Unraveling the Relation between Trucking Modes: A Correlation Analysis between Less Than Truckload Metrics and Truckload Market Tension

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ABSTRACT

In 2021, The United States trucking industry generated over $400 billion in revenues. As the economy cycles through waves of contractions and expansions, the transportation industry moves through cycles of slack and tension. This research quantifies the relationship between TL market tension metrics and key LTL metrics on a national and corridor level. To evaluate the strength of the relationship between the variables we used Pearson's correlation. Our models spanned 6 years of data and used public national LTL carrier data as well private C.H. Robinson data. The research found a positive, statistically significant correlation for key truckload metrics, including from the contract market (route guide depth) and the spot market (cost per mile and load to truck ratio), especially when lagged 1-3 months. We find this relationship to be true for national public LTL carrier data as well as private C.H. Robinson data. However, because the cost per mile data is correlated with future LTL volume and LTL volume is correlated with future cost per mile, we believe route guide depth and load to truck ratio to be better bellwether indicators.

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I would like to thank my friend and capstone partner, Nicolo. You brought endless positivity, joy, and organization at critical moments throughout the past 9 months. I am grateful for our time together. - Sean Moran

Thank you, Sean, for your insightful comments and thoughtful suggestions that challenged me to think more critically and creatively. It has been a pleasure to work with you. - Nicolo Tosi

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1. INTRODUCTION

The United States full truckload (TL) industry generated an estimated $332 billion in revenue in 2021, while the less than truckload (LTL) industry generated an estimated $83 billion (Zimmerman et al., 2022). Both figures represent a greater than 10% growth from 2020. In the past two years, this growth, volatility due to the COVID pandemic, and increase in e-commerce has created significant tension in the U.S. trucking market. In situations where demand outstrips supply, shippers increasingly consider trade-offs between price and service level, such as on-time delivery and damages, among transportation modes and carriers update pricing to choose freight that is more desirable. This tension leads freight to migrate between full truckload and less than truckload shipping options. Companies that are well-placed to manage that migration for their clients are freight brokerages.

C.H. Robinson (CHR) is a leading freight brokerage in the United States. They offer various types of shipping, including full truckload, less than truckload, and consolidation. C.H. Robinson wants to determine whether there is a relation between truckload market tension and less than truckload metrics, to understand freight migration.

If this research can identify a strong and statistically significant relation, C.H. Robinson can build a predictive model that will help them anticipate, prepare, and quickly respond to market changes, which would provide a competitive market advantage. Specifically, they could share with their customers how the shipping industry is expected to react to different market scenarios. Insights from this research could help shippers better plan LTL strategies in the future as the American economy grows and contracts. Finally, the actions C.H. Robinson would take to help customers and the broader industry prepare for pricing and freight changes could ultimately make a more efficient marketplace, driving value to the end consumers.

1.1 Problem Statement and Research Questions

As the economy cycles through waves of contractions and expansions, the transportation industry moves through cycles of tension and slack, resulting in truckload market tensions (i.e., demand outstripping supply and supply outstripping demand). This research determines the correlation between the cycles of truckload market tension and less than truckload metrics, as well as an external index.

The data available for this research spanned a period of six years, from January 2017 to December 2022. Our analyses were conducted at a monthly level, which gave us 6 years x 12 months per year = 72 data points and a quarterly level which resulted in 6 years x 4 quarters per year = 24 data points. Pearson's correlation requires a minimum of twenty-five data points (Bonett and Wright, 2000). Because the quarterly analysis only has 24 data points compared to the requirement of 25 data points, we closely examined results and took an inclusive approach to potential correlations. We began our analysis at a national level with public LTL data and private C.H. Robinson data, and then zoomed into key market areas within the C.H. Robinson data. Finally, we compared an external index to the LTL and TL metrics. Throughout these analyses, a key aspect of this research was identifying the lag between TL market tension and LTL metrics.

1.2 Research Goals and Expected Outcomes

The research's overall goal is to provide C.H. Robinson with the results of correlation evaluations of LTL business and TL market tension metrics across the period and during high and low market tension.

