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Transportation, Strategy

Summary: We evaluated the impact that disruptions, like hurricanes and other disasters, might have on spot market rates for freight services. The research work focused on US market and used transaction data from one of MIT CTL's partners. The research work provides insight into how the occurrence of disruptions, also referred to as special events in the research work, affect capacity, and eventually, the pricing of trucking in the United States. Using regression models, we did not find evidence to suggest meaningful linear correlation between the occurrence of the special events, in time and space, relative to freight volume and rates. We propose utilizing machine learning approaches in future studies, however, additional features will be required to provide improved correlation metrics.

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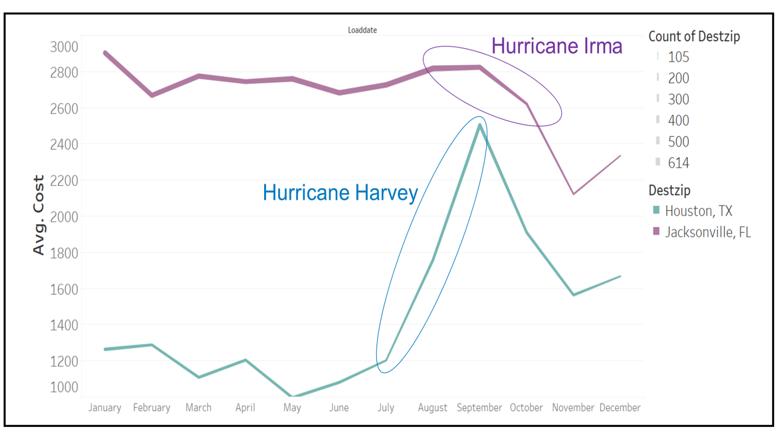
Adam is a former U.S. Army Captain that served in multiple roles in the 101st DIV and 52nd EOD (Explosive Ordnance Disposal) prior to his admittance to the program. He will be continuing his studies at the University of Maryland where he will pursue an M.B.A.

KEY INSIGHTS

1. **Linear Regression is too constrained for temporal-spatial modeling**
2. **Special events have an almost inexhaustible number of features, don't get wrapped up in trying to define them all**
3. **Beware aggregation, try and find a balance between including everything and not enough**

Introduction

Currently there is a gap in knowledge regarding the relationship between spot market rate price fluctuations and special events. Data aggregation provides a mappable and synthesizable test space which aligns itself with the use of a multivariable linear regression. The MLR tests for the temporal-spatial correlations that are at the core of a special event's impact.



Methodology

"Special events," while physically observable, are relatively ambiguous when transferred into the database space. The many characteristics that represent hurricanes, like wind velocity and rainfall, are easily quantifiable and incorporated into singular datasets, but there is little more than binary designators when attempting to depict the whole. A binary matrix was created from the temporal-spatial relationships with regards to disaster occurrences in the United States within the seventeen-week timespan surrounding Hurricane Harvey.

Distance, d (Miles)

Time, t (Weeks)

