Outlier Detection in Event Logs of Material Handling Systems

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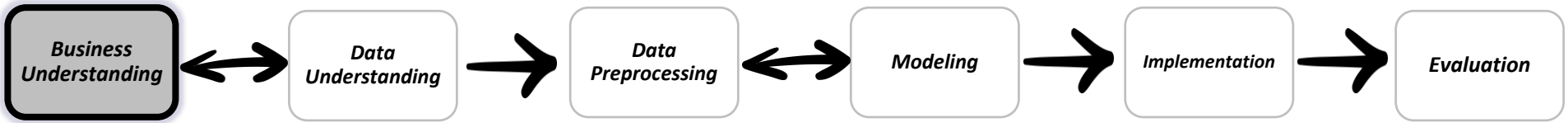
The problem

Performance problems of baggage handling system causes bottlenecks and slows down the process. Bottlenecks of the system therefore should be identified and fixed to ensure an efficient process.

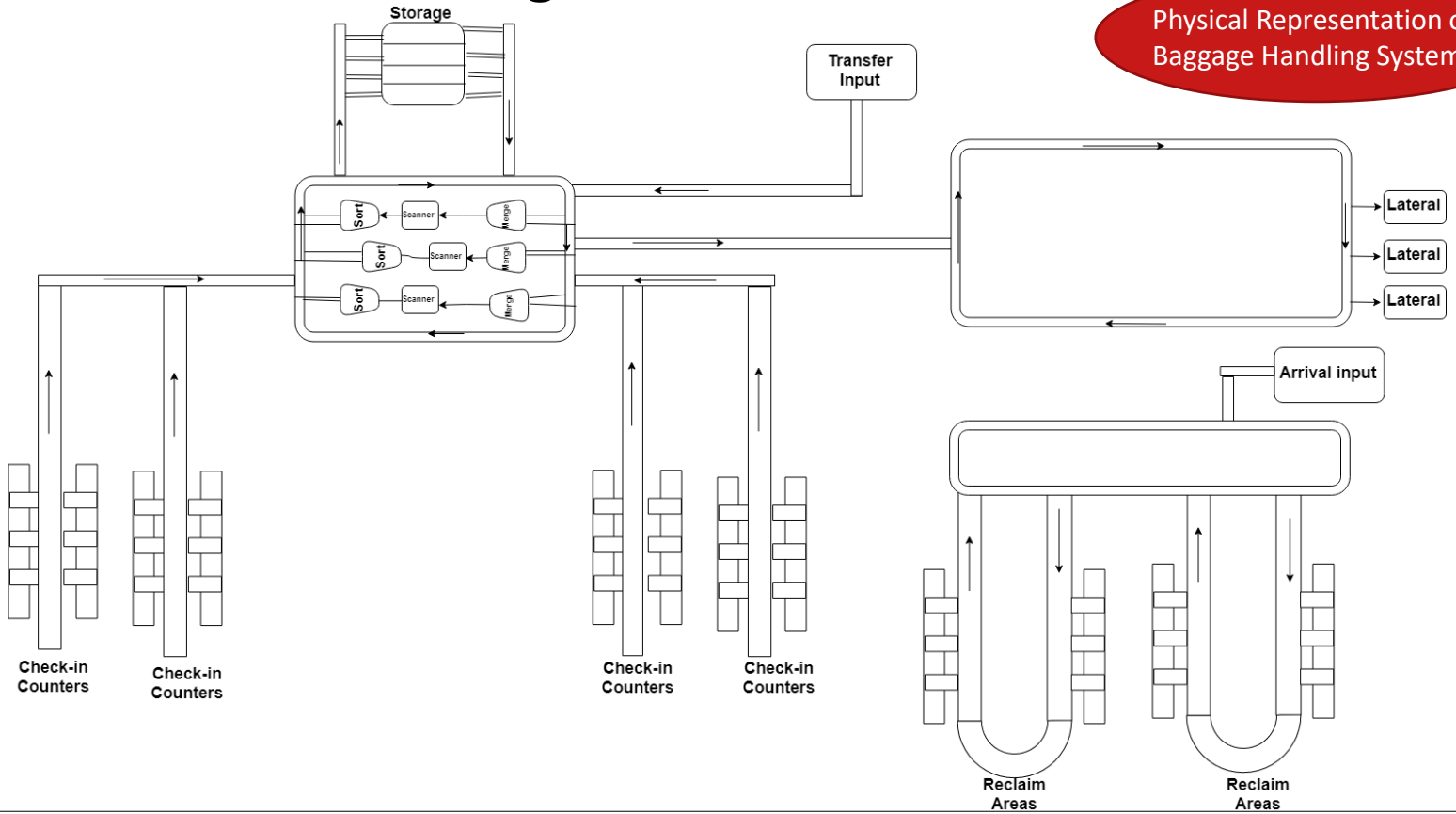
Objective

Automatically identify which parts of a baggage handling system suffer from non-normal operations and under which conditions these non-normal operations arise.

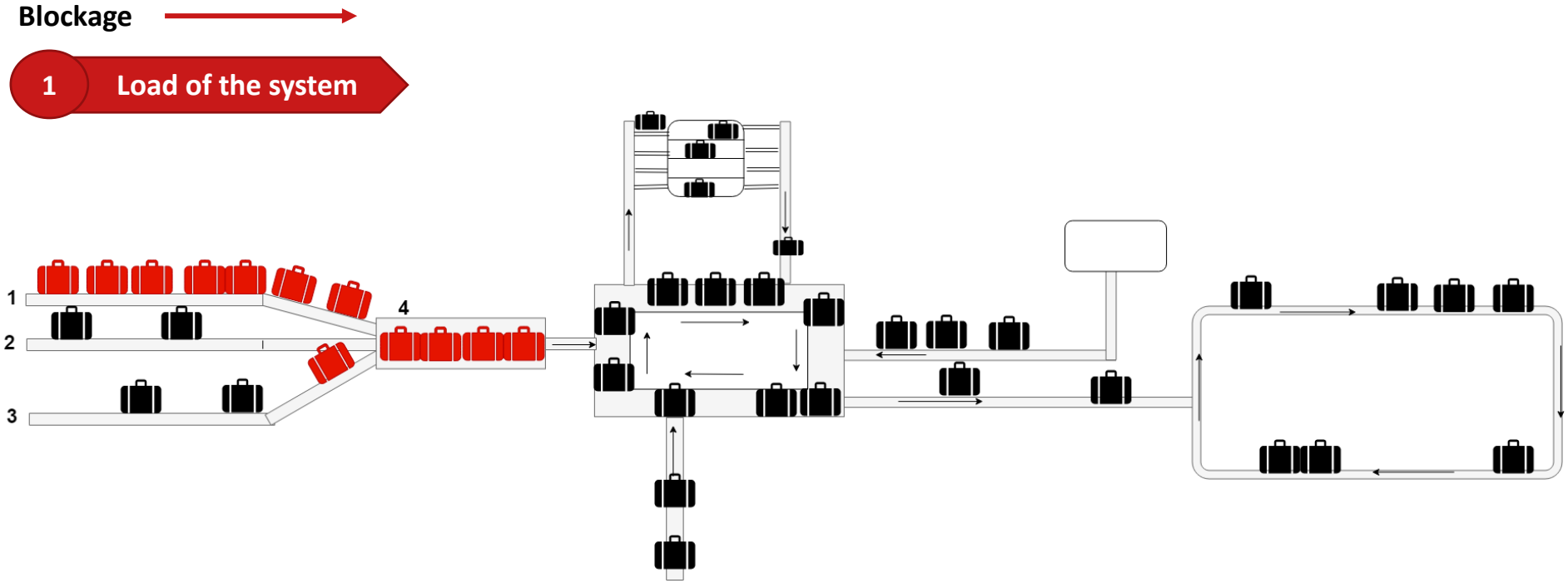

Business Understanding
Data Understanding
Data Preprocessing
Modeling
Implementation
Evaluation

Business Understanding

Physical Representation of the Baggage Handling System



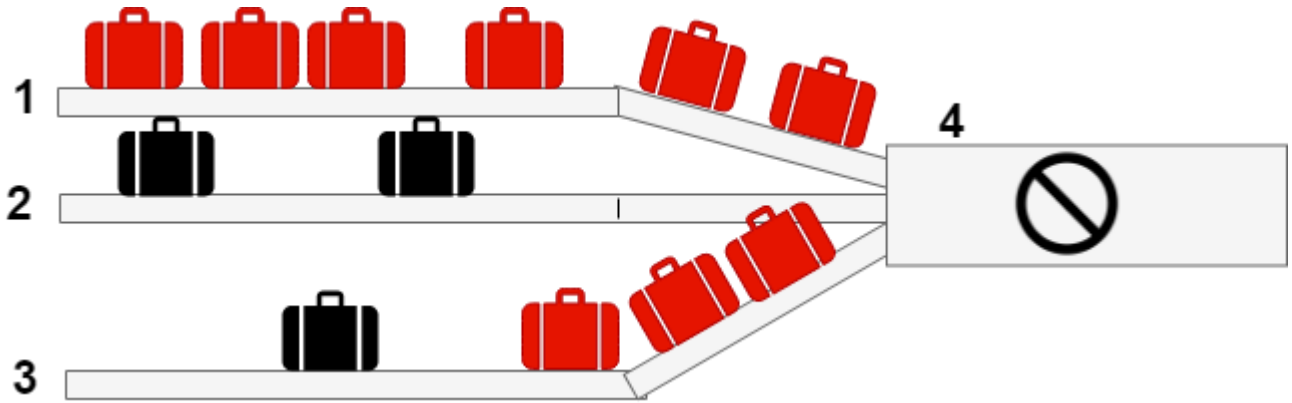
Problems in the Baggage Handling System



Problems in the Baggage Handling System

Blockage →

2 Unavailability in system parts



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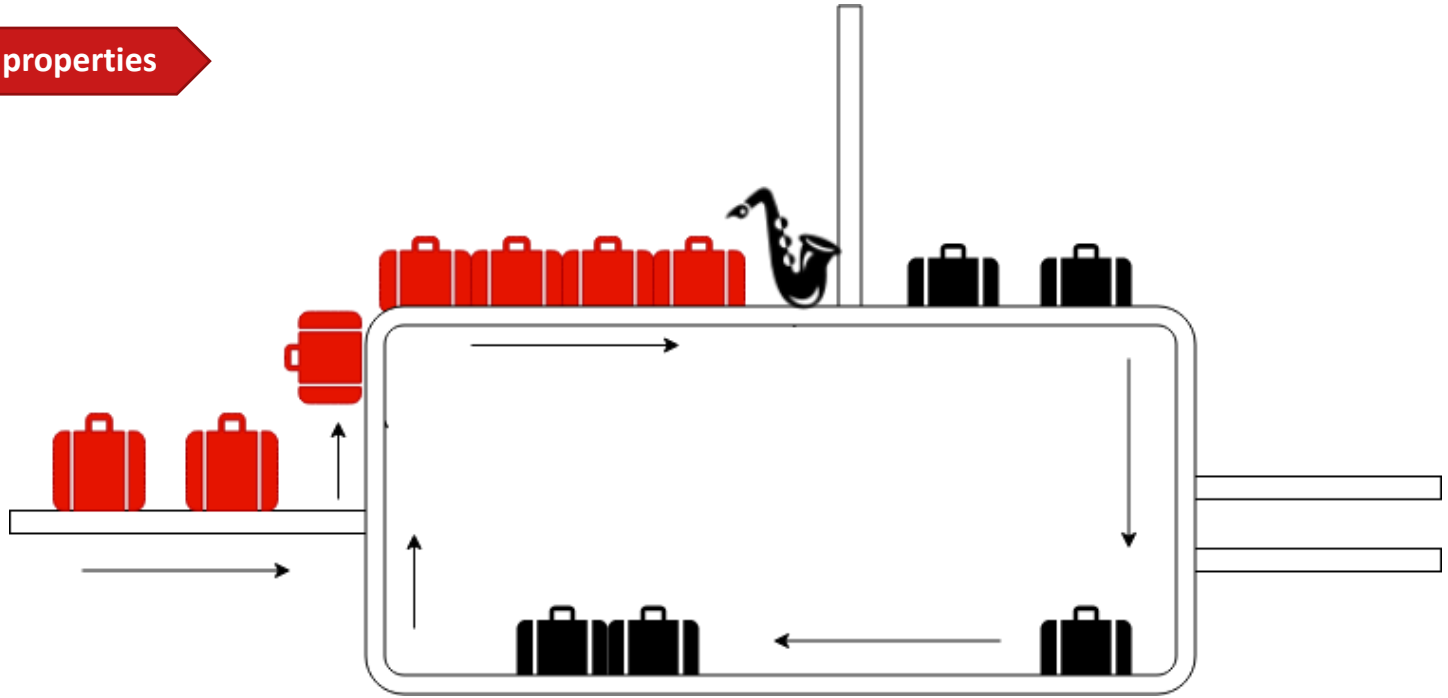
Problems in the Baggage Handling System

Blockage →

3 **Item properties**



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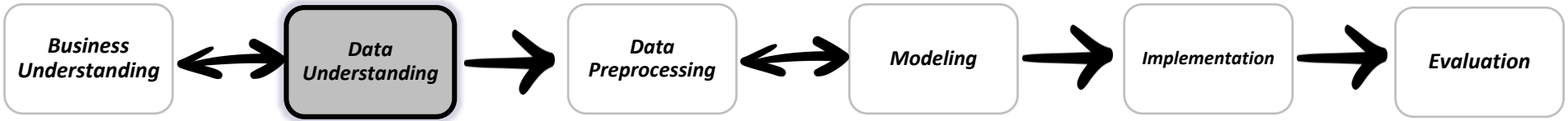
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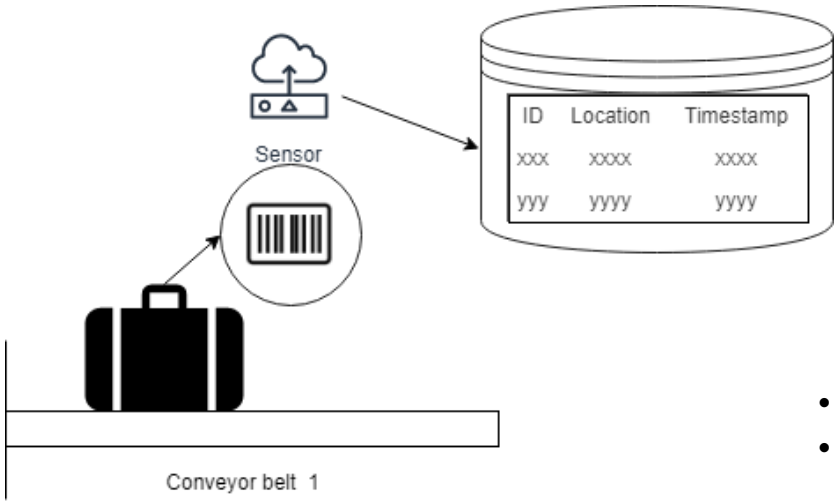
Data Understanding

Nature of the Input Data

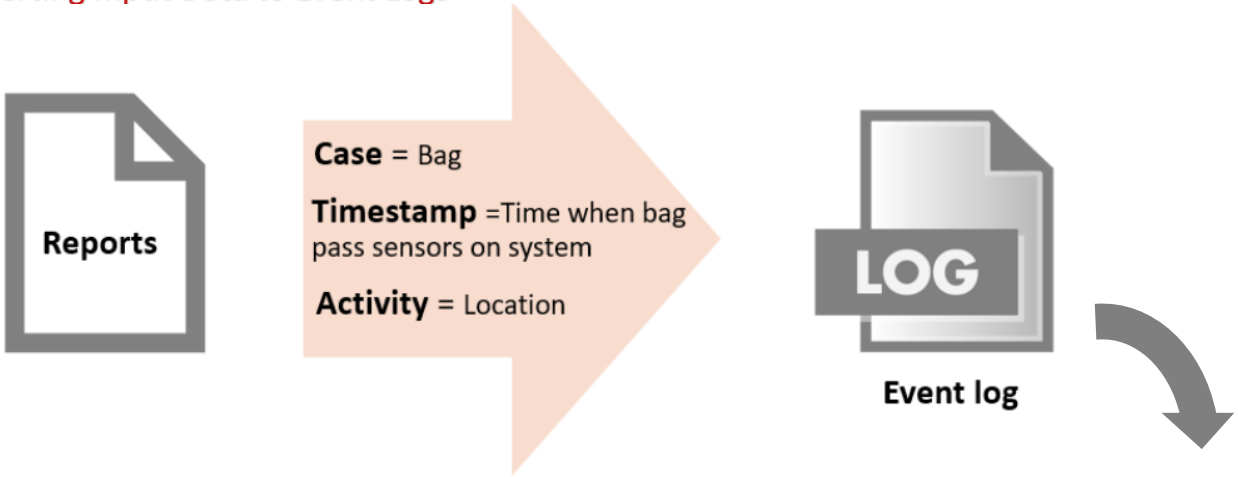


ID	Timestamp	Location	...
1111111	2019/05/21 23:21:01.058	X	...
1000000	2019/05/21 23:21:07.945	Y	...