The research focused on three main areas:

- Correlation of LTL metrics to TL market tension at the national level. In the first part of our analysis, we evaluated on a national level the correlation of TL market tension metrics, in both the spot-market and contract market, with LTL business metrics. We further evaluated this area by analyzing LTL at two levels: public LTL companies and C.H. Robinson data.
- Correlation of LTL metrics to TL market tension at the corridor level. In the second part of our analysis, we replicated the previous analysis on a corridor level, using C.H. Robinson data to see if the results obtained at national level can be replicated on a regional level.
- Correlation economic indicators to key LTL and TL metrics. Finally, this analysis evaluated whether there is a correlation between key LTL and TL metrics and an index tracking the growth or contraction sentiment of the U.S. economy, using C.H. Robinson data.

2. STATE OF THE ART

We are analyzing possible correlations between different key metrics of the transportation industry and this chapter serves as a review of relevant literature on the topic, with a focus on:

1. Trucking industry: This section provides an overview of the trucking industry to determine the size of the addressable market and define the geographical perimeters of the research. It also introduces the logic behind the shipper-carrier business model and its role in facilitating the transportation of goods.
2. Trucking modes: This section provides an overview of the three main transportation modes in the trucking industry: truckload, less than truckload, and consolidation. It also presents the hub and spoke model used in less than truckload mode.
3. Trucking market tension: This section provides an overview of trucking market tension. The trucking sector experiences different cycles of over and under capacity, leading to periods of high and low market tension. This section discusses why this phenomenon occurs.
4. Freight migration between modes: This section provides an overview of the key research that has been carried out to address the main question of our project. Is there a correlation between key metrics and the way freight moves between modes?

2.1 Trucking Industry

The trucking industry is an essential component of the U.S. economy. The American Trucking Association (ATA) estimates that the industry in 2021 moved 10.93 billion tons of freight. According to Bob Costello, ATA chief economist, motor carriers collected about 80.8% of the nation's freight revenues compared to all other transport modes (American Trucking Association, 2021). Consulting company Kearney estimated that, in 2021, road freight grew by 23.4% and continues to represent the biggest portion of U.S. logistics expenditures (Zimmerman et al., 2022).

Within the trucking industry, shippers are defined as those who have the need to move freight while carriers are those who have available trucking capacity to move this freight. Third-party logistics (3PLs) companies provide different types of services, including freight brokerage. This service matches the demand for freight transportation of shippers to the available transportation capacity of the carriers. C.H. Robinson, the sponsor of this research, is one of the largest third-party logistics providers, with more than 100,000 customers and 85,000 contract carriers (C.H. Robinson, 2023a).

Following the deregulation in the 1980s (Motor Carrier Act, 1980), shippers have been using two primary means to tender freight for the full truckload market: they can either enter long term contracts or use the spot market. A third means of shipper-carrier relationships are private and dedicated fleets, which effectively combine the roles of shipper and carrier into one organization.   However, private, and dedicated fleets are not in the scope of our research.