OUTBOUND	0	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800
0	0.75	0.80	0.84	0.87	0.89	1.17	1.17	1.17	1.15	1.13	1.10	0.80	1.01	0.95	0.88	0.54	0.72	0.62	0.52
1	0.70	0.75	0.79	0.83	0.85	1.12	1.13	1.13	1.11	0.83	1.06	1.02	0.97	0.91	0.84	0.77	0.68	0.59	0.48
2	0.67	0.72	0.76	0.79	0.82	1.10	1.10	1.10	1.09	1.07	1.04	1.00	0.95	0.89	0.82	0.75	0.66	0.57	0.46
3	0.65	0.70	0.74	0.78	0.80	0.82	0.83	0.82	0.81	0.79	1.02	0.98	0.94	0.88	0.81	0.74	0.65	0.56	0.46
4	0.90	0.96	1.00	1.04	1.06	0.82	0.82	0.82	0.81	0.79	1.02	0.99	0.94	0.88	0.82	0.74	0.66	0.57	0.46
5	0.91	0.96	1.01	1.05	1.07	0.83	0.84	0.84	0.83	0.81	1.04	1.00	0.96	0.90	0.83	0.76	0.68	0.59	0.48
6	0.93	0.99	1.03	1.07	1.10	1.11	1.12	1.12	1.11	0.83	1.07	1.03	0.99	0.93	0.87	0.79	0.71	0.62	0.52
7	0.97	1.02	1.07	1.11	1.13	1.15	1.16	1.16	1.15	1.14	1.11	1.07	1.03	0.97	0.91	0.84	0.76	0.67	0.57
8	1.02	1.07	1.12	1.16	1.19	1.20	1.22	1.22	1.21	1.19	1.17	1.13	1.09	1.03	0.97	0.90	0.82	0.73	0.63
9	1.08	1.13	1.18	1.22	1.25	1.27	1.28	1.28	1.28	1.26	1.23	1.20	1.16	1.10	1.04	0.97	0.89	0.80	0.70
10	1.15	1.21	1.26	1.30	1.33	1.35	1.36	1.36	1.36	1.34	1.32	1.28	1.24	1.19	1.13	1.06	0.98	0.89	0.79
11	1.24	1.30	1.35	1.39	1.42	1.44	1.45	1.46	1.45	1.44	1.41	1.38	1.34	1.29	1.23	1.16	1.08	0.99	0.89
12	1.34	1.40	1.45	1.49	1.53	1.55	1.56	1.57	1.56	1.55	1.52	1.49	1.45	1.40	1.34	1.27	1.19	1.10	1.01

Hurricane Harvey was chosen to determine if there exists any correlation between the event that happened and the observed effects for two reasons. First, the Hurricane affected the Houston region which happened to have sizable traffic that can be used as a representative sample for the evaluation of the designators into the generalized time of when the special events occurred, impact of the event on cost of freight. Second, there was a significant change in volume of freight to and from the Houston area during around the occurrence period compared to similar Hurricanes that affected a different part of the country. The emergence of trends in relation to the binary special event designators along the temporal sphere provide the potential for synthesis of the outliers to occur.

With a general idea of the temporal-spatial regression model, and a cleaned data set with millions of data points, the team began conducting further analysis. In order to recognize the temporal changes, the date-based data points needed to be aggregated into larger units that could present a calmer representation of the experienced average. Weekly clustering achieves both requirements and provides visibility to seasonal and temporal trends that could possibly appear. This form of clustering also can incorporate a binary designator.

$$Y = \beta_0 + \beta_1 d + \beta_2 d^2 + \beta_3 t + \beta_4 t^2 + \beta_5 td + \beta_6 e \ldots\ldots\ldots Eq. 2$$

The spatial datapoints were grouped within associated geographic regions that the partner service provider had previously generated. The cluster map had regional groups within a system of 136 distinct clusters that were used to aggregate the volume and cost for the trips. A centroidal value for the cluster based on density was created, in order to assign a tangible physical location to the partner's proprietary clustering system. This led to the creation of a distance map that would be integral to the spatial aspect of the model.

With the distance and transaction cost known, cost per mile became a viable metric of interest that could be leveraged to capture and measure spot market behavior. Given that the average volume and cost per mile were calculated for each region, the spatial characteristics of the outbound and inbound costs and volumes were readily definable within the same region. The time effect of the costs and volume metrics were evaluated on a per week basis to synthesize the models in order to discern any possible patterns from the weeks before and after the incident. Any dissipation of the effects of costs and volumes over time were also tracked so as to more effectively define the temporal behavior of the model.

Three separate consolidated matrixes of cost-per-mile, inbound volume, and outbound volume were inputs to develop a regression model. The d represents distance from the event location, and t represents time since the event occurred, with each β acting as a representation for the corresponding coefficient. In later testing, a binary dummy variable was included within the equation and tested with the same multivariable regression technique as previously described, with e representing the binary variable. The e is used to represent any special event determined from the FEMA database that was input into the binary map.