- *Data is coming from one of the busiest airports in Europe*
- *6 months of historical data was provided*

Data Understanding

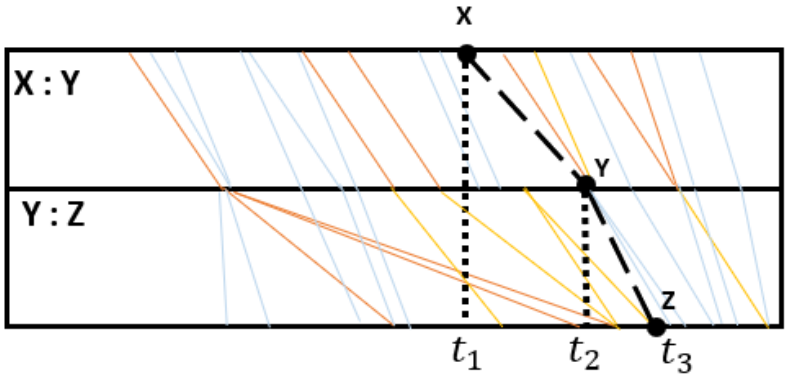
Converting Input Data to Event Logs

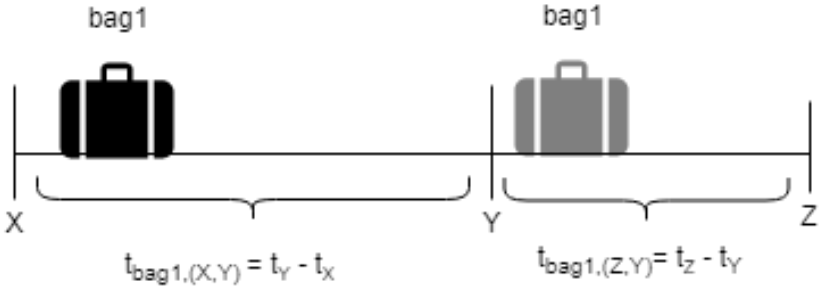


ID	Timestamp	Activity
1111111	21-05-19 13:44:54.948	X
1111111	21-05-19 13:45:42.760	Y
1111112	21-05-19 13:45:47.277	Y
1111112	21-05-19 13:49:21.290	Z

Data Understanding

Event Log Segmentation





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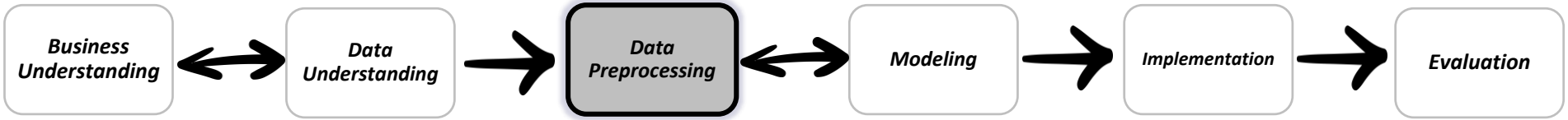
1111112	21-05-19 13:49:21.290	Z

ID	Timestamp	Activity	Duration(ms)
1111111	21-05-19 13:44:54.948	X:Y	48188
1111112	21-05-19 13:45:47.277	Y:Z	124013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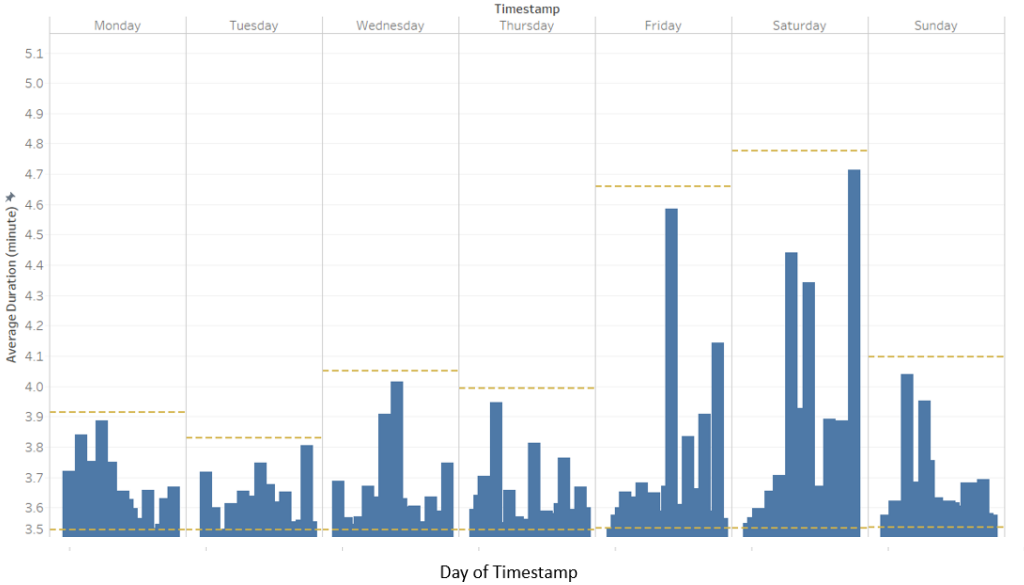
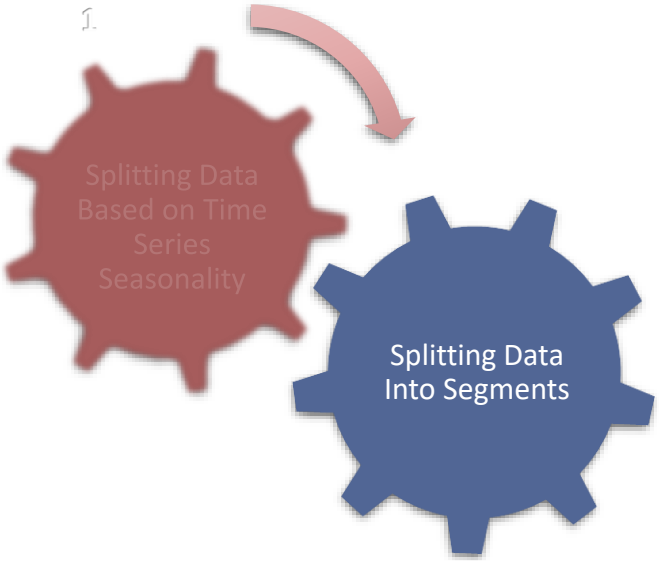
Data Preprocessing For Outlier Detection

Weekly seasonality

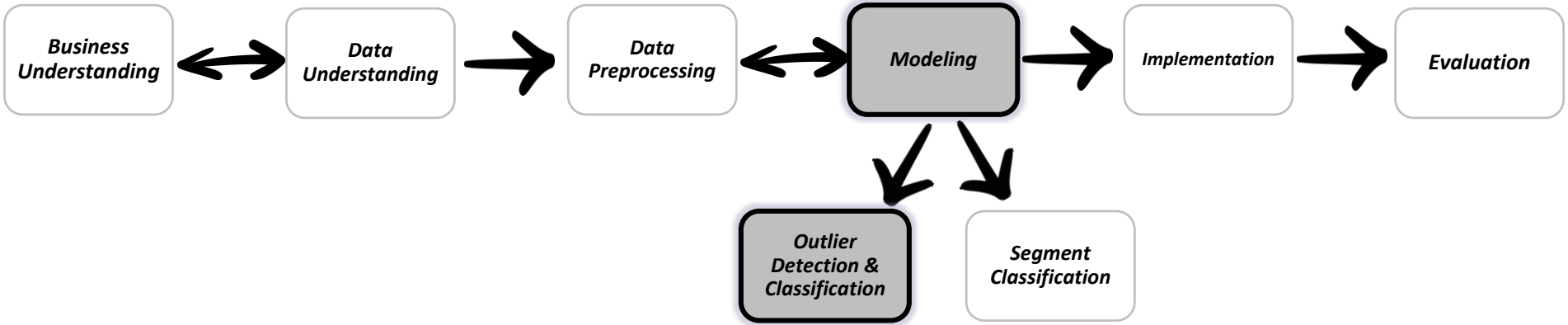


Data Preprocessing For Outlier Detection



	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Segment A							
Segment B							
Segment C							
Segment D							
⋮							

>2000 segments


Business Understanding
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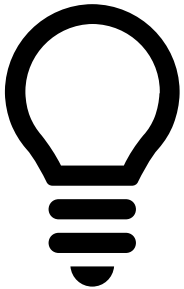
Outlier Detection & Classification
Segment Classification

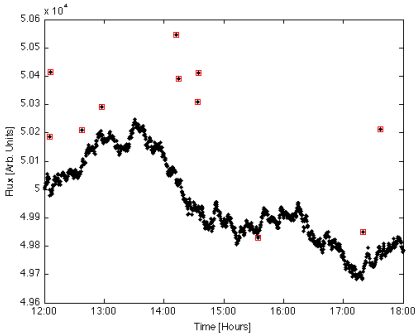


RQ1: Is it possible to have a general purpose technique that can automatically identify performance related deviations within the performance spectrum?

Outlier Detection Methods

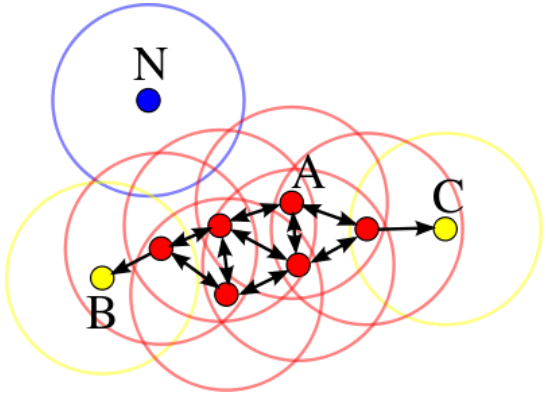
Basic Statistical Methods:

1. IQR (Box Plot)
2. 3 Sigma
3. Grubb's Test
4. Histograms
5. **Modified Z-score method**
6. Z-Score



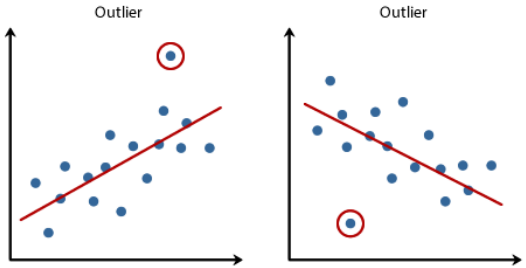
Proximity Based Methods:

1. K-Nearest Neighbor
2. K-means
3. K-medoids



Other Methods:

1. Linear Regression
2. Neural Networks
3. STL
4. Isolation Forests



Modified Z-score method

! Good for detecting univariate outliers

! Median is a robust statistic, meaning it will not be greatly affected by outliers

We can calculate the Modified Z-score * like this:

$$M_i = \frac{0.6745(x_i - \tilde{x})}{MAD}$$

$$MAD = \text{median}\{|x_i - \tilde{x}|\}$$

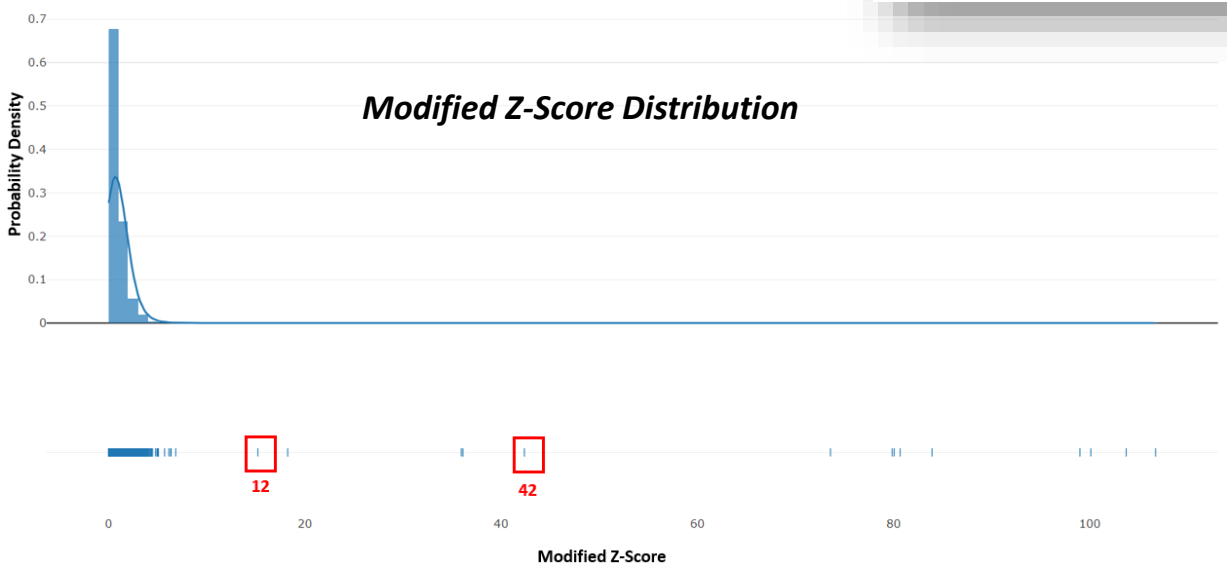
M_i > threshold ⟹ 1 (Outlier)

M_i < threshold ⟹ 0 (Normal Behaving Bag)