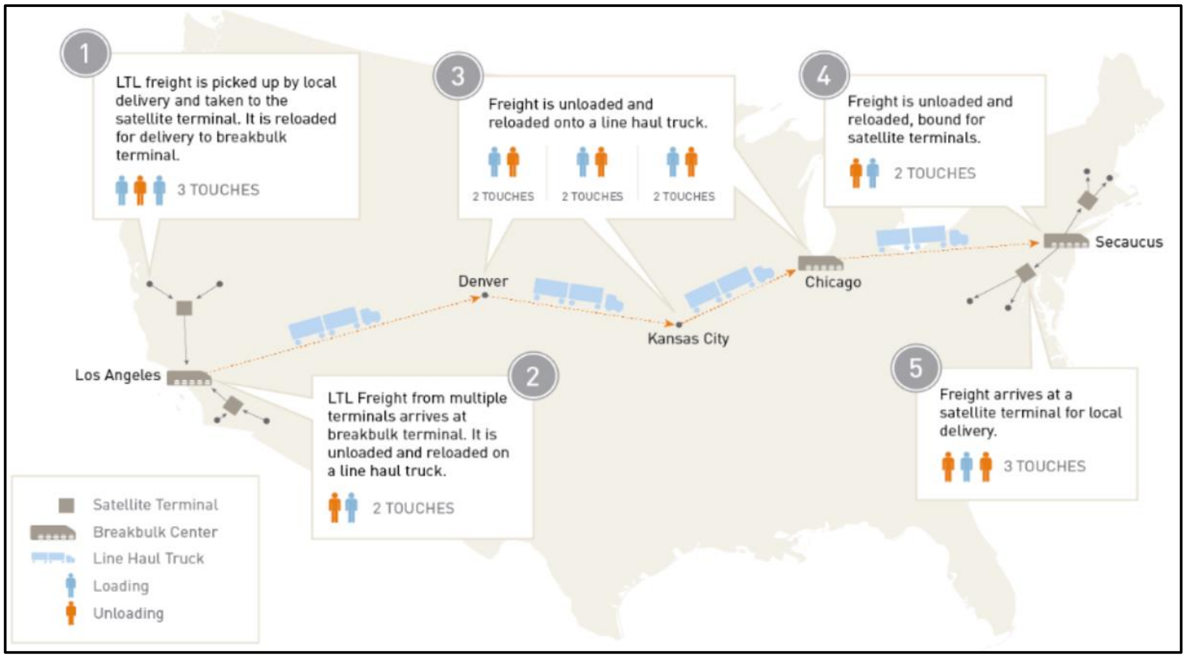
Spot-market interactions are single-load transactions used most of the time as a backup option when the shipper cannot find available capacity in the contract market while contracts between shippers and carriers are designed to cover a specific network segment over a defined period (Acocella & Caplice, 2022). Our research focused on metrics that cover market spot rates as well as long term contracts rates.

2.2 Trucking Modes

The trucking industry is made up of two segments: private carriage and for-hire carriage. The for-hire carriage can further be divided into two modes of transportation: truckload or “TL” and less than truckload or “LTL”. The TL mode deals with the transportation of large quantities of cargo using the full truck from an origin to a destination without intermediate stops. Conversely, in the LTL mode, shippers need to move smaller quantities, so carriers collect cargo from different shippers and consolidate multiple shipments into a single truck. After local collection of freight, it is routed to a series of intermediate consolidation stops - rarely is the shipment routed directly to the destination (Bignell, 2013). This process involves multiple stops and therefore longer lead times. To move freight along the network in an optimal way, the LTL mode uses a hub and spoke model. This model is represented in Figure 1.

Figure 1

LTL Hub and Spoke Model



Note. C.H. Robinson (2023b). Unpublished internal company document.

The growth capacity of the LTL physical network infrastructure is limited, because it requires higher capital investments compared to the TL mode. To expand existing LTL networks or to create new ones, a series of infrastructure needs to be built, such as satellite terminals and breakbulk centers. The difference in investment required for capacity expansion is discussed in more depth in the Trucking Market Tension section.

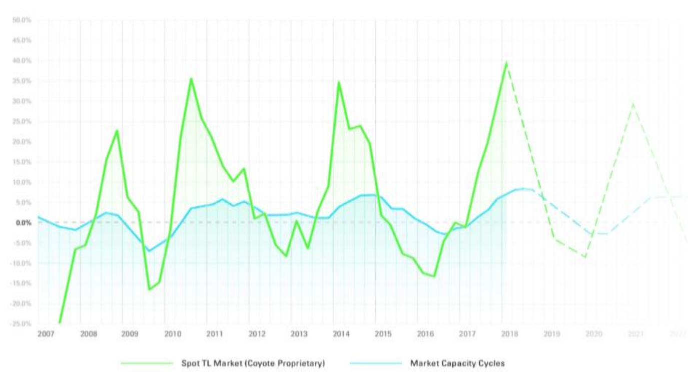
The private carriage segment is made up of private carriers which are owned by private companies to transport their products. The American Trucking Association estimates that private carriers account for 8.2%, while TL mode makes up about 81.7% of the market revenue, and LTL mode represents 10.1% (American Trucking Association, 2021). In our research we focused on the relationship between TL and LTL modes.

2.3 Trucking Market Tension

The trucking transportation industry goes through different cycles of contractions and expansions. In a report issued in 2018 by Coyote Logistics, Chris Pickett identifies key variables that contribute to the shift: overall economy sentiment, labor force shortages, weather events and regulations (Pickett, 2018). These cycles can be grouped into two: a loose and a tight market. In a loose market the demand for transportation services is less than the available trucking industry capacity, hence, shippers can benefit from lower prices. In a tight market situation, the opposite happens. The demand for transportation services is high and because of the limited capacity of the trucking industry, prices increase, giving the carriers the opportunity to select between freight and simultaneously driving their profits up. Figure 2 shows how spot TL rates fluctuate across time to reflect changes in demand and offer of transportation services.

