, lanes, or detectors depending on the level of drill-down needed for a specific analysis. In Figure 3, the total number of split failures per day are plotted over the six month period across all seven corridors. Each bar represents one day, with different colors in the stack representing subtotals for different corridors. The bars can be adjusted to examine shorter timespans, down to a 15-minute resolution. Since within each bin the absolute number of split failures are quantified, corridors with a higher number of intersections or movements may overshadow smaller systems. An alternative unstacked plot may graph the percentage of total phase occurrences that have split failed (not shown).

The total number of split failures detected during the 0600 to 1900 period over six months is 106,914 out of over 217 million phase occurrences (0.08%). In this multi-month view, an emerging trend appears to be a gradual increase in the number of split failures from winter to summer. Weekly patterns can also be observed, with spikes towards the end of each week (with Fridays usually the peak day), and valleys on Sundays. Callout i indicates a drop in split failures across all corridors over the three-day Memorial Day weekend period.

Since each corridor has between 5 and 14 intersections, routes with a higher number of intersections such as SR-37 Noblesville and US-31 Greenwood tend to have the most split failures. However, this is not always the case. Pendleton Pike, with 14 intersections, performs better than US-31 Greenwood, which has
11 intersections, on 178 out of 180 days. The split failure counts allow system engineers to assess the magnitude of split failures in each corridor relative to the entire network, thereby objectively identifying the corridors that require more attention. To implement this graphical view in a software application, the number of corridors presented at once can be reduced to target different management areas or specific teams responsible for the re-timing activities. For example, engineers working in one particular district could remove corridors outside their district from the graph.

Figure 3. Daily split-failures in Indiana in 2015.

PSFT charts for the three TOD periods are shown by Figure 4 for the weekdays across six months. Each chart shows only the split failures occurring within a particular TOD. Figure 4a shows a relatively low number of split failures for the three-hour AM period (Figure 4a) compared to the three-hour PM period (Figure 4c). The number of split failures in the AM period is relatively stable throughout the year (Figure 4a), while gradual increases occur in the midday (Figure 4b) and PM period (Figure 4c). The highest number of split failures in the AM period occurred on February 26, and was caused by an early morning snowstorm (note the news item featured in the callout). For the seven-hour midday TOD period, Figure 4b shows consistently pronounced spikes on Fridays, similar to the PM period. On Friday, April 3, a dramatic spike appears for the midday period, while on the same day the PM period shows relatively little activity. This can be attributed to the NCAA Final Four championships being hosted in Indianapolis during that weekend. This event evidently led to a large increase in midday traffic, while its effects on PM traffic were not as severe.
Figure 4. Weekday split-failures in Indiana in 2015.
PARETO RANKINGS

While the PSFT displays the raw split failure performance for a set of corridors over number of months, a pareto-sorted ranking diagram over the same period is helpful for comparing different time periods and days of the week, and quickly identifying problematic corridors. In the PSFT graphics (Figure 3 and Figure 4) most Fridays and some Saturdays exhibit many more split failures than the other days of the week. Overall, it is difficult to determine the overall trend in the graphs or to compare different TOD periods against each other. Figure 5 shows an alternative view of the same data that has been segmented for Fridays, Saturdays, and Sundays across the six months. The data are Pareto-sorted by the number of split failures per hour. Each point represents the average number of split failures per hour across the entire system during a particular TOD period in a single day. As in the PSFT diagrams, three generic time of day periods are represented: 0600 to 0900 AM period, 0900 to 1600 midday period, and 1600 to 1900 PM period.

Figure 5a shows the PM period consistently exhibiting a higher number of split failures per hour than the AM and midday period on Fridays, while the AM period performs slightly better than the midday period. By comparison, on Saturdays (Figure 5b), the midday period has more split failures per hour than both the AM and PM periods, and is worse than midday periods on Fridays for the top 23 of 26 Saturdays. In contrast, Figure 5c shows that the network generally performs well on Sundays for all TOD periods, with under 40 split failures per hour on average.