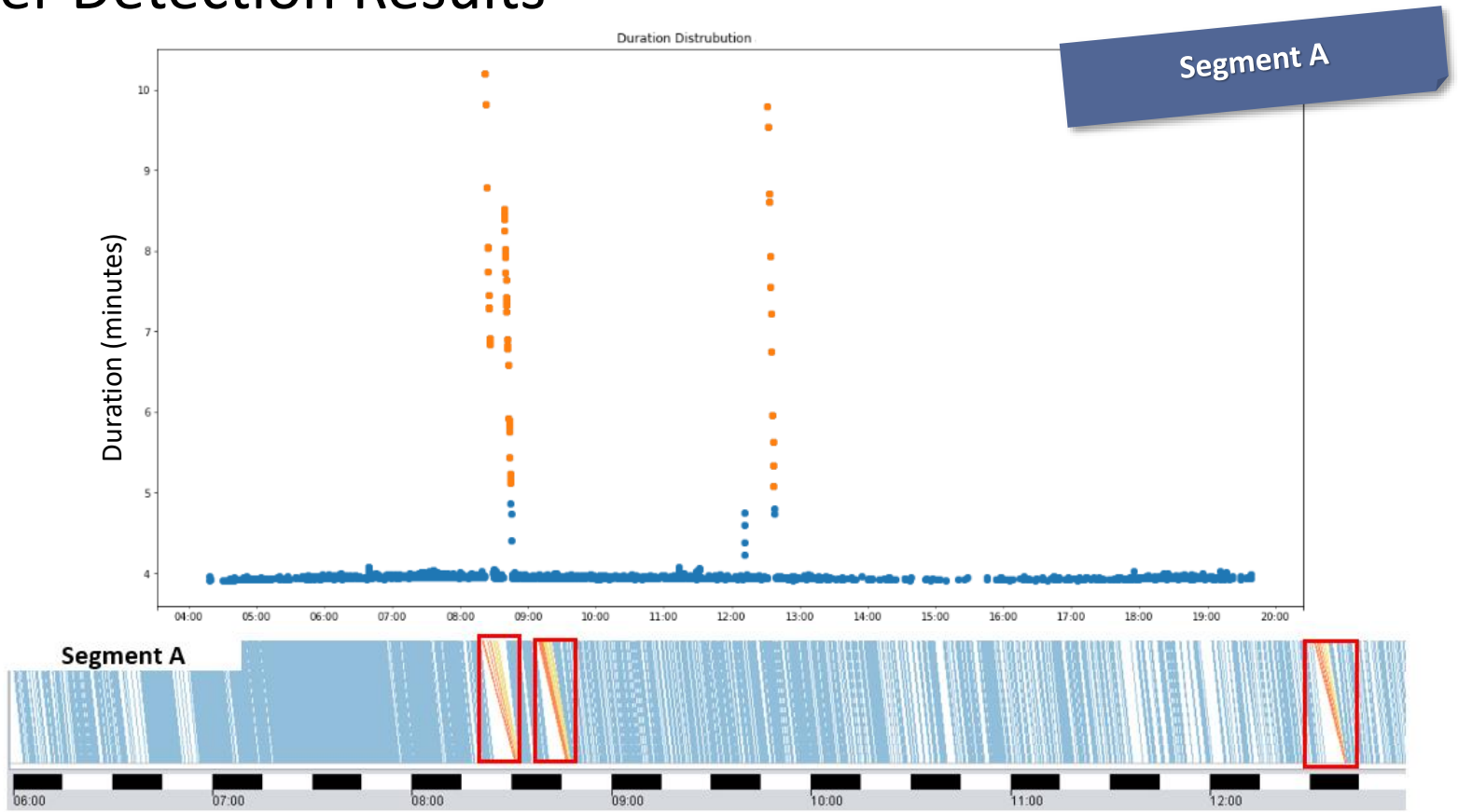
*Boris Iglewicz and David Hoaglin (1993), "Volume 16: How to Detect and Handle Outliers", The ASQC Basic References in Quality Control: Statistical Techniques, Edward F. Mykytka, Ph.D., Editor.

Outlier Scoring

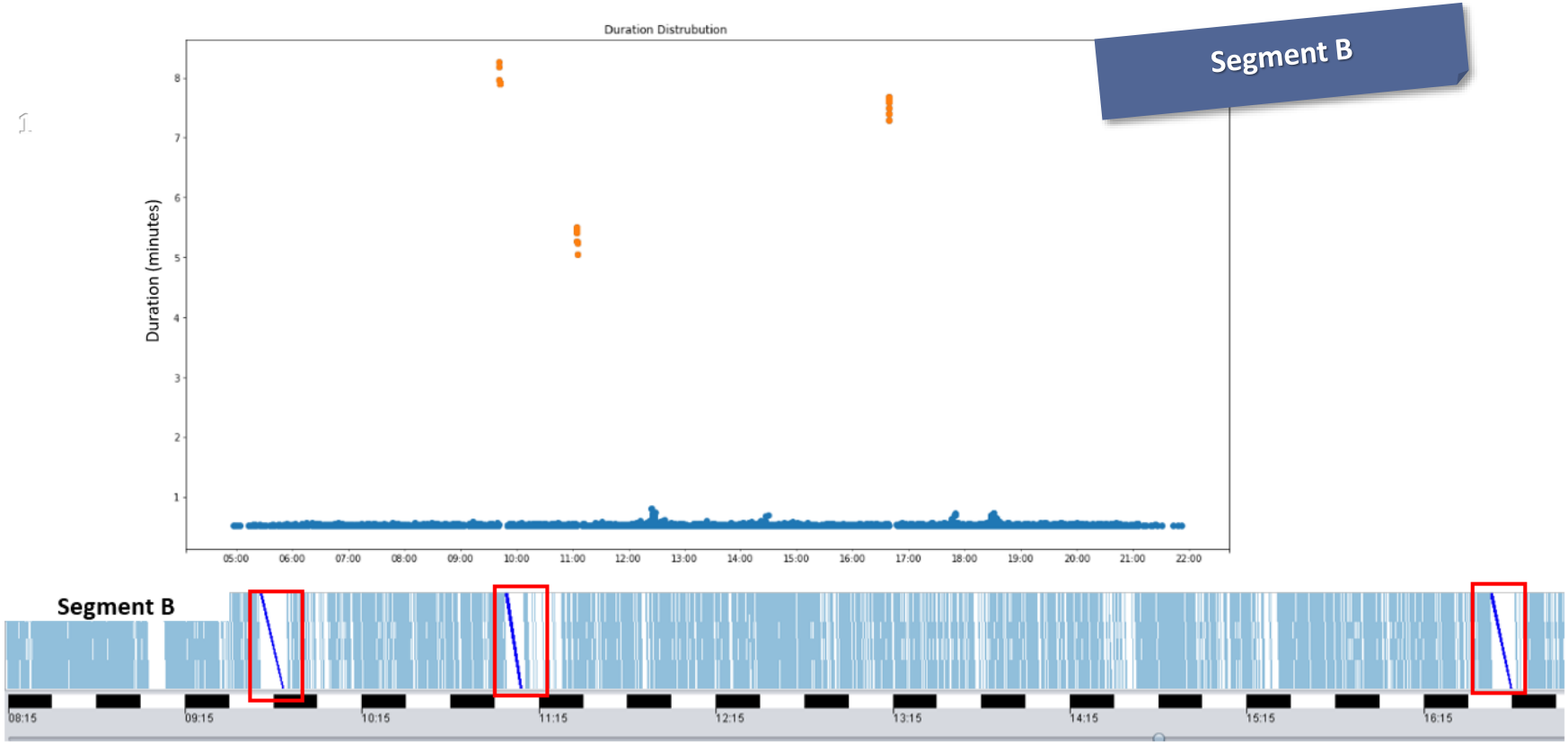
Bag ID	Timestamp	Activity	Duration (minute)	Outlier	Modified Z-Score
100000	2019-05-21 07:41:05.782	Segment A	3.497	0	0.630
100001	2019-05-21 08:13:34.145	Segment A	3.584	0	1.369
100002	2019-05-21 09:10:24.856	Segment A	7.321	1	542.124
100003	2019-05-21 09:15:14.154	Segment A	4.949	1	106.712
...	...	...	...	...	...
110000	2019-05-21 08:13:11.114	Segment B	0.555	0	0.072
110001	2019-05-21 10:14:17.412	Segment B	8.256	1	786.423



Outlier Detection Results

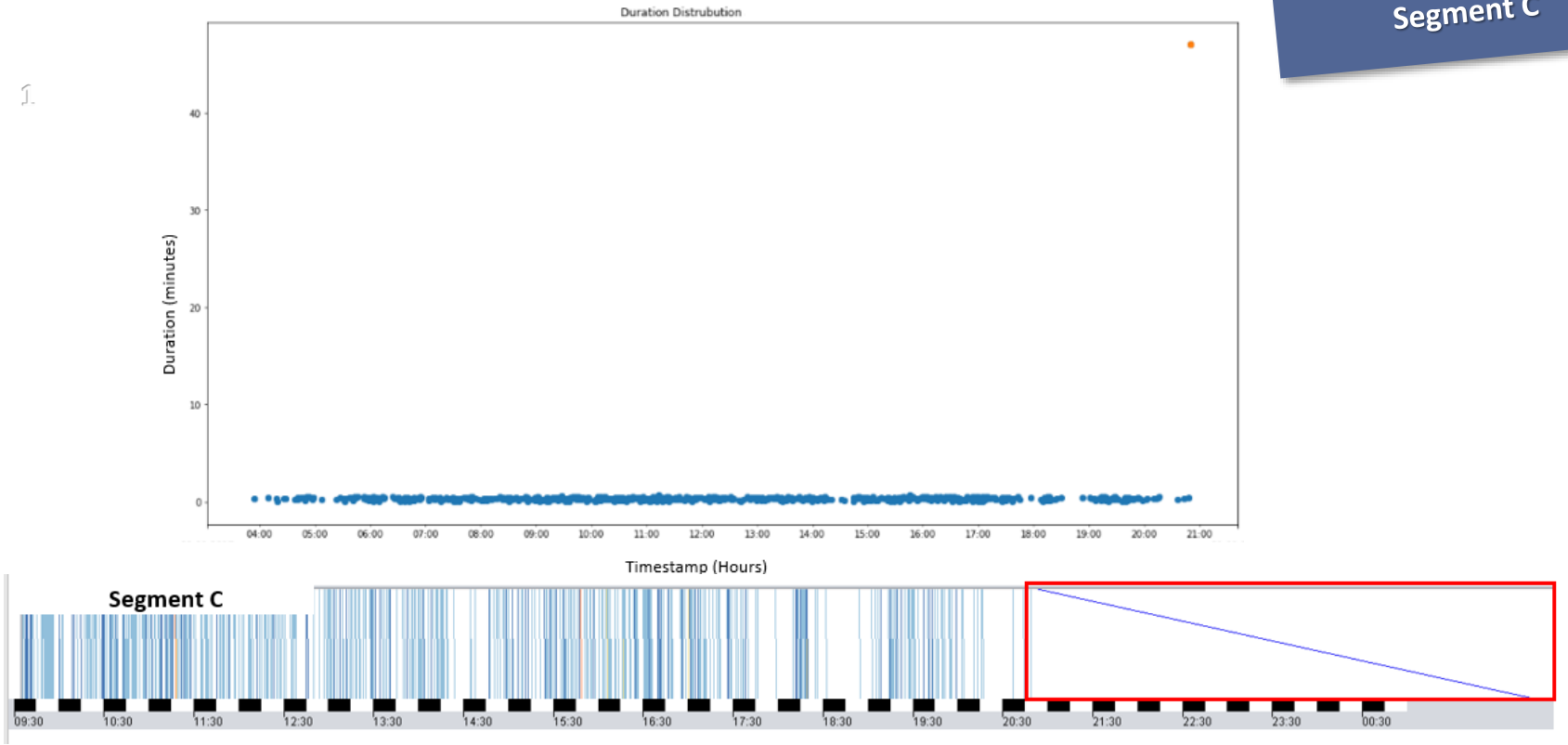


Outlier Detection Results

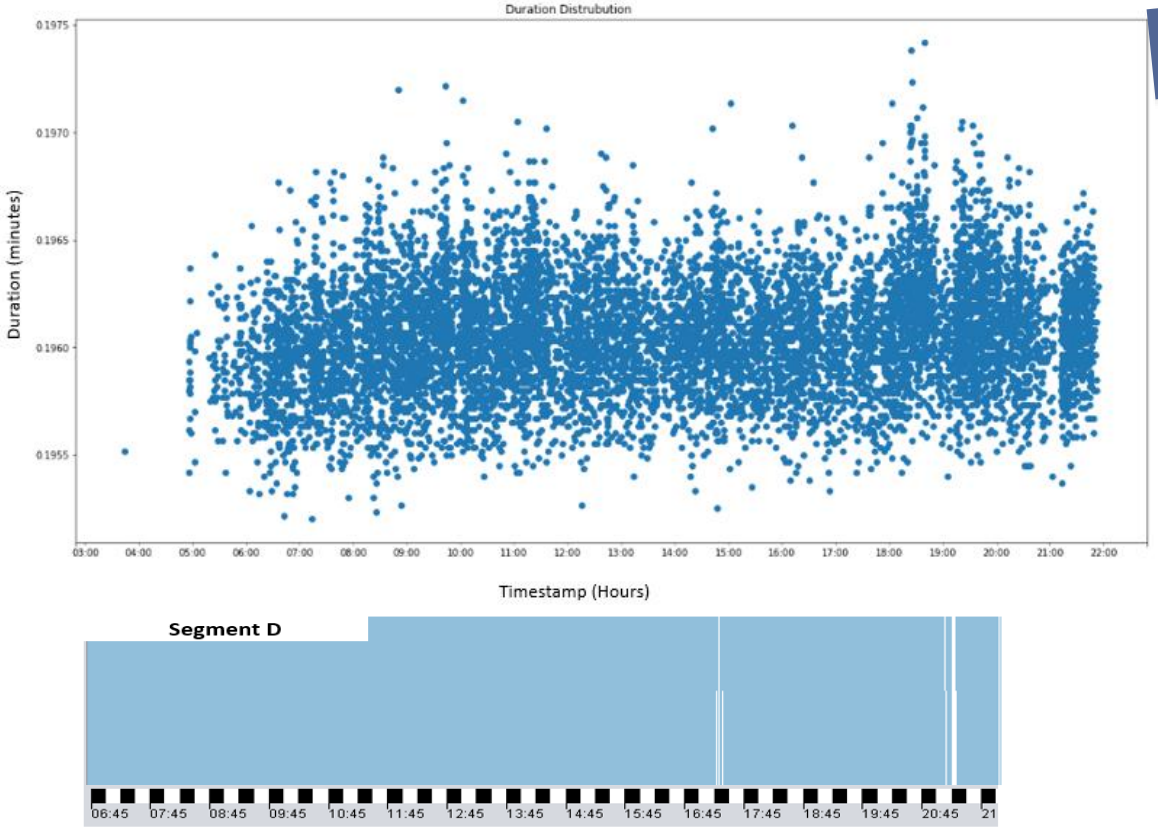


Outlier Detection Results

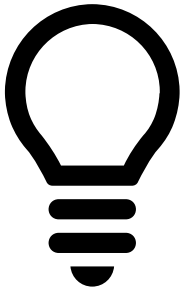
Segment C



Outlier Detection Results



Segment D



RQ2: Can we find patterns of outlier behavior and which outlier patterns make sense for the system?