Figure 2

Spot vs. Contract TL Rate Behavior through Market Capacity Cycles from 2007 to 2018



Note. Pickett, 2018

Based on a personal communication with C.H. Robinson (2023), we assumed that in the months preceding the Covid-19 pandemic, the market for trucking services could be classified as loose, while a new tight market began with the onset of the pandemic in March 2020 when prices for trucking services started to increase. Higher prices were linked to the limited trucking capacity available at the time, in part driven by the shortages of drivers available on the market. This market cycle, which started with the onset of the pandemic in March 2020, lasted until the spring of 2022, when declining spot prices for freight services indicated the start of a new loose cycle. As agreed with C.H. Robinson, we divided the data frame into loose and tight windows using the following structure:

- From January 2017 to August 2017: Loose
- From September 2017 to September 2018: Tight
- From October 2018 to February 2020: Loose
- From March 2020 to March 2022: Tight (Covid)
- From April 2022 to December 2022: Loose

Although the trucking capacity expands and contracts overtime, the rate at which this phenomenon occurs is not the same across different trucking modes. While the TL mode can add or remove capacity in a time span of months, when new truck owners join the market, the LTL mode is more rigid and cannot expand or contract in the same way. LTL is constrained in the short term because it relies on a network of terminals whose investments can only be justified in the long term. In our research we investigated the correlation between results in both loose and tight markets, and how this compared to an analysis of the entire time period. Further, we use TL market tension metrics in both the spot and contract market to evaluate the correlation with LTL business metrics.

2.4 Freight Migration between Modes

It is well documented within industry that freight migrates between truckload and less than truckload shipping options. Wlazlowski (2004) noted that LTL carriers boosted profits as shippers moved freight from TL to LTL, due to increased market tension. Similarly, Malloy (2014) noted that a tight truckload market drove more freight to LTL, which also drove up LTL prices. These identical business outcomes happened 10 years apart, demonstrating that they are consistent over time.

According to C.H. Robinson internal analysis, as of 2020, there were only about 110 companies that offer LTL shipping with the top 25 companies' control roughly 90% of the market. The situation is different for the truckload market where 90% of the market is controlled by 280,000 owner-operator carriers (C.H. Robinson, 2023b). The difference here can largely be attributed to the large capital-intensive nature of LTL, where companies need to build, staff, and maintain regional hubs in key markets while it is relatively easier to add capacity in the TL mode.

One theory about how freight migrates between the trucking modes is that LTL carriers hold sufficient market power that they can pull more freight in or push freight away, particularly when the truckload market is in high tension. Schulz (2018) noted that:

> Unlike truckload (TL), there are few new entrants in LTL because of the steep initial economic outlay to replicate most carriers' complex hub-and-spoke, brick-and-mortar terminal networks. At the same time, shortening supply chains, more emphasis on smaller and lighter loads, tighter capacity throughout the entire trucking industry as well as the e-commerce boom all point to more business for LTL carriers.

In other words, this market power consolidation is compounded by the fact of the growing LTL market, driven by e-commerce and retail over the past 20 years. Because of the market power accrued to the LTL carriers, they are then able to set prices in a way that welcomes the easiest to move freight, while pushing more challenging freight towards truckload. We can look at historical pricing trends during economic upturns to see this. While LTL carriers needed to slash prices during the Great Recession (from late 2007 to 2009 - low Market Tension), within 18 months of the end of the recovery, pricing-power shifted back to LTL carriers (Schulz, 2011). This example demonstrates that during non-recessionary periods and healthy TL markets, LTL should enjoy price-setting abilities in negotiations.

Another theory on how freight moves between transportation modes that we will evaluate in this research, is that freight moves to LTL when TL is too expensive or when the service is too poor, both from the contract and spot market. Industry reports and academic articles have not identified and published correlations between LTL - TL market tension metrics. Our research investigated this gap in literature.