The Pareto diagrams can be reconfigured to identify the geographic distribution of split failures. Focusing on the midday period, Figure 6a ranks all Fridays of all corridors together by the number of split failures per hour, with a different symbol representing each corridor. The corridors with the highest average split failures per hour on Fridays within the worst 20 rankings are SR-37 Noblesville and US-31 Columbus, each with seven days, and US-31 Greenwood with six days. US-31 Greenwood is also the worst-performing corridor in the network for the top two Fridays. Figure 6b shows a similar Pareto sorted view for Saturdays during the midday period. Interestingly, the worst performing corridor-days for midday TOD periods on Saturdays show more split failures than Fridays. Fridays’ worst-performing corridor (June 19 at US-31 Greenwood) had 29.1 average split failures per hour, which is fewer split failures than Saturday’s ten worst corridor-days (number 10, May 9 at US-31 Greenwood, has 29.7 split failures per hour). US-31 Greenwood is conspicuously top ranked with nine out of the ten worst corridor-days on Saturdays. The worst had 43.9 average split failures per hour, on March 7.
Figure 5. Pareto ranking of average split-failures per hour in Indiana, January 1 to June 30, 2015.
Friday's 20th-worst corridor-day was June 12 at SR-37 Noblesville, with 16.7 average split failures per hour during the midday (Figure 6a, callout i), while the 20th-worst corridor-day on Saturdays was 22.9 average split failures per hour at US-31 Columbus on February 7 (Figure 6b, callout i). At the 40th-worst corridor-day, Fridays still had better performance, with 13.1 average split failures per hour at SR-37 Noblesville on April 17 (Figure 6a, callout ii), compared to 17.1 average split failures per hour in the same corridor on Saturday, January 24 (Figure 6b, callout ii). It is not until the 59th-worst corridor-day when Saturdays have fewer split failures than Fridays (Figure 6a, callout iii; Figure 6b, callout iii).

Figure 6. Pareto ranking of average split-failures per hour during 0900 to 1600, January 1 to June 30, 2015.
PARETO RANKING BY INDIVIDUAL CORRIDOR

The performance of individual corridors can be ranked separately to further distill the data and to compare one corridor against another. Figure 7 illustrates the performance rankings by corridor over 26 Fridays (Figure 7a) and 26 Saturdays (Figure 7b). Figure 7a shows that US-31 Greenwood, US-31 Columbus, and SR-37 Noblesville have more split failures per hour than the other four corridors on Fridays. However, two of the systems, US-31 Greenwood and SR-37 Noblesville, perform consistently worse on Saturdays than on Fridays during the same period. US-31 Greenwood has 25 out of 26 Saturdays with more split failures than on Fridays, while for SR-37 Noblesville this is true for 23 out of 26 Saturdays.

Figure 7b also shows that the performance of the worst-performing three corridors is less consistent on Saturdays than on Fridays. That is, while US-31 Greenwood, SR-37 Noblesville, and US-31 Columbus have similar Friday split failure profiles, there are considerable differences among their Saturday split failure profiles. This likely indicates that the weekday timing plans are better tuned to traffic conditions than the weekend timing plans. Agencies often have fewer resources to make manual adjustments to signal timing on weekends.

(a) Fridays.
(b) Saturdays.

Figure 7. Pareto ranking of average split-failures per hour by corridor during 0900 to 1600, January 1 to June 30, 2015.

DRILLING DOWN TO DAILY PATTERNS ON A CORRIDOR

The previous graphics suggest that the US-31 Greenwood corridor (Figure 8) should be investigated further. Figure 9 presents a PSFT that aggregates the daily split failure trends throughout the corridor, on all Saturdays in the first 6 months of 2015. The stacked bars segment the data by intersection. The dotted box in the diagram shows the limits of the midday TOD period that was previously considered in the higher-level Pareto ranking views (Figure 6, Figure 7). Interestingly, although the somewhat arbitrarily defined midday TOD period does not perfectly coincide with the distribution of split failures for this corridor on Saturdays, it nevertheless captures a sufficient amount of them to have initiated further drill-down. The analysis period is adjusted to 1100 to 1900 using the information from Figure 9.

As Figure 9 indicates, the majority of the split failures occur at the three northern-most intersections of the corridor. County Line Rd in particular experiences a consistent number of split failures practically throughout the entire day. The peak split-failing period starts at 1345, with 283 total split failures. This represents 26 15-minute bins throughout the year, or a total of \(26 \times (0.25 \text{ hr}) = 6.5 \text{ hr}\). Therefore, the average hourly rate is \(283 / 6.5 = 43.5\) split failures per hour on average for the entire corridor. During that period, Fry Rd has the highest proportion of the split failures, with 113 split failures (40% of the corridor total), or 17.4 split failures per hour on average. Other notable intersections include County Line Rd (65 split failures or 10 per hour, at 1500), Greenwood Mall Entrance (61 split failures or 9.8 per hour, at 1445), and Stop 18 Rd (36 split failures or 5.5 per hour, at 1400).
It is possible to drill down still further to identify the individual movements that are contributing to the total per intersection. Figure 9 shows that most of the Saturday split failures on US-31 Greenwood occur between 1100 and 1900. Figure 10 shows a movement summary for each of the 11 intersections in the corridor. The number of split failures are shown with a stacked bar graph, wherein each bar represents the total number of split failures per intersection over the first six months of 2015. Three of the intersections have fewer than 10 split failures. Three others have fewer than 100 throughout the six-month period. The remaining four intersections each have a substantial number. County Line Rd had 1557 split failures that were counted over 8 hours per day across 26 days, so the average rate per hour is $1557 / (26 \times 8) = 7.5$. The other intersections are Greenwood Mall Entrance with 1065 split failures (average 5.1 per hour), Fry Rd with 2096 split failures (average 10 per hour), Smith Valley Rd with 238 split failures (average 1.1 per hour), and Stop 18 Rd with 699 split failures (average 3.4 per hour), all with over 200 total split failures during the period.