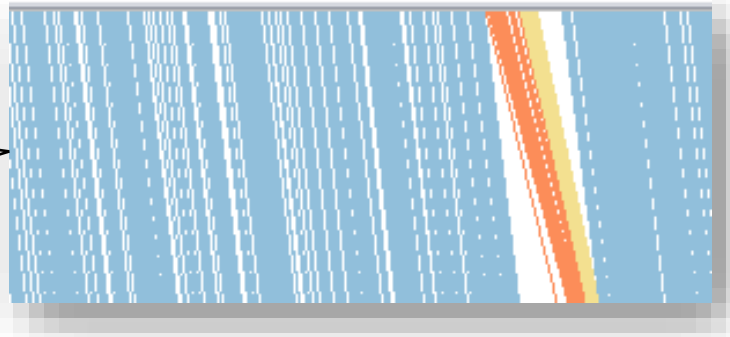
Outlier Classification

1 Blocking bags

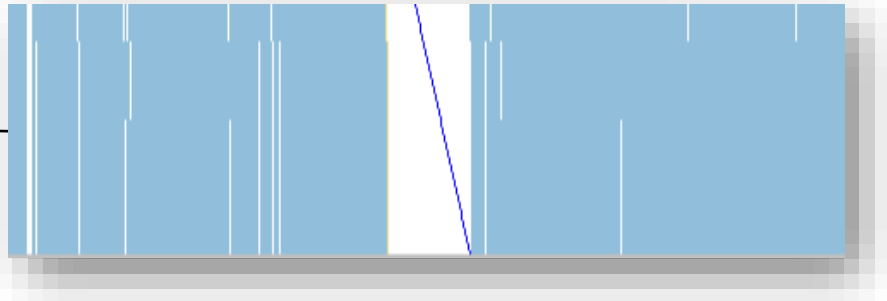
2 Stuck bags

3 Isolated bags

4 Fast bags



Blockage



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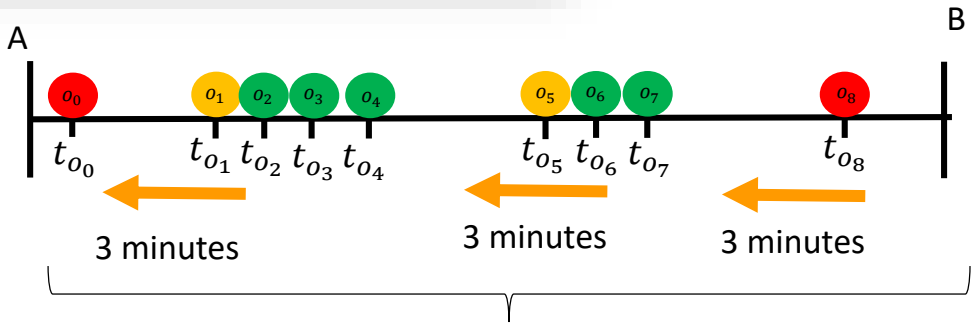
Outlier Classification

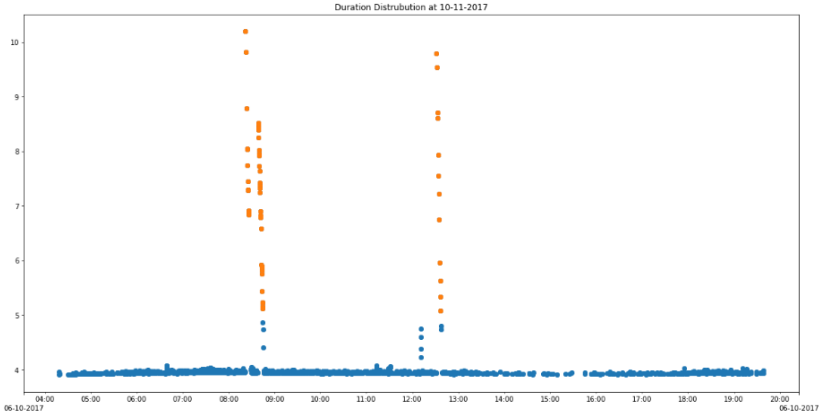
Timestamp	Activity	CaseID	Duration (Minute)	Blockage Duration (Minute)	Outlier Type
2019-05-21 07:41:05.782	Segment A	10000000	1.8036	1,095	1
2019-05-21 07:41:42.772	Segment A	10000001	1.7031	1,095	0
2019-05-21 07:42:05.623	Segment A	10000002	1.7028	1,095	0
2019-05-21 07:42:27.920	Segment A	10000003	0.1034	0	3
2019-05-21 07:42:30.457	Segment A	10000004	1.1077	0	2
....	...	...	...	...	...
2019-05-21 10:47:11.800	Segment B	11000001	2.0427	0	3
2019-05-21 10:47:12.851	Segment B	11000002	2.0426	0	3

Blocking bag (1)
Stuck bag (0)
Isolated bag (2)

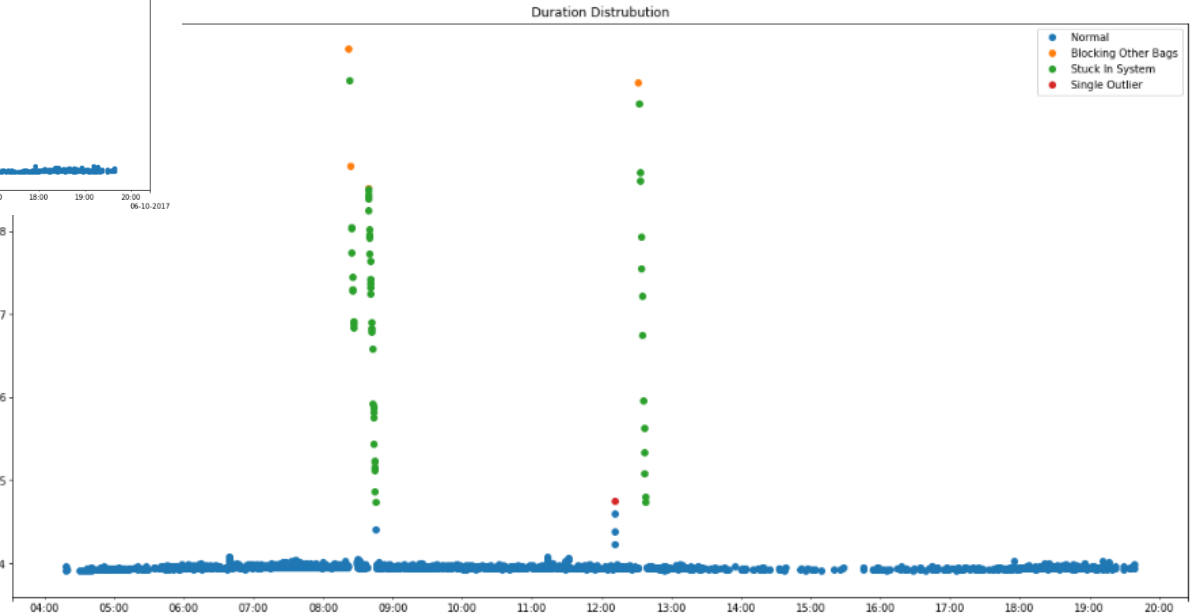


All detected outliers in the segment ($\boldsymbol{Outlier\ List(O)}$)