3. DATA AND METHODOLOGY

This chapter presents the data and the methodology used to evaluate the correlations between TL market tension and LTL volume metrics. We provide an overview of the key metrics analyzed, the source of these metrics, and how we transformed and cleaned them. We then present our data analysis approach, including time series decomposition, correlation, lag analysis and statistical significance. Finally, we introduce each of our models to answer our research questions.

3.1 Metrics

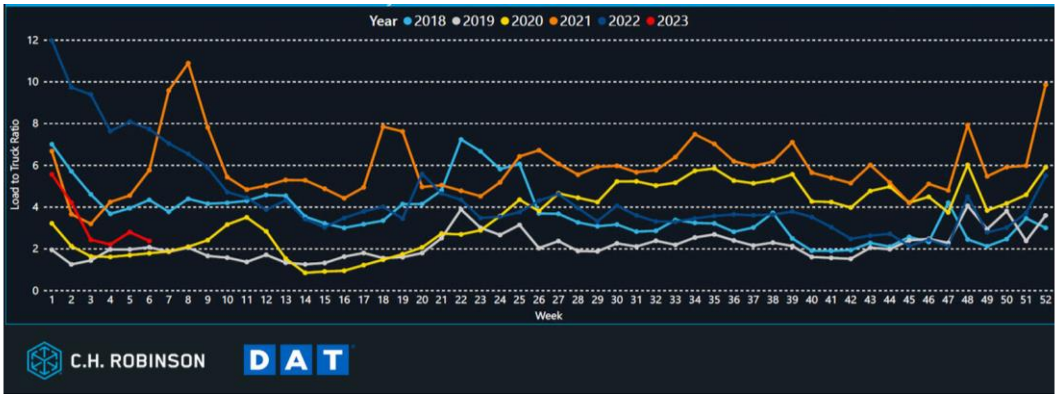
The research analyzed several metrics to test TL Market tension's relationship to LTL Volume. We defined these metrics and, if relevant, explained their calculations.

Truckload Market Tension Metrics

- Load to Truck Ratio (LTR): this ratio is calculated by dividing the total numbers of freight requests to be transported by the total number of trucks available to transport these loads. This can also be considered demand over supply. This ratio is useful because it is an indicator of the spot-market cycles. Prices and costs are related to this intersection of supply and demand. A high load to truck ratio indicates a tight spot-market, while a low load to truck ratio indicates a loose spot-market. Figure 3 shows load to truck ratio from 2018 to early 2023, as compiled by DAT, a marketplace that offers real-time truckload freight rate service.

Figure 3

DAT Load to Truck Ratio from 2018 to early 2023



Note. C.H. Robinson (2023). Unpublished internal company document.

- Cost Per Mile (CPM): this metric represents the cost drivers charge to operate a truck for each mile of driving. A high cost per mile indicates a tight market, while a low value indicates a loose market.
- Route Guide Depth (RGD): A route guide is a document that helps shippers organize specific routes based on submitted tenders, which carriers to use, based on price and service. Usually, these contracts are tendered on an annual basis. If the RGD is 1, it means the shipper's preferred carrier, based on the combination of price and service level, has accepted the load. But if the RGD is 5, it means the carriers #1-4 declined to accept the route at the previously agreed price and service. In this example, the carriers would decline the tender because the previous price offer is no longer competitive in the market. A high RGD indicates a high market tension, while a low value indicates a loose market tension.

LTL Market Metrics

- Average Cost (or Revenue) per Hundredweight (CWT): The average cost per hundredweight is a measure of the expense of transporting 100 pounds of freight. It is used to standardize the transportation cost across different shipments and carriers. Once again, like cost per mile, a high value here indicates high market tension while a low value indicates a loose market tension.
- Average Weight (or Tonnage) per Shipment: Like average weight, this metric is calculated by summing all the weights and all the shipments, and then dividing the two numbers. A higher number here could mean more dense items are being shipped.
- Total Tonnage: Total Tonnage is calculated simply by adding up all the weights of the shipments, but it does not consider any denominator such as shipments. It is valuable to understand at a high level whether LTL is being used to move freight.
- Total Shipments or LTL Volume: These are the number of loads carried by an LTL carrier for that time period. A high number means more loads and business.
- Average Revenue per Shipment: This is a metric that is calculated by taking total revenue and dividing it by total shipments. It is a good estimator to understand whether LTL carriers can charge a high or low margin for that time period.