Besides the intersection total, Figure 10 breaks down the split failures by movement. The westbound left turn movement at County Line Rd stands out as having more split failures than any other movement in the corridor. The phase has a total of 1373 split failures, which is 23.5% of the total for the entire corridor during the first six months of Saturdays between 1100 and 1900. This information warrants further investigation into whether green times could be rebalanced at the intersection. For example, the eastbound through movement has a relatively small number of split failures, which suggests an opportunity to exchange split time with the westbound left.

There are several additional, similar opportunities that can be identified by pairing a movement exhibiting many split failures with another movement that has very few split failures, or none at all:

- Eastbound left turn at Greenwood Mall Entrance (westbound through has few split failures);
- Westbound left turn at Fry Rd (eastbound through has few split failures);
- Eastbound left turn at Smith Valley Rd (westbound through has no split failures), and
- Westbound left turn at Stop 18 Rd (eastbound through has few split failures).
Figure 8. US-31 Greenwood corridor.
Figure 9. Aggregated split-failures over 24 hours on US-31 Greenwood for all Saturdays from January 1 to June 30, 2015.

Figure 10. Aggregated split-failures from 1100 to 1900 by intersection and movement, US-31 Greenwood for all Saturdays from January 1 to June 30, 2015.
RECOMMENDED SPLIT FAILURE TRIAGING PROTOCOL

Using the methods developed in this study, large quantities of high-resolution signal event data can be transformed into actionable information for agency personnel. By using a suite of performance measures built around a split failure metric, from the system-wide, multi-corridor view of the PSFT (Figure 3, Figure 4), down to the intersection movement summary (Figure 10), engineering resources can be effectively allocated to target the locations with the greatest need. Further, by scaling the quantitative analysis to a system-wide level, it is possible to proactively identify unanticipated trouble spots. Table 2 lists some of the general questions that traffic engineers would be likely to ask regarding the systems that they are tasked to manage. Each is matched to one or more of the performance measures presented earlier, which would provide insights to the answer.

To simplify the procedure further, a network-wide average split failure table may be used to summarize the spatial and temporal retiming targets. Table 3 lists the seven corridors in the study over the three TOD periods, and across the different days of the week, using split failures measured over the first six months of 2015. Each cell shows the average number of split failures per hour during a particular TOD and day of week. The most challenging corridors are SR-37 Noblesville during 1600-1900 on Monday-Thursday and Friday, and US-31 Greenwood during 1600-1900 on Fridays and Saturdays, as well as during 0900-1600 on Saturdays. This summary table is useful for at-a-glance decision-making using the aggregated information, with further details being available using the graphics presented earlier at a variety of drill-down levels.

Table 2. Use cases for agency-wide performance measures.

<table>
<thead>
<tr>
<th>Question</th>
<th>Performance Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>How is my network doing overall?</td>
<td>✓</td>
</tr>
<tr>
<td>What days of the week should I focus on?</td>
<td>✓</td>
</tr>
<tr>
<td>Which corridors are experiencing the most problems?</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>What time of day do they occur?</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>At which intersection(s) do they occur?</td>
<td>✓</td>
</tr>
<tr>
<td>What movement(s) along a corridor should I focus on?</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Examples</td>
<td>Figure 3, Figure 4</td>
</tr>
<tr>
<td></td>
<td>Figure 5, Figure 6, Figure 7</td>
</tr>
<tr>
<td></td>
<td>Figure 8, Figure 9</td>
</tr>
<tr>
<td></td>
<td>Figure 10</td>
</tr>
</tbody>
</table>
Table 3. Average split failures per intersection per hour, January 1 to June 30, 2015.