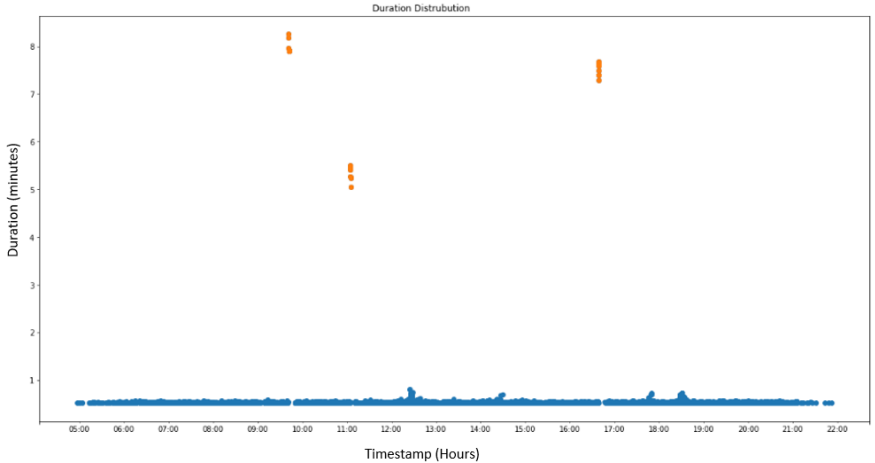
Result of the Outlier Classification



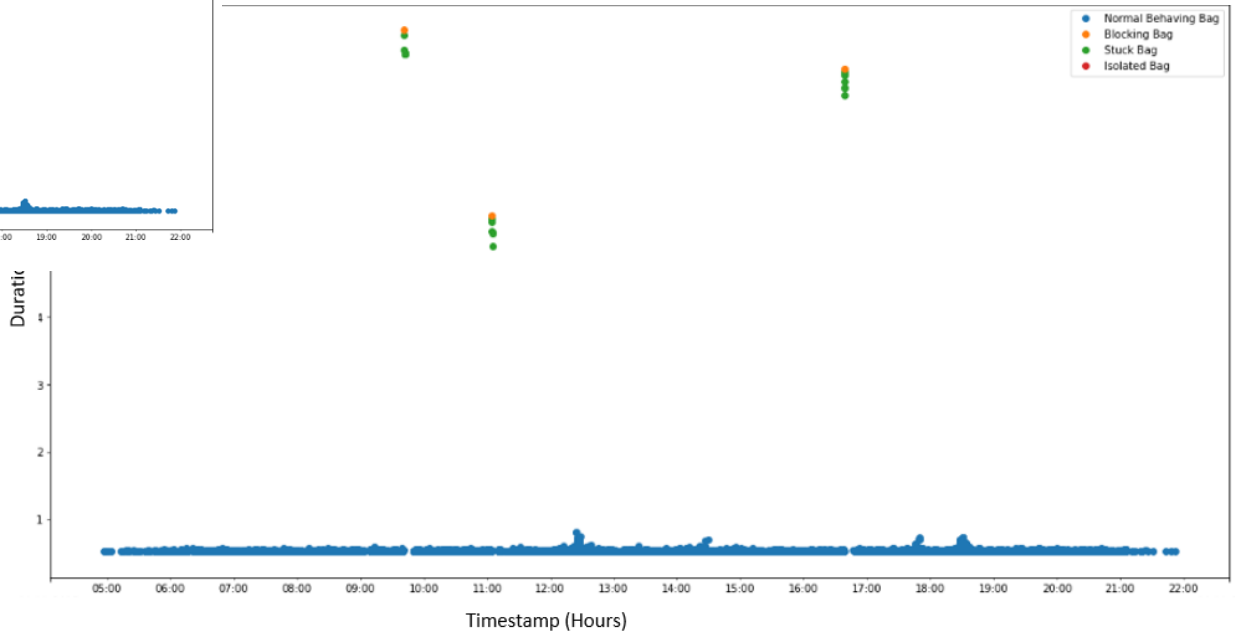
Segment A



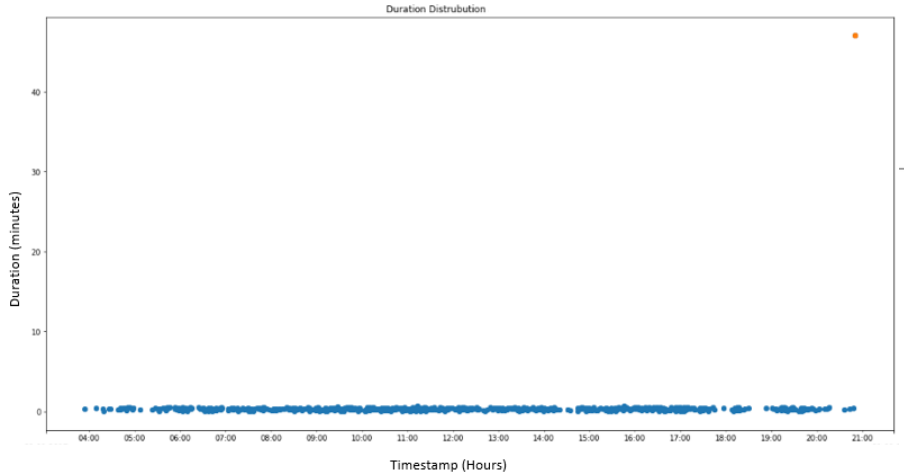
Result of the Outlier Classification



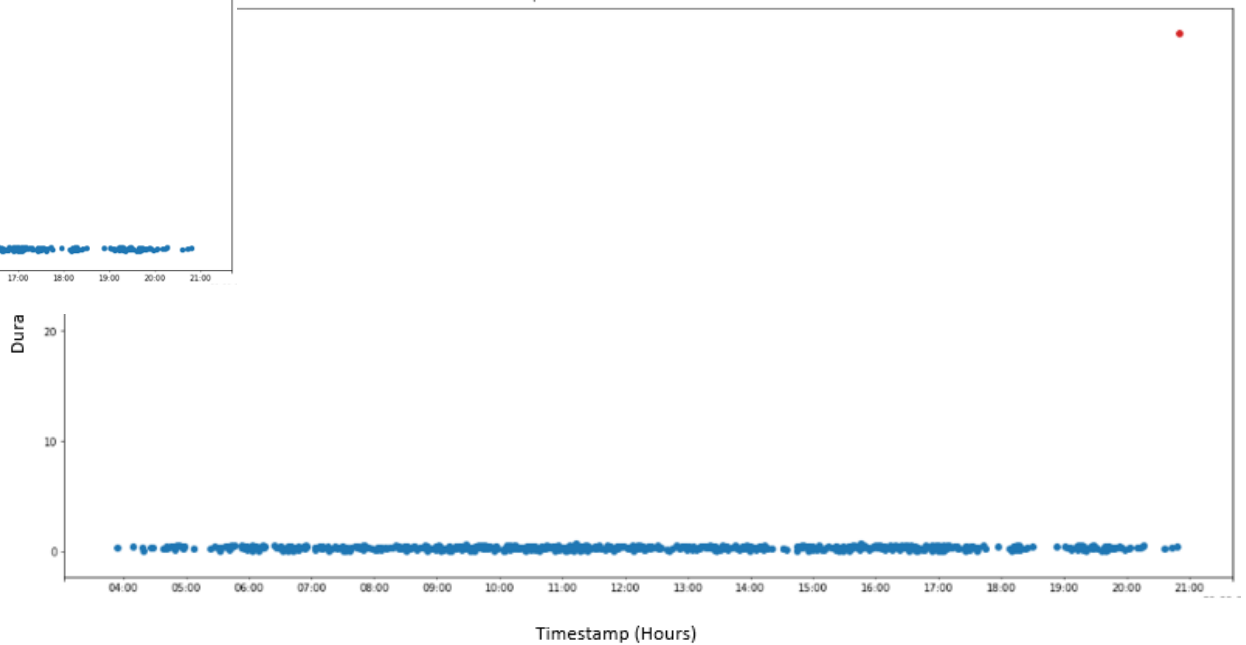
Segment B



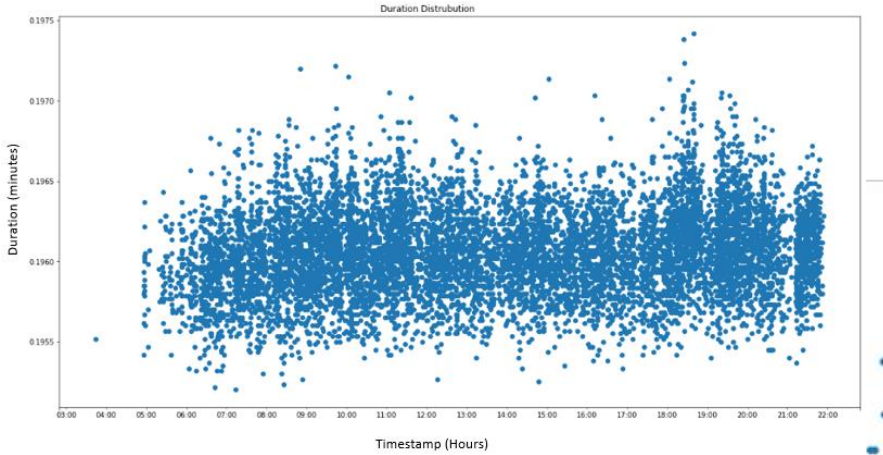
Result of the Outlier Classification



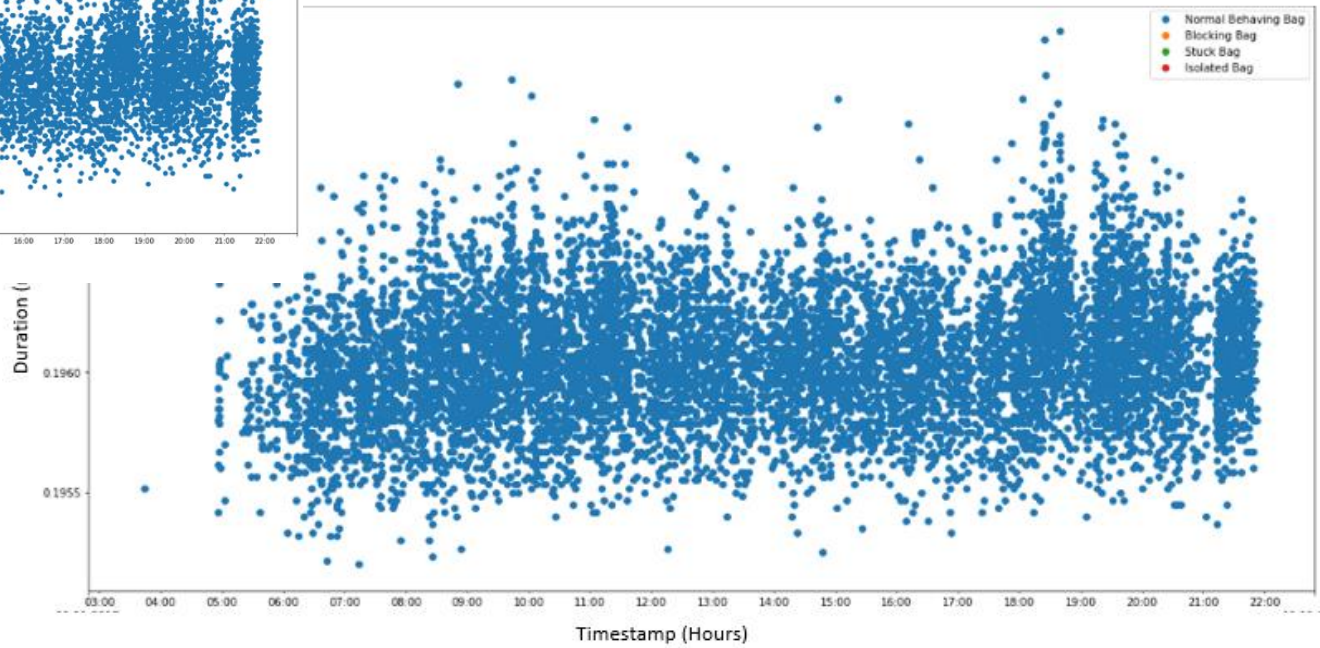
Segment C



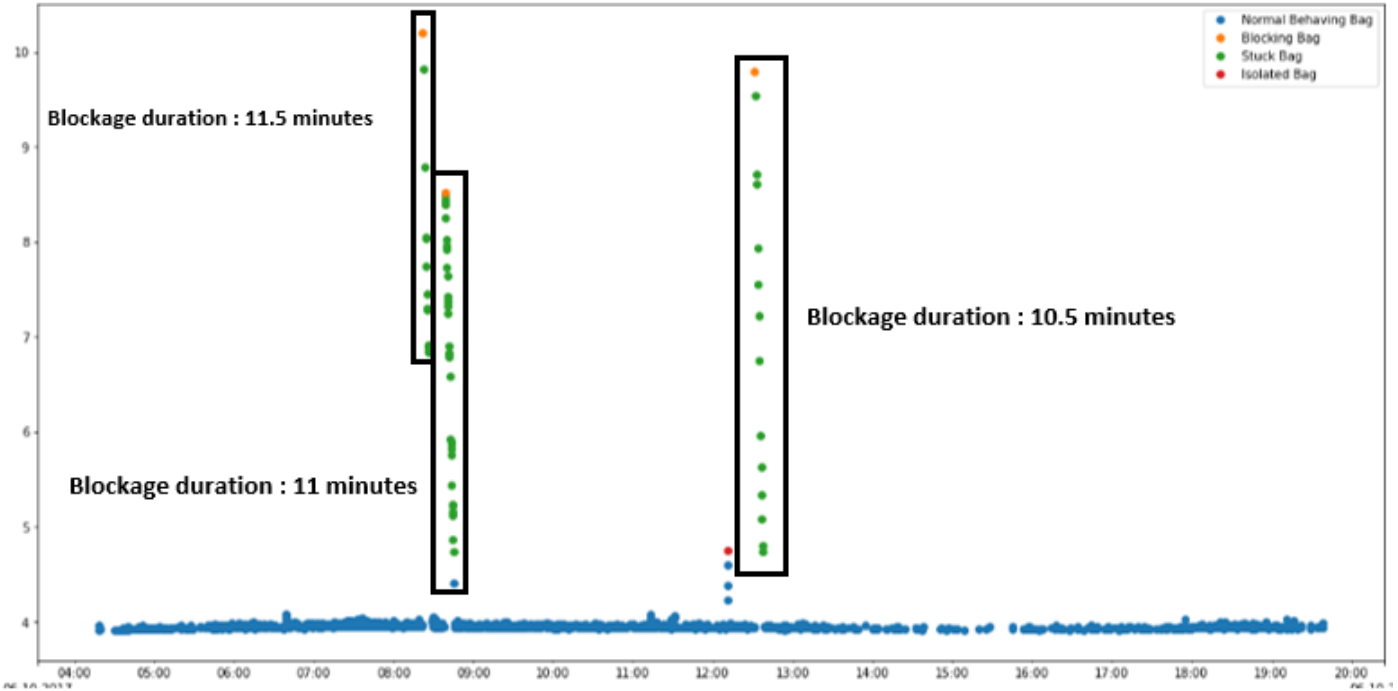
Result of the Outlier Classification

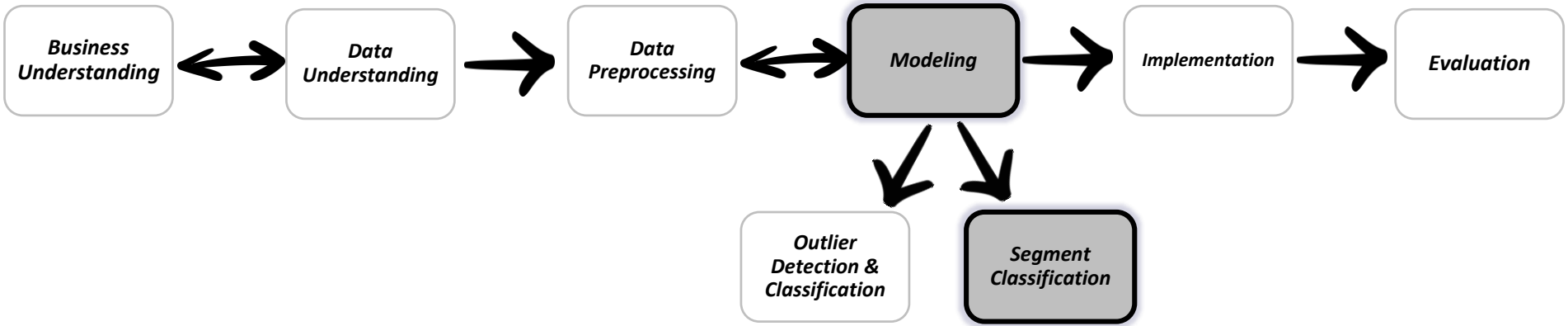


Segment D



Blockage Attribute Detection

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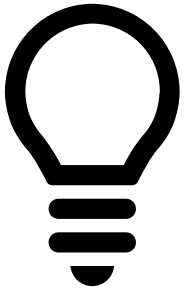


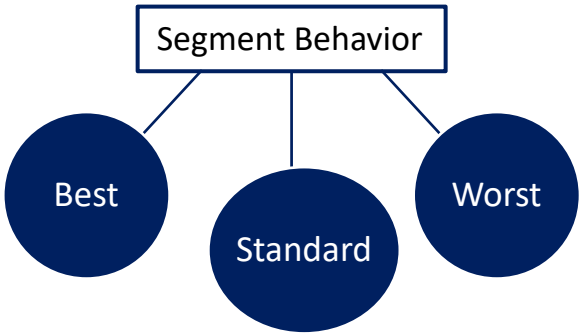
RQ3: Can all states of normal performance behavior for each segment and over multiple segments of the system be identified?

Segment Behavior Classification

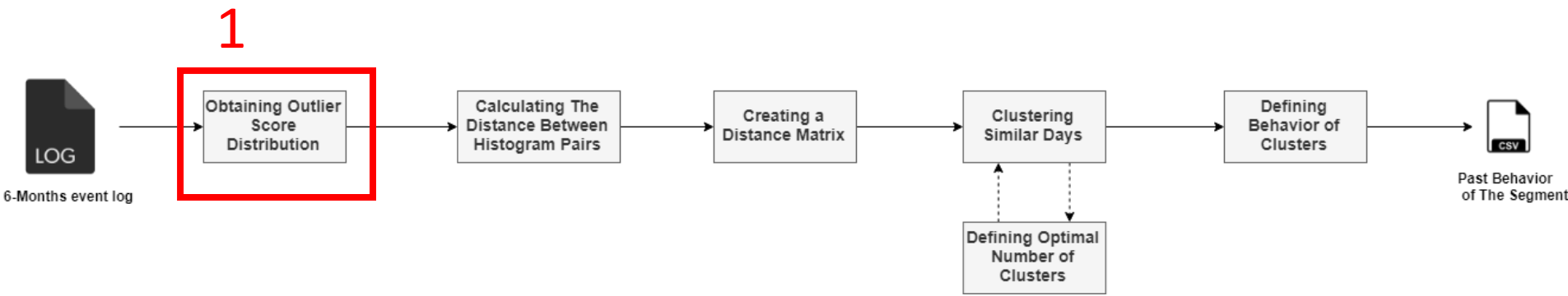
?

Given any day, how bad the segment behaves compared to **other days**?

Ground truth about the types of outlier behavior in the baggage handling system.

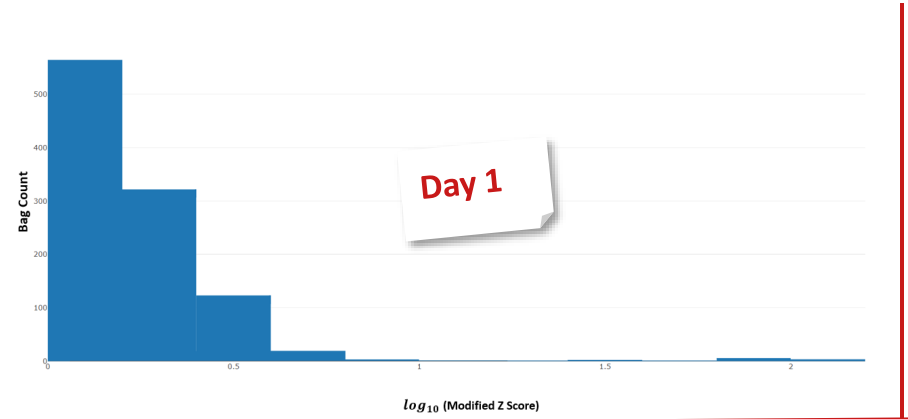


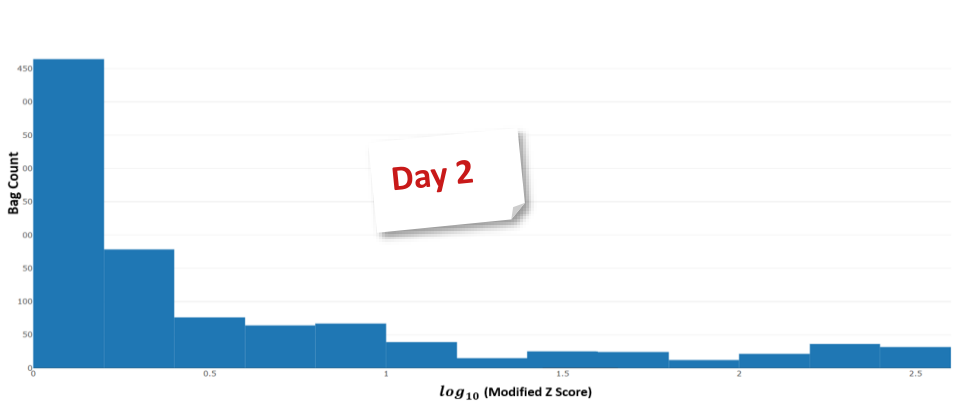
Segment Behavior Classification

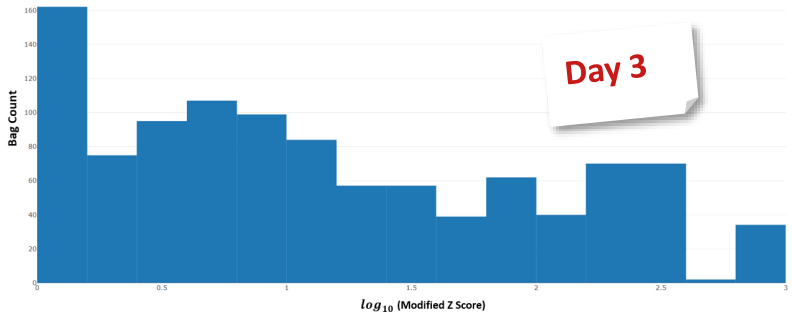


Obtaining Outlier Score Distribution

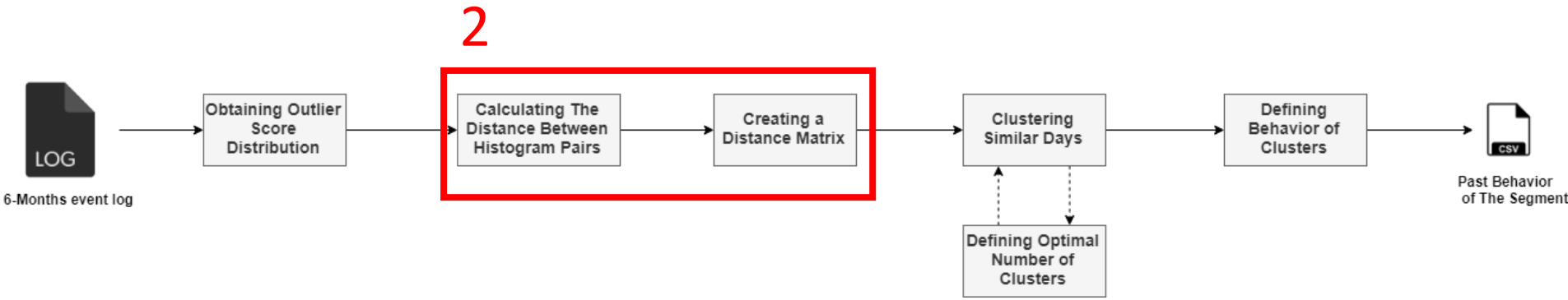
Daily distributions of outlier scores for segment A & Fridays:







Segment Behavior Classification



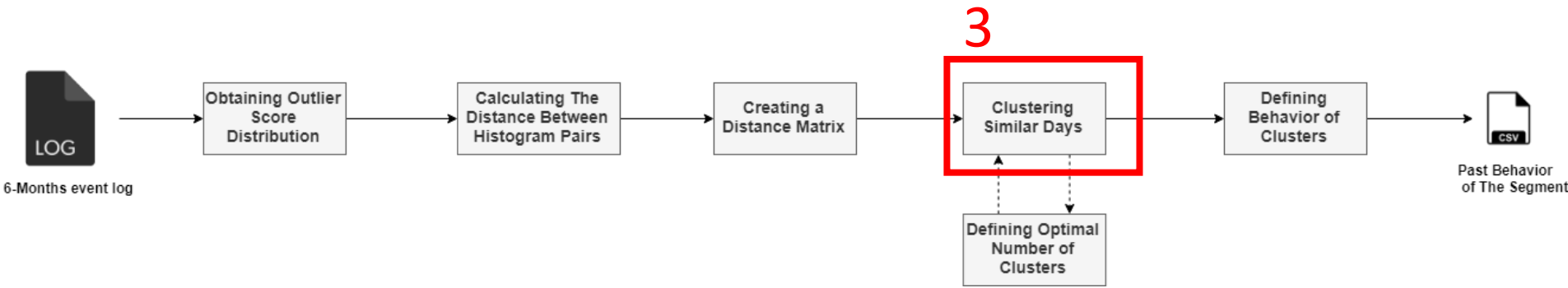
Calculating Distance Between Histograms of Outlier Score

For *each segment & weekday* :

	Day 1	Day 2	Day 3	…	Day 26
Day 1	0	0.78	1.52	…	1.96
Day 2		0	0.53	…	0.72
Day 3			0	…	0.085
⋮				0	…
Day 26				…	0

Wasserstein metric is used to calculate the distance between two histograms

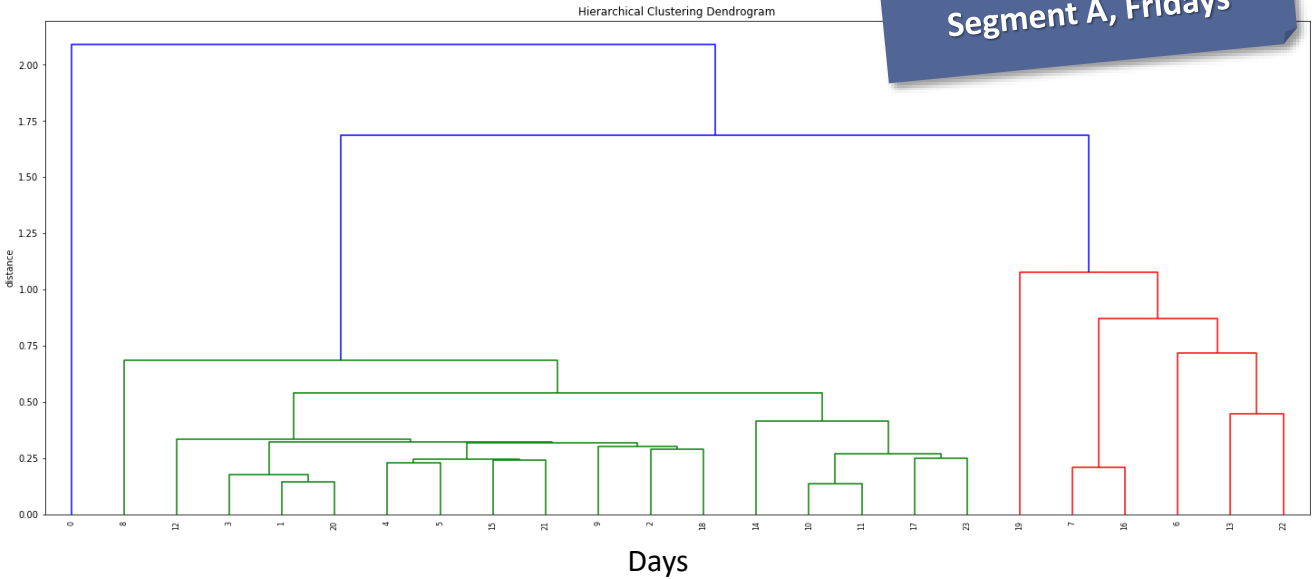
Segment Behavior Classification



Clustering the Similar Days of the Segment

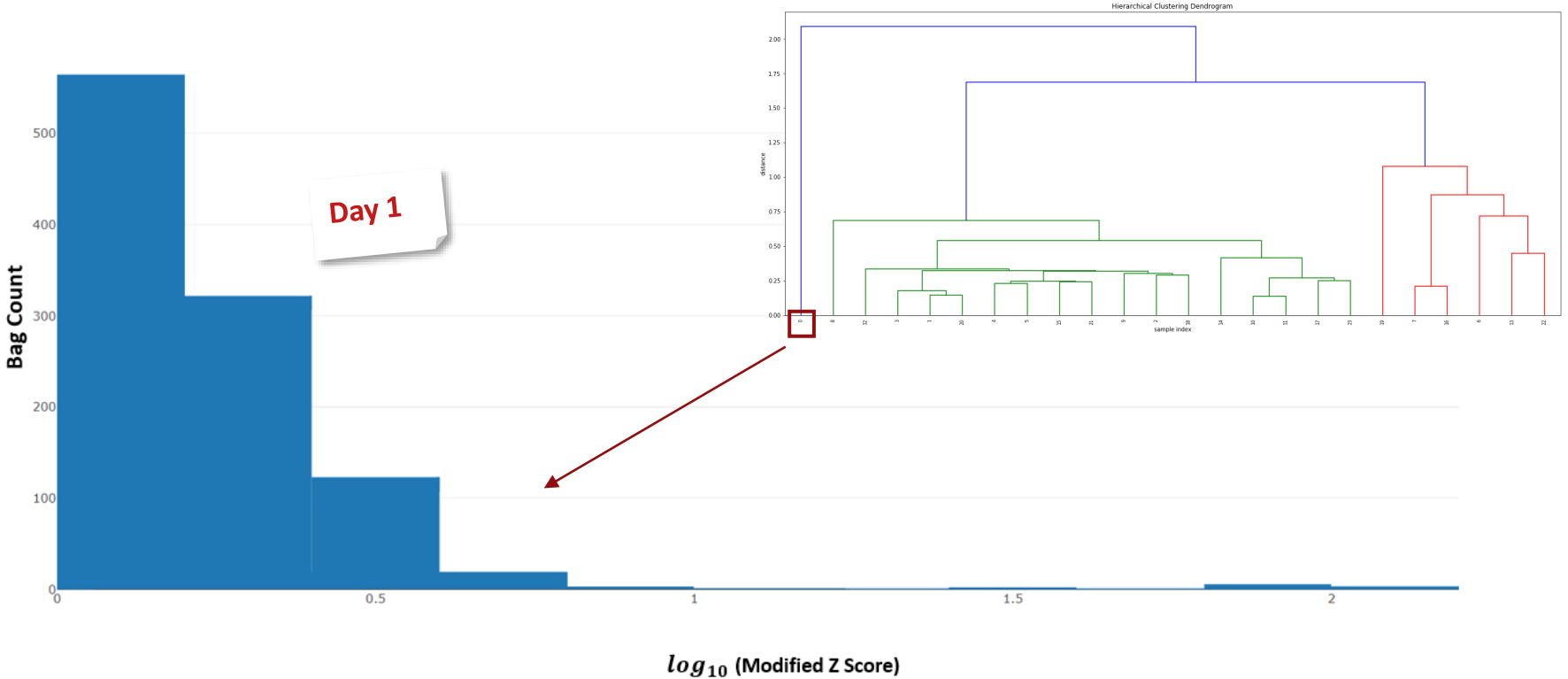
1. *Which sets of days are similar for the system?*

2. *Which types of outlier behaviors the system shows regarding the clusters of similar outlier behaviors?*

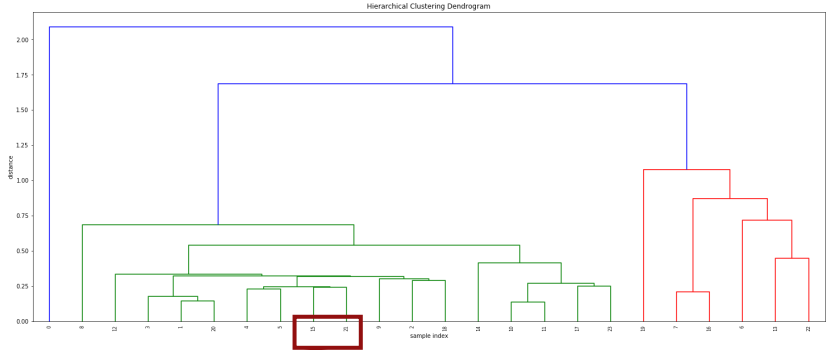


Agglomerative Clustering is used to group similar days together

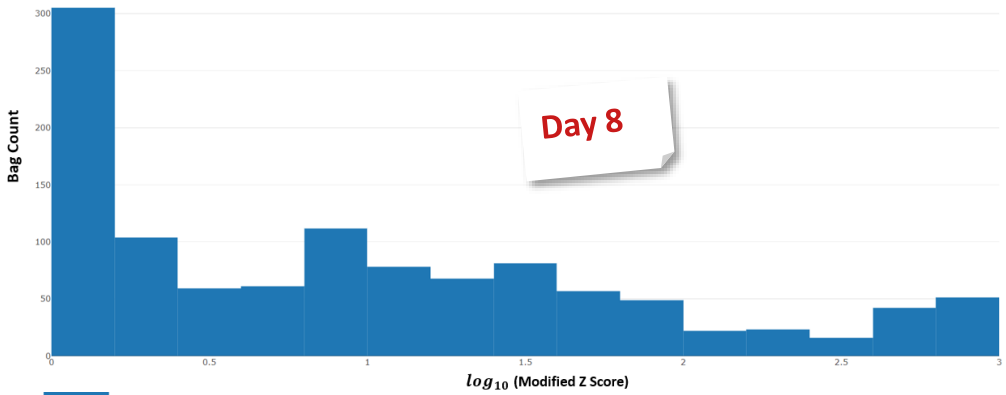
Clustering the Similar Days of the Segment

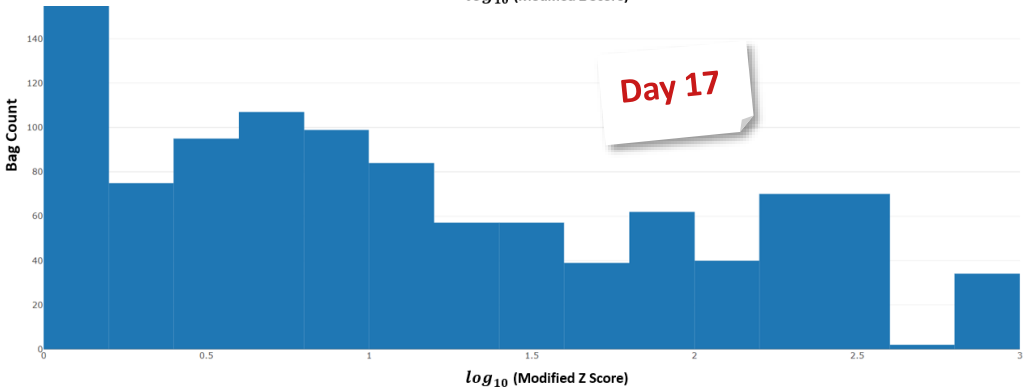


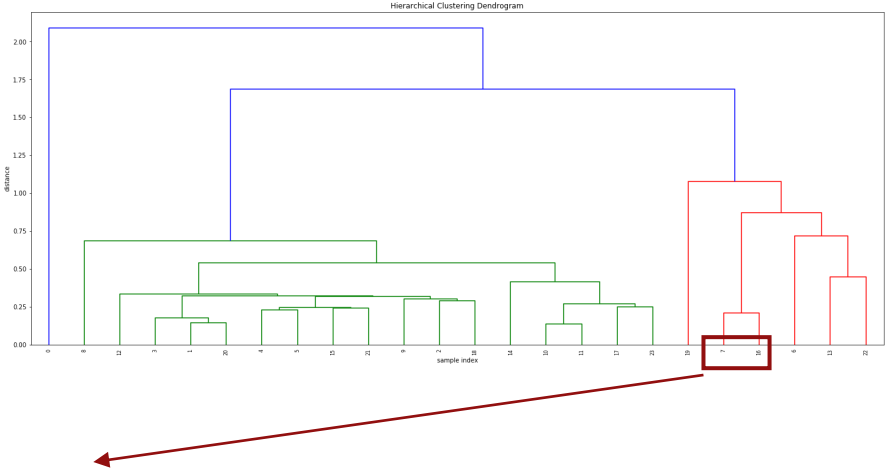
Clustering the Similar Days of the Segment



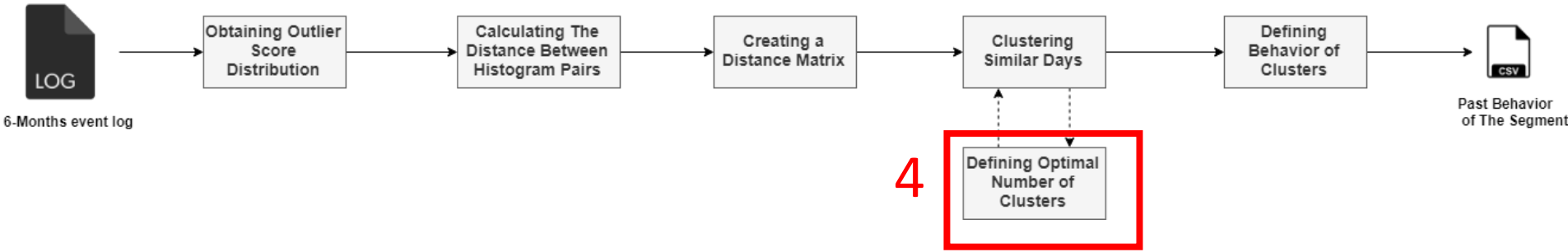
Clustering the Similar Days of the Segment