Other Metrics

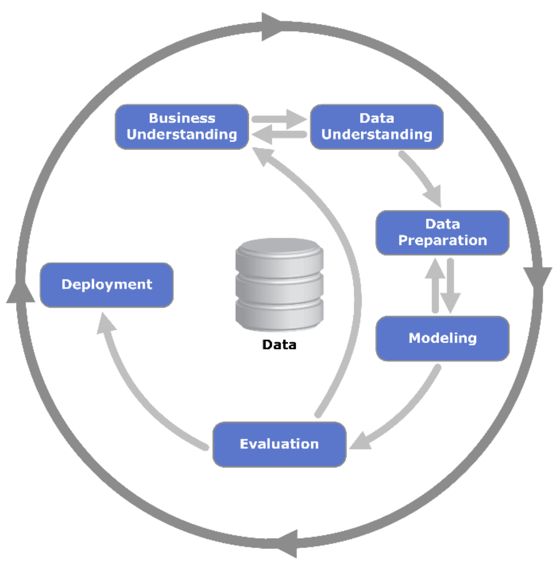
- Purchasing Managers' Index (PMI): this index is calculated based on a survey sent to 400 company representatives across 19 industries, completed monthly. Measured from 0 to 100, it can indicate a coming period of contraction when the index falls below the threshold of 50 for a prolonged period. When values are above the 50 threshold, the

PMI indicates a period of expansion (Munichiello, 2020). In other words, the index is an indicator of the most likely future direction of the economy in the manufacturing and service sector as it is perceived by purchasing managers. This index is also notable as we have learned from personal conversations with C.H. Robinson (2023) that the LTL community believes is a leading indicator on LTL volumes.

3.2 Data Understanding

To approach our research in a systematic way, we used the Cross-Industry Standard Process for Data Mining "CRISP-DM", a standard iterative workflow that can be applied to data mining projects (*Shearer 2000*). As depicted in Figure 4, the framework is made up of six steps.

Figure 4
CRISP-DM Framework



Note. Shearer, C. (2000). CRISP DM Framework

1) Business understanding: The objective of this step is to understand how the specific business and industry works. We reviewed the available literature on the topic and documented our findings in State of the Art. C.H. Robinson organized a two-day workshop with domain experts in Minneapolis, MN to give us an overview of the business and present the research objective. As this is an iterative process, we organized a weekly call conference to discuss progress and clarify questions.
2) Data understanding: The objective of this step is to understand which data are available and if they are relevant to answer the questions we have identified in the previous steps. To better understand the different fields and the relationship between different entities, we used Visual Paradigm, a software design tool, to graphically depict the data schema.
3) Data preparation: To prepare our data, we uploaded and manipulated our data files in a data analytics software, Alteryx. Some of the data preparation included: creating fields such as Load to Truck Ratio, reformatting datetime variables, and combining separate data frames. We provide detailed information in our 'Data Preparation and Cleaning' Section. Once our data was organized in appropriate time series files, we exported it to be used in other software.
4) Modeling: To create our models and evaluate our hypotheses, we moved our analysis to a more flexible and stronger data analysis platform: Python coding. In this step, we applied different algorithms to the data collected; these are discussed later in the section.

5) Evaluation: To evaluate our findings, we discussed progress in our weekly conference calls with C.H. Robinson if the results matched their expectations, or if we had any surprising results that needed more analysis.
6) Deployment: We presented these results to C.H. Robinson so that they could share them with the larger LTL community.

3.3 Raw Data Source

The data we received from C.H. Robinson was in six dataframes accounting for over 7 million rows. We categorized the data into three types of data: LTL volume or LTL metric was our dependent variable (y), truckload market tension metrics were our independent variables (x), and market tension data was used to segment the data. This is true except for Model 4 which used PMI as the independent variable (x) and LTL and TL metrics as the dependent variables (y). Tables 1-7 provide an overview of the data we used in our research.