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Time of Day</th>
<th>Mon-Thur</th>
<th>Fri</th>
<th>Sat</th>
<th>Sun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pendleton Pike</td>
<td>0600-0900</td>
<td>0.52</td>
<td>0.44</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>0900-1200</td>
<td>0.65</td>
<td>0.23</td>
<td>0.17</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>1200-1500</td>
<td>1.49</td>
<td>1.17</td>
<td>0.12</td>
<td>0.08</td>
</tr>
<tr>
<td>US-31 Greenwood</td>
<td>0600-0900</td>
<td>0.67</td>
<td>0.60</td>
<td>0.21</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>0900-1200</td>
<td>0.83</td>
<td>1.35</td>
<td>2.22</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>1200-1500</td>
<td>1.89</td>
<td>2.99</td>
<td>2.28</td>
<td>0.70</td>
</tr>
<tr>
<td>US-31 Columbus</td>
<td>0600-0900</td>
<td>0.25</td>
<td>0.26</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>0900-1200</td>
<td>0.76</td>
<td>1.43</td>
<td>0.94</td>
<td>0.39</td>
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<tr>
<td></td>
<td>1200-1500</td>
<td>1.21</td>
<td>1.86</td>
<td>0.73</td>
<td>0.33</td>
</tr>
<tr>
<td>SR-37 Martinsville</td>
<td>0600-0900</td>
<td>0.06</td>
<td>0.07</td>
<td>0.02</td>
<td>0.01</td>
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<tr>
<td></td>
<td>0900-1200</td>
<td>0.12</td>
<td>0.34</td>
<td>0.69</td>
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<td>1200-1500</td>
<td>0.28</td>
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<td>0.26</td>
<td>0.12</td>
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<tr>
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<td>0.83</td>
<td>0.21</td>
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<tr>
<td>SR-37 Indianapolis South</td>
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<td>0.48</td>
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<td>0.32</td>
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<td>US-421 Zionsville</td>
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<td>0.33</td>
<td>0.06</td>
<td>0.05</td>
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<td>0.25</td>
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</table>

CONCLUSIONS AND FUTURE WORK

The performance of 70 intersections totaling 637 phases and 126 million phase occurrences in the State of Indiana were presented and analyzed using split failure visualizations developed from aggregated high-resolution signal controller data. Using the PSFT, over 106,000 split-failed phase occurrences (0.08% of total phase occurrences) were visually triaged over a six month period in the entire network (Figure 3).

A two-step 15-minute binning method was developed to reduce 3 billion high-resolution event records by 99.7% to improve the efficiency of the performance measure and to distill actionable information out of raw stateless data. A Pareto-sorted list ranked the seven corridors to determine which had the highest number of split failures for different times of day and days of week (Figure 5, Figure 6, Figure 7). The Pareto ranked graphs found that US-31 Greenwood was the most challenging corridor in the system. More surprisingly, the Saturdays were found to have more split failures than Fridays for 25 out of 26 weeks compared in the study.
The split failures were further broken down by intersection (Figure 9) and movement (Figure 10) was developed to identify the specific locations where the split failures were occurring. One movement in particular, the westbound left turn at US-31 Greenwood and Fry Rd, was found to account for 23.5% of the corridor total, with over 1373 split failures across the first six months of 2015 (or 10 per hour average).

By deploying a systematized process for identifying capacity deficiencies at a system-wide level, traffic engineers can more rapidly and effectively prioritize their resources for signal retiming activities. The logical extension of the PSFT would be to apply the principles described by Freije et. al. (15) to further filter the PSFT, Pareto, and subsequent drill downs to only list split failures where there are competing phases with green time that are candidates for reallocating to failing phases. Lastly, before after evaluations with Purdue Coordination Diagrams (PCDs) and travel time distribution have been demonstrated to be excellent tools for evaluating and documenting outcome assessment of offset changes. Similar outcome assessments could be done with the PSFT after splits are adjusted by performing before/after Pareto sorts of split failures on particular corridors. Positive impacts would be reflected by correlated drops in split failures on the PSFT or Pareto curves shifting down.

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REFERENCES


FIGURES AND TABLES

Figures
Figure 1. Locations of seven corridors in Central Indiana.................................................. 5
Figure 2. Cumulative record count based on data type, over six months.................................. 7
Figure 3. Daily split-failures in Indiana in 2015................................................................. 8
Figure 4. Weekday split-failures in Indiana in 2015............................................................. 9
Figure 5. Pareto ranking of average split-failures per hour in Indiana, January 1 to June 30, 2015.
......................................................................................................................................................... 11
Figure 6. Pareto ranking of average split-failures per hour during 0900 to 1600, January 1 to June
30, 2015............................................................................................................................................. 12
Figure 7. Pareto ranking of average split-failures per hour by corridor during 0900 to 1600,..... 14
Figure 8. US-31 Greenwood corridor. ......................................................................................... 16
Figure 9. Aggregated split-failures over 24 hours on US-31 Greenwood................................. 17
Figure 10. Aggregated split-failures from 1100 to 1900 by intersection and movement, US-31
Greenwood for all Saturdays from January 1 to June 30, 2015............................................ 17

Tables
Table 1. Detailed information on study corridors in Indiana.................................................. 6
Table 2. Use cases for agency-wide performance measures................................................. 18
Table 3. Average split failures per intersection per hour, January 1 to June 30, 2015............. 19