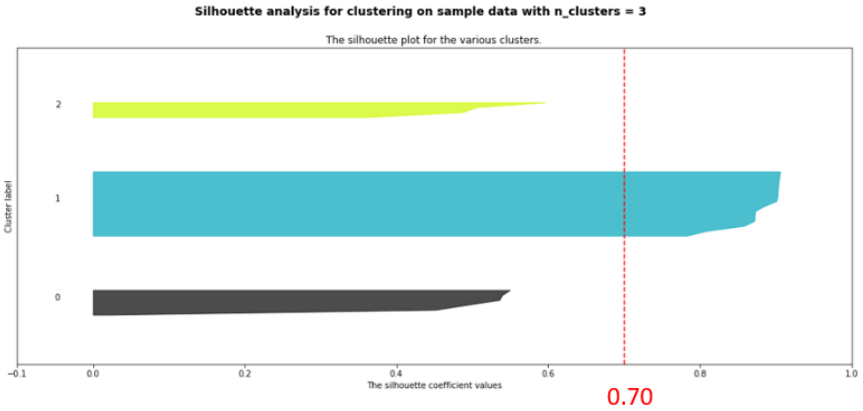




Segment Behavior Classification

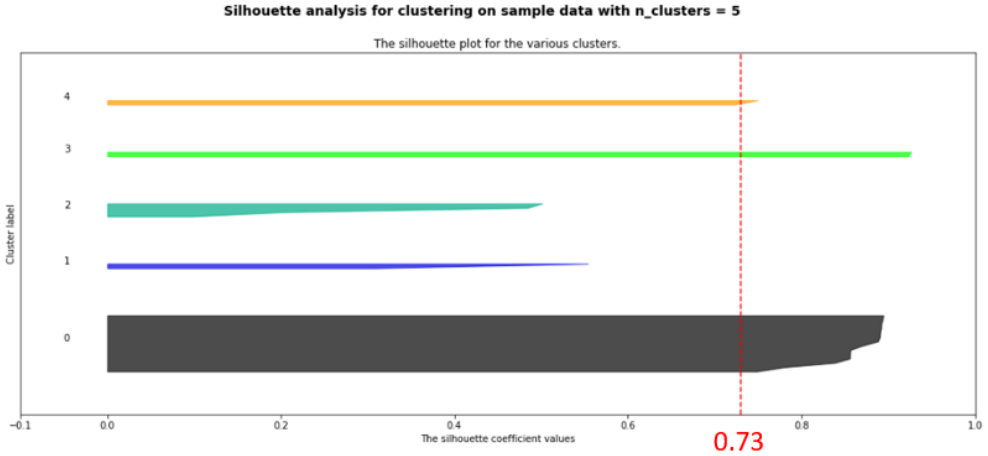


Defining Optimal Number of Clusters



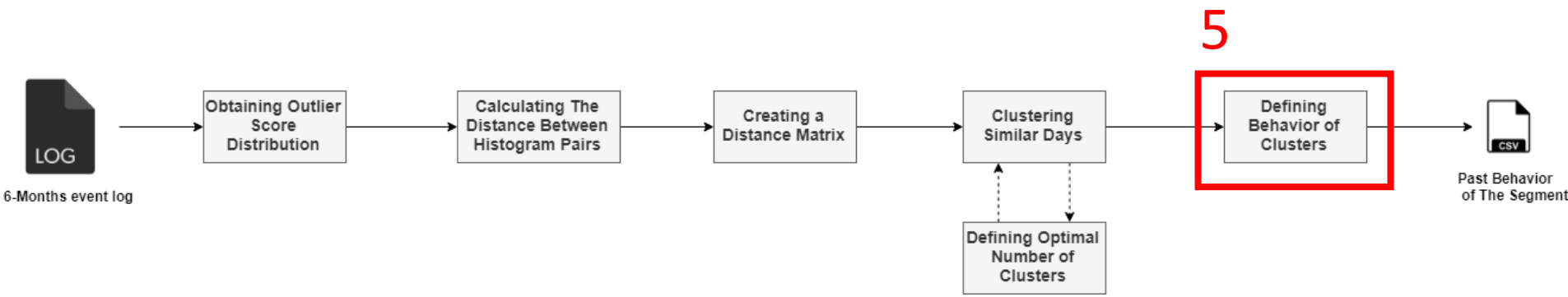
Number of clusters=3

Number of clusters=5



We compare ***average silhouette scores***

Segment Behavior Classification



Defining the Behavior of Clusters

Cluster standardized rank = $\frac{Cluster\ rank}{number\ of\ clusters}$

Cluster	Distribution	Average Outlier Score	Minimum Outlier Score	Maximum Outlier Score	Bag Count	Day Count	Cluster Rank	Cluster Standardized Rank
0	[1.7, 0.3, ….,0.16]	2.25	0	119.43	39498	14	1	0.2 → $\frac{1}{5}$ → Best- Behaving Cluster
1	[1.94, 1.69, ….,0.52]	2.47	0	892.28	6040	2	2	0.4 → $\frac{2}{5}$
2	[0.64, 0.45, ….,1.99]	28.26	0	10863.28	13092	4	4	0.8 → $\frac{4}{5}$
3	[41.09, 97.36, ….,23.04]	55.83	0	92796.62	8407	2	5	1 → $\frac{5}{5}$ → Worst Behaving Cluster
4	[1.09, 1.51, ….,0.14]	4.48	0	2087.33	4393	2	3	0.6 → $\frac{3}{5}$

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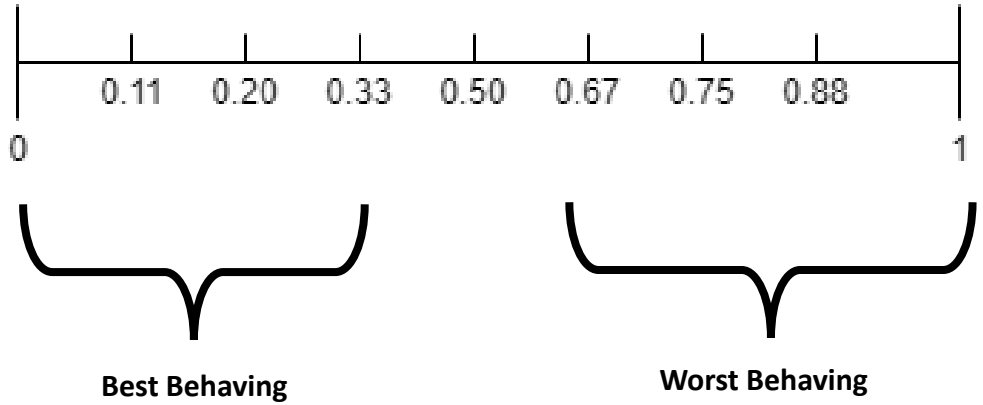
Defining the Behavior of Clusters

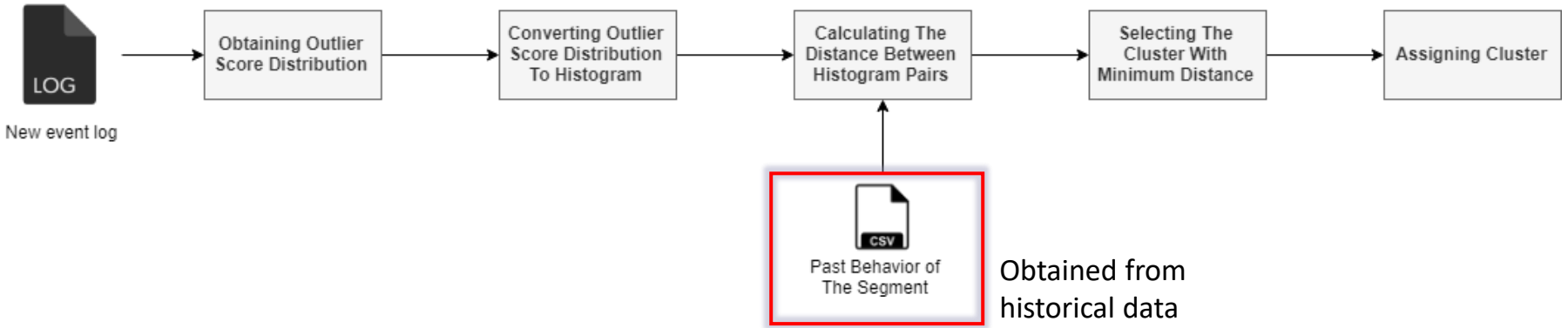
3 Clusters	4 Clusters	5 Clusters		10 Clusters
1/3 2/3 3/3	1/4 2/4 3/4 4/4	1/5 2/5 3/5 4/5 5/5	……..	1/10 …… 10/10

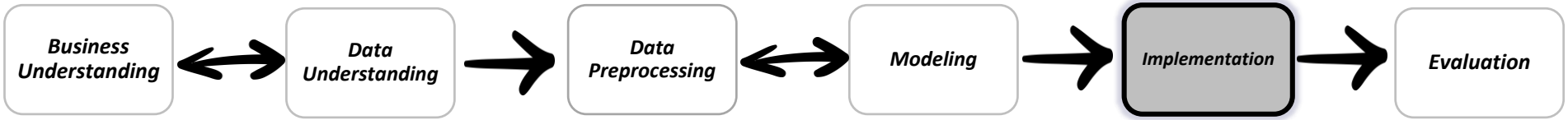


Assigning Appropriate Cluster to Daily Outlier Behavior

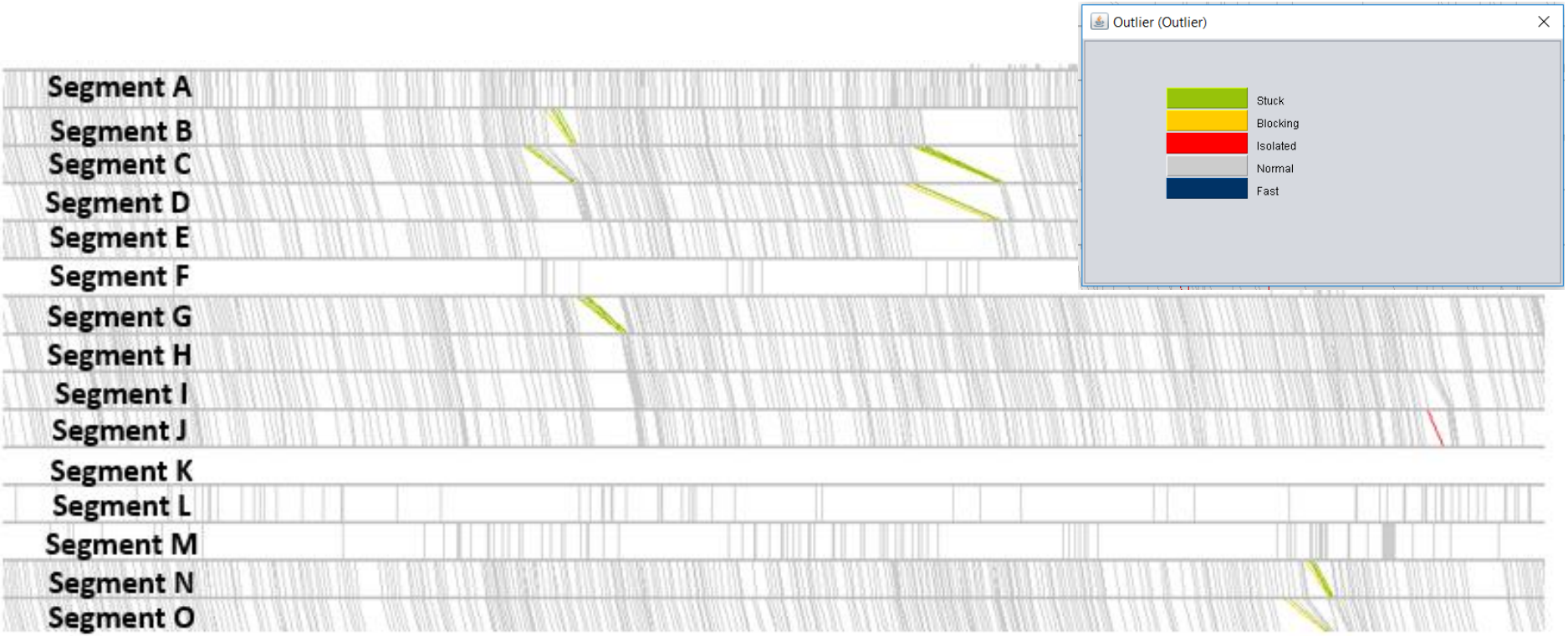
1. For the new (day,segment) pair, find the cluster that is most similar regarding its modified Z-score distribution.

2. The normalized rank of this most similar cluster is the severity of the outlier behavior on that day.

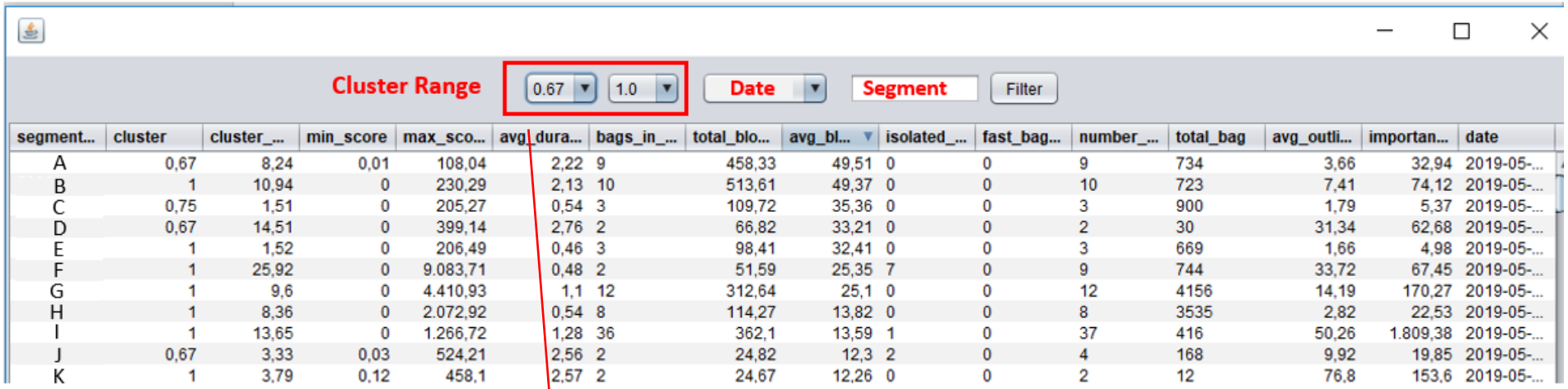



Business Understanding
Data Understanding
Data Preprocessing
Modeling
Implementation
Evaluation

Implementation of the Outlier Classifier In the PSM



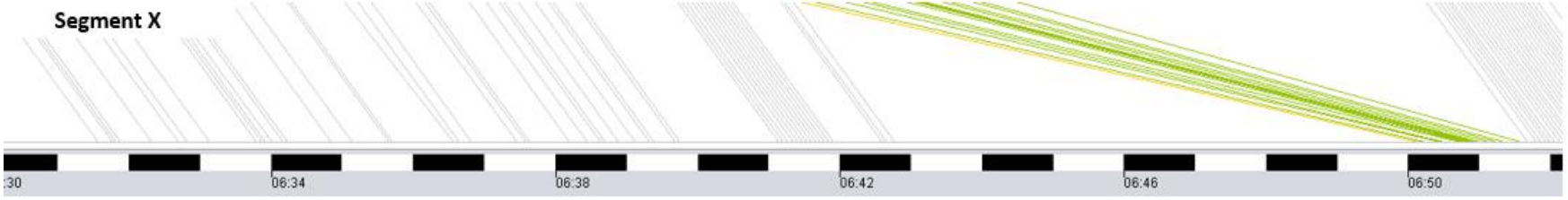
Visual Dashboard for Problematic Segments



segment...	cluster	cluster_...	min_score	max_sco...	avg_dura...	bags_in_...	total_blo...	avg_bl...	isolated_...	fast_bag...	number_...	total_bag	avg_outli...	importan...	date
A	0,67	8,24	0,01	108,04	2,22	9	458,33	49,51	0	0	9	734	3,66	32,94	2019-05-...
B	1	10,94	0	230,29	2,13	10	513,61	49,37	0	0	10	723	7,41	74,12	2019-05-...
C	0,75	1,51	0	205,27	0,54	3	109,72	35,36	0	0	3	900	1,79	5,37	2019-05-...
D	0,67	14,51	0	399,14	2,76	2	66,82	33,21	0	0	2	30	31,34	62,68	2019-05-...
E	1	1,52	0	206,49	0,46	3	98,41	32,41	0	0	3	669	1,66	4,98	2019-05-...
F	1	25,92	0	9.083,71	0,48	2	51,59	25,35	7	0	9	744	33,72	67,45	2019-05-...
G	1	9,6	0	4.410,93	1,1	12	312,64	25,1	0	0	12	4156	14,19	170,27	2019-05-...
H	1	8,36	0	2.072,92	0,54	8	114,27	13,82	0	0	8	3535	2,82	22,53	2019-05-...
I	1	13,65	0	1.266,72	1,28	36	362,1	13,59	1	0	37	416	50,26	1.809,38	2019-05-...
J	0,67	3,33	0,03	524,21	2,56	2	24,82	12,3	2	0	4	168	9,92	19,85	2019-05-...
K	1	3,79	0,12	458,1	2,57	2	24,67	12,26	0	0	2	12	76,8	153,6	2019-05-...