Table 1
National LTL Dataframe Details

Data Source	Publicly Traded LTL Carriers 10-Q Reports
DataFrame Name	National LTL
Date Range	2008 Quarter 1 - 2022 Quarter 4
Trucking Mode	Less Than Truckload
Time Granularity	Quarters
Geographic Granularity	National
Key Variables	Average Revenue CWT, Total Tonnage, Total Shipments, Average Revenue per Shipment, Average Weight per Shipment

Table 2
CHR LTL Dataframe Details

Data Source	C.H. Robinson
DataFrame Name	CHR LTL
Date Range	January 2017 - December 2022
Trucking Mode	Less Than Truckload
Time Granularity	Daily
Geographic Granularity	Origin - Destination Key Market Areas
Key Variables	Average CWT, Total Shipments, Average Weight per Shipment

Table 3
TMC TL RGD Dataframe Details

Data Source	C.H. Robinson (TMC)
DataFrame Name	TMC TL RGD
Date Range	January 2016 - December 2022
Trucking Mode	Truckload (Contract)
Time Granularity	Monthly
Geographic Granularity	Origin - Destination Key Market Areas
Key Variables	Route Guide Depth

Table 4
DAT TL CPM Dataframe Details

Data Source	DAT
DataFrame Name	DAT TL CPM
Date Range	January 2017 - December 2022
Trucking Mode	Truckload (Spot Rate Market)
Time Granularity	Daily
Geographic Granularity	Origin - Destination Key Market Areas
Key Variables	Cost Per Mile

Table 5
DAT TL LTR Dataframe Details

Data Source	DAT
DataFrame Name	DAT TL LTR
Date Range	January 2017 - December 2022
Trucking Mode	Truckload (Spot Rate Market)
Time Granularity	Daily
Geographic Granularity	Origin Key Market Areas
Key Variables	Load to Truck Ratio

Table 6
CHR Market Tension Data frame Details

Data Source	C.H. Robinson
DataFrame Name	CHR Market Tension
Date Range	January 2017 - December 2022
Trucking Mode	Truckload Market Tension
Time Granularity	Monthly
Geographic Granularity	National
Key Variables	High Market Tension or Low Market Tension

Table 7
ISM PMI Data Frame Details

Data Source	Institute for Supply Management (ISM)
DataFrame Name	Purchasers Manufacturing Index (PMI)
Date Range	January 2017 - December 2022
Trucking Mode	Neither / Both
Time Granularity	Monthly
Geographic Granularity	National
Key Variables	PMI

3.4 Data Preparation and Cleaning

We performed several data cleaning and preparation steps prior to completing our analyses.

- Load to Truck Ratio: We calculated this ratio by taking the number of loads for a given lane and dividing it by the number of trucks available to take Loads. Any time a lane had 0 trucks available, this created an error as one cannot divide by 0 and receive a numerical output. For this reason, we replaced all 0 values for trucks with a very small number, .00001. This effectively made the load to truck ratio very high, which represents that there were indeed many more loads than trucks available.
- Total Weight: In the CHR LTL data, there were data observations that indicated 0 total weight had actually been carried. We dropped these observations as these mean that the shipment was not successfully shipped via C.H. Robinson, or at least, not documented in this observation.
- CHR LTL CWT: This field was calculated by dividing the rate total by the total actual weight. To ensure we did not receive formula errors, we dropped any observations where total weight value was 0.
- Time Granularity: For time series analysis, we need data to be in the same time format, which requires two conversions. We took the lowest common denominator and transformed the other data to match. For our first analysis the National LTL data was in quarters, so we converted TMC RGD and DAT TL dataframes into quarters. Similarly, for our CHR LTL analysis, we converted this data to monthly to match the TMC RGD and DAT TL. Notably, each time we did a conversion, we took the original data and then grouped it by the appropriate time period, thus avoiding any averages of averages.

- Key Market Area (KMA): For the corridor analysis, we selected the appropriate data by filtering on the KMA origin and destination fields.
- Market Tension: While market tension was provided in months, we needed to transform this into quarters. There were two occasions when a quarter was not completely defined by one market tension and instead included two market tensions within the 3 months. For these occasions, we discussed with C.H. Robinson, and agreed that the tension which was 2/3rds of the quarter should be the label for that quarter.