Results

As the model was developed around the key performance indicators of cost per mile and volume, the associated indices changed with regards to their temporal-spatial relationship to the event. Unfortunately, the regression model's independent variables explained only a small percentage of the forecast, as indicated by the low adjusted R^2 value found in the summary statistics. An interesting result of the models that had $d*t$ included was an extremely low co-efficient that never exceeded 1.03×10^{-6}.

The binary designator's effect on the models was determined through two stages of tests. The first stage included using only distance and time as the independent variables in order to discern the baseline correlations. The second stage of analysis incorporated the binary designator as the surrogate for a special event's occurrence within a cluster. The results showed a slight change (0.003-outbound, 0.0004-inbound) in the R^2 value of the inbound and outbound volume of the Harvey model. The introduction of the binary designator did not provide consistent results with regards to an improved R^2 value when used in the Harvey and Florence models. Potential future research should include a variability smoothing addition to the regression equation with the binary addition.

Given that the first sets of models were built considering the shipment nationwide, a constrained model was created to narrow the loads to only include freight movements that directly related to the cluster affected by the special event. Hurricane Harvey was the only disaster tested due to its comparatively high freight rates, both into and out of the cluster. An attempt to repeat the experiment with Florence was determined to be ill-advised because of its lack of direct freight relationships with the other clusters. The region associated with Harvey (C133) that was used in the constrained model, had over 23-thousand datapoints, but numerous clusters had no relatable data with regards to C133 over the tested timespan. Of the 136 available clusters, only 22 had relatable data within the associated model. The inclusion of the "ghost regions" resulted in an almost 7% better R^2 value, but this change did not result in the R^2 surpassing the 0.15 mark. Through limitation, any relational trends between the spot market pricing and the C133 cluster should have materialized through demand fluctuations that are expected post-event. The fact that there was no major relational change when restricted to a single afflicted area provides even greater support against the initial hypothesis that special events directly affect the freight spot market.

The results showed that by considering the cluster affected by a natural event in isolation, there is a noticeable increase in volume and cost per mile going into the cluster location while outbound metrics were reduced. The reason for this trend might be associated with the movement of relief materials into the area, leading to more trucking inbound. The reverse is the case for outbound which has a negative coefficient as shown in the model.

We delineated the distance parameter into radius buckets of 100 miles from the affected cluster as the center. With this approach we were able to further group together ranges within an average value of cost per mile and volume of freight. This aggregation of volumes had the potential to skew spatial results and a weighting scheme will need to be included in the future.

The model heatmaps and actual heatmaps presented different trends in the cost per mile and volume indices, indicating that the predictions were not as accurate as expected. The very low R^2 values further exacerbated the results of the models. This might be due to a lack of correlation, but it is more probable that there are external factors directly related to special events, that were not included as input parameters, which have unknown but direct impacts on the freight market.

Conclusion

After the completion of multiple models for four different hurricanes which were tested against cost-per-mile and volume provided by the corporate sponsor, the analysis shows that the methods used were not sufficient to determine meaningful correlation between the trucking spot market and special events. These initial findings are contrary to the general expectation that when something occurs, the socio-economics within the afflicted region will affect the supply and demand requirements of the nation. It is still possible that this idea is true, as future tests could utilize other non-linear techniques to find a solution that linear regression is too rigid to recognize. Special events that are pre-planned could provide more data to train the non-linear models that could coincide with the unplanned binary map already developed. The trucking industry runs off seasonality, and special events are already involved in decision-making as a result. When a randomly occurring special event happens and affects a region, the size of the United States and its cross-national interdependence remains largely unaffected as shown by Table 11. While it was discovered that FEMA pays $1.33 more per mile than the average spot market load, the relatively small and dispersed volume of these loads doesn't offset the weekly regional average. Post-Harvey, Cluster C133 did not see an increase in inbound freight from any other region, relying on only eleven regions to bring the supplies it needed to rebuild. Potential future research on this subject could include machine learning techniques such as random forest or a neural network. It is important to note that this is just an initial step towards determining any temporal-spatial relationships inherent within the United States' trucking spot market and it can be further extrapolated into broader social and/or economic studies.