Showing the worst behaving segments for the given day based on the historical analysis

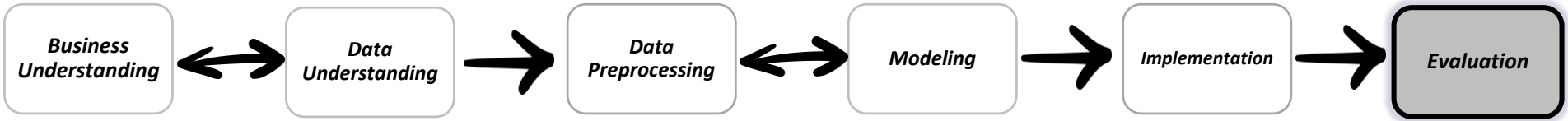
Visual Dashboard for Problematic Segments



Segment: **Segment X** | Date: 2019-05-31

segmen...	Patter...	block...	count_...	avg_du...	blockage_start	blockage_end	date
X	80268...	10,19	14	7,94	2019-05-31 06:41:27.345	2019-05-31 06:51:39.036	2019-05-31
	80270...	8,15	2	8,08	2019-05-31 07:01:28.598	2019-05-31 07:09:37.484	2019-05-31
	80275...	3,44	8	2,32	2019-05-31 08:25:31.111	2019-05-31 08:28:57.394	2019-05-31
	80277...	4,97	4	4,35	2019-05-31 08:46:27.562	2019-05-31 08:51:25.532	2019-05-31
	80280...	1,86	2	1,8	2019-05-31 09:35:15.128	2019-05-31 09:37:06.514	2019-05-31
	80286...	2,66	5	1,98	2019-05-31 11:01:12.645	2019-05-31 11:03:52.359	2019-05-31
	80291...	2,04	5	1,8	2019-05-31 12:24:21.054	2019-05-31 12:26:23.723	2019-05-31

Blockage window shows the blockages in the segment


Business Understanding
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Identifying Abnormal Behavior and Providing Similar Outliers in Segments

1. Which bags show an abnormal behavior in the segments of the system?

Outliers	Non-Outliers
1.32%	98.68%

Outliers	Non-Outliers
12.792	958.149

Given new data, we find all outliers in each segment of the baggage handling system.

Identifying Abnormal Behavior and Providing Similar Outliers in Segments

2. Which outlier pattern does each bag belong to?

Blocking Bag	Stuck Bags	Isolated Bags	Fast Bags
18.05%	40.67%	38.95%	2.33%

Blocking Bag	Stuck Bags	Isolated Bags	Fast Bags
2.309	5.202	4.982	299

Given new data, bags are assigned with an outlier pattern in each segment of the baggage handling system

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Identifying Segments that Experience More Performance Problems

1. Which parts of the system suffer from the most significant abnormal behavior on the given day?

0.67 | 1.0 | 2019-05-31 | Filter

segment_name	cluster	cluster_mean	min_score	max_score	avg_duration_bags	bags_in_blockage	total_blockage_ti...	avg_blockage_ti...	isolated_bag_co...	fast_bag_count	number_of_outli...	total_bag	avg_outlier_score	importance
Segment A	1	1.042,58	0,06	31.441,87	1,24	6	19,95	3,66	2	7	15	30	3.780,99	22.685,96
Segment B	1	5.331,94	0	10.703,1	2,45	6	55,86	4,41	1	0	7	11	1.811,82	10.870,91
Segment C	1	89,97	0	435,5	0,05	67	203,82	0,07	0	0	67	191	143,43	9.609,78
Segment D	0,67	46,22	0	939,18	1,19	80	375,18	3,21	23	0	103	365	91,63	7.330,28
Segment E	0,67	66,23	0	4.955,38	0,04	214	434,7	0,07	47	0	261	2431	33,95	7.264,27
Segment F	0,67	42,15	0	1.205,21	1,28	68	320,64	3,56	23	0	91	313	95,34	6.483,21
Segment G	1	45,42	0	1.917,92	0,83	54	186,42	2,56	33	0	87	360	86,63	4.677,96
Segment H	1	58,06	0	1.405,4	1,34	33	181,21	4,07	10	0	43	164	126,18	4.164,04
Segment I	1	28,08	0	944,59	0,08	70	96,34	0,26	82	0	152	716	52,42	3.669,54
Segment J	1	118,46	0	170,27	0,05	50	25,03	0,07	117	0	167	367	67	3.350,15
Segment K	1	69,36	0	1.349,81	1,21	27	166,26	3,99	5	0	32	141	108,12	2.919,15
Segment L	1	46,92	0	20.346,24	0,14	17	45,17	2,42	6	0	23	903	129,21	2.196,53
Segment M	0,67	10,21	0	6.225,86	0,09	25	6,59	0,11	188	0	213	477	73,39	1.834,67
Segment N	1	13,65	0	1.266,72	1,28	36	362,1	13,59	1	0	37	416	50,26	1.809,38
Segment O	0,8	17,95	0,32	1.716,29	2,32	4	28,03	2,99	0	0	4	9	361,12	1.444,47
Segment P	0,75	20,69	0	1.120,59	0,06	37	55,86	0,17	80	0	117	752	38,04	1.407,34
Segment Q	0,67	13,79	0	237,87	0,06	30	89,8	0,1	15	0	45	157	46,45	1.393,51
Segment R	0,75	72,89	0	1.084,53	1,93	6	22,33	3	0	0	6	14	222,78	1.336,66
Segment S	1	80,71	0,04	2.246,28	1,4	3	9,86	2,14	0	0	3	13	417,62	1.252,86
Segment T	0,67	95,92	0	1.437,06	1,72	26	118,55	2,59	1	0	27	476	47,24	1.228,35
Segment U	1	17,81	0	9.713,03	0,11	54	136,99	2,18	5	0	59	6696	22,25	1.201,71
Segment V	0,67	16,06	0	682,47	0,09	40	75,56	0,37	86	0	126	800	27,54	1.101,68
Segment W	0,67	17,36	0	1.577,92	1,25	118	515,25	2,88	1	0	119	5358	7,94	937,15
Segment X	1	16,3	0	3.934,26	0,06	30	29,81	0,15	80	0	110	759	29,69	890,59
Segment Y	1	70,95	0	15.229,54	0,14	26	60,36	1,85	114	0	140	4059	31,32	814,41
Segment Z	1	31,31	0,01	613,25	0,15	24	56,26	0,59	86	0	110	836	32,93	790,21

Importance = average outlier score X number of outliers

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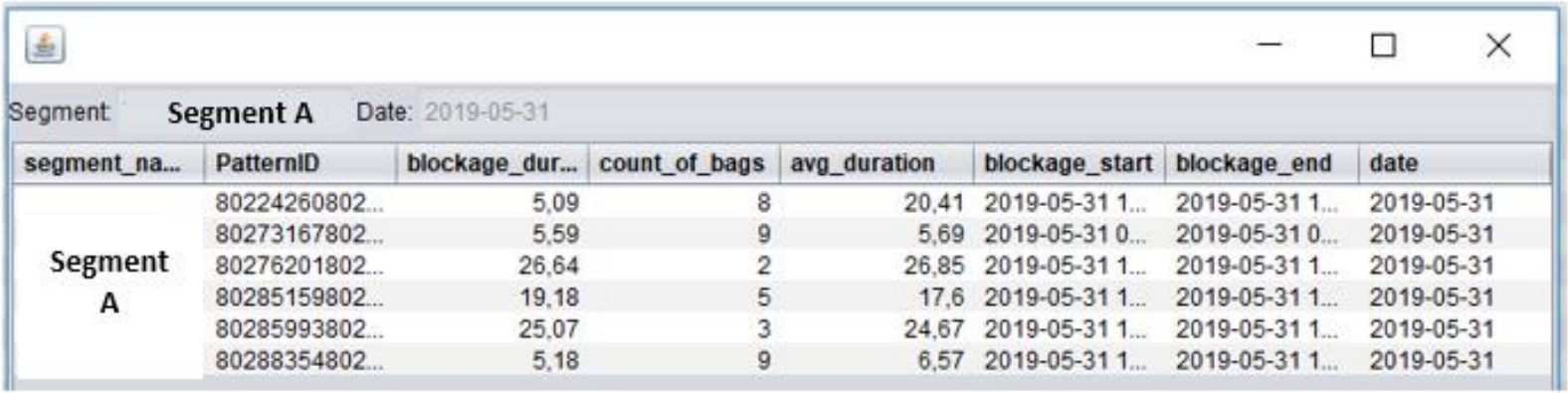
Identifying Segments that Experience More Performance Problems

2. For a given day, what is the total amount of time bags spent in blockages and which attributes does each blockage have?



Segment: **Segment A** Date: 2019-05-31

segment_na...	PatternID	blockage_dur...	count_of_bags	avg_duration	blockage_start	blockage_end	date
Segment A	80224260802...	5,09	8	20,41	2019-05-31 1...	2019-05-31 1...	2019-05-31
	80273167802...	5,59	9	5,69	2019-05-31 0...	2019-05-31 0...	2019-05-31
	80276201802...	26,64	2	26,85	2019-05-31 1...	2019-05-31 1...	2019-05-31
	80285159802...	19,18	5	17,6	2019-05-31 1...	2019-05-31 1...	2019-05-31
	80285993802...	25,07	3	24,67	2019-05-31 1...	2019-05-31 1...	2019-05-31
	80288354802...	5,18	9	6,57	2019-05-31 1...	2019-05-31 1...	2019-05-31

Blockage window enables users to see the importance of each blockage in the segment.

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Categorizing Abnormalities in Segments Based on Occurrence

1. Which parts of the system regularly suffer from serious blockages?

Segment	Average Blockage Time	Number of Days Blockage Observed	Blockage Importance
Segment A	3.23	22	73.7
Segment B	3.62	19	68.76
Segment C	2.95	23	67.78
Segment D	2.80	24	67.24

Blockage Importance= Average Blockage Time X Number of days

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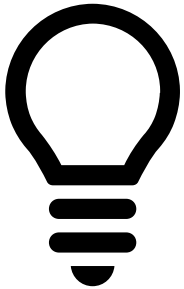


RQ4: Which context factors cause outlier behavior in the system and what is the effect of outliers on performance of the system?

Identifying the Properties that are Leading to the Abnormality

1. Are there any cause-effect relationship between segments / sequence of segments in the sense of abnormal behavior?

Visually we can see the ***dieback effect***

Identifying the Properties that are Leading to the Abnormality

2. Can we find temporary malfunctions in the system that cause abnormal behavior?

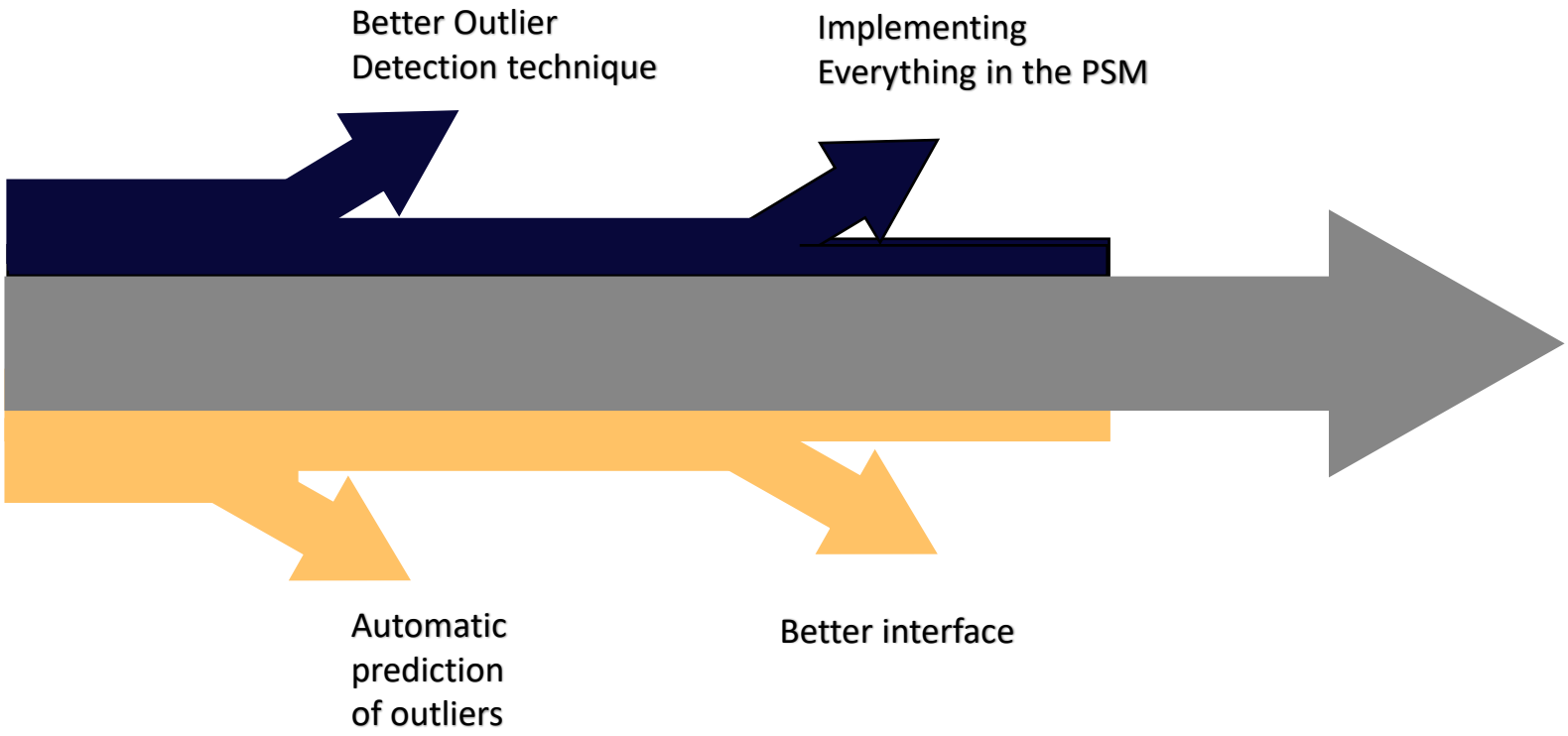
Visually we can see ***temporary malfunctions*** in the system

CONCLUSION

Contributions

1. Detecting outlier bags in specific locations of the system
2. Classifiying the outlier types
3. Blockage properties
4. Classifying segment behavior
5. Identifying a baseline behavior for each segment
6. Finding problematic segments of the system

Future Work


Better Outlier
Detection technique
Implementing
Everything in the PSM
Automatic
prediction
of outliers
Better interface


Thank you for your attention.
Questions?