3.5 Time Series Analysis

We used time series analysis to identify patterns in the data. Box and Jenkins (1970) identified the issues of performing correlations on time series data. They realized and documented that removing the trend, thus making the data 'stationary,' was critical to understanding the true relationships between time series data. To make data stationary, we decomposed each time series data points into its three[1] components:

- Trend: The long-term behavior or direction of a time series, ignoring any short-term fluctuations or noise. It is important to understand the long-term direction of the data.
- Seasonality: The regularly repeated pattern of fluctuations. This is common at a weekly, monthly, or even annual level.
- Residuals: Anything unexplained by the trend and seasonality. This is the 'randomness' factor that cannot be explained by other components.

[1] Note - some data includes a 4th component, Cyclical; however, we did not see this component in our data.

To make our time series data stationary, we used NeuralProphet, an open-source library written in Python and developed by Facebook's data science team in 2020. This model decomposed the original data sets into the three components discussed above. Depending on the lowest common denominator time period, we fed monthly and quarterly time series data into the model. The result of the NeuralProphet decomposition were:

- Trend: In our case, the growth of the trucking industry means that our LTL volumes had large trend components. This is partially explained by the U.S. economy growing over this time, including the growth of e-commerce. In contrast, our TL market tension metrics, such as cost per mile and load to truck ratio, are bound between two numbers, for example, 0 to 8, which means the trend component was smaller.
- Seasonality: across all our data points, there was a very strong seasonality component. From personal conversations with C.H. Robinson (2023), this is well accepted within the industry.

Our stationary time series data is created by taking the data and subtracting the trend; or, alternatively it can be thought of as the seasonality plus the residuals.

3.6 Correlation Analysis

To evaluate the strength of the relationship between the variables we used Pearson's correlation. This is used as a measure of association between two continuous variables (Chok, 2010). The coefficient ranges from -1 to +1. A value of +1 represents that the two numbers are perfectly positively correlated - i.e., they move in the same direction; and a -1 represents a perfectly negative correlation where the numbers move in opposite directions. The Pearson's Correlation Coefficient is calculated as the ratio of the covariance of the two variables to the product of their respective standard deviations. The coefficient is usually indicated by the Greek letter rho (Chok, 2010), ρ:

$$p = \frac{Cov(X, Y)}{\sigma x \; \sigma y}$$

In our case, since we do not know the entire population, we will apply the sample formulation for which the coefficient r is calculated as follow:

$$r = \frac{\mathrm{n}(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n \sum x^2 - (\sum x)^2][n \sum y^2 - (\sum y)^2]}}$$

3.7 Lag and Lead Analysis

We hypothesized that if we lag the TL market tension metrics, then the correlation is a larger and a more statistically significant positive correlation. We hypothesized this because shippers would choose to ship LTL mode after they have had some time to experience the higher prices via the cost per mile or a lower standard of service via the route guide depth or the load to truck ratio. From personal conversations with C.H. Robinson (2023), we believed the time delay difference to be about 2 months.

We lagged each variable by shifting it back in time by one time period, either 1 quarter or 1 month. We then repeat this process for 1,2,3 units of time. To further test our hypothesis, we also lagged the variables in a negative direction, -1, -2, -3 units of time, which is also known as leading. In other words, instead of pushing them backwards in time, we push them forward in time. We hypothesized that the correlation here to be 0. This is because we expected that LTL volume is not correlated with future TL market tensions.

Each unit of lag requires that we drop 1 data observation from our analysis. So, when we lagged by 2 quarters or 2 months, it resulted in 2 fewer data points because these data points no longer have complete data for all the variables in question. For simplicity, we only conducted lag and lead analysis for the National LTL, C.H. Robinson LTL, and PMI datasets. We expected any variables found with a higher correlation with a lagged variable than the current period variable, would also hold true for lane specific analyses. However, we did not evaluate this hypothesis in this research.

3.8 Statistical Significance

As is standard in academic research, we utilized significance testing framework to evaluate the correlations. This hypothesis testing allows researchers to test a null hypothesis that the relationship between two variables is 0. If the p value is below < 0.1 , <0.05, or <0.01 we reported it in this research, as we would only expect to receive results at least as extreme as this when the true relationship is 0, 10%, 5%, or 1%, respectively, of the time. We chose this approach for a few reasons. Primarily, our goal in this research was to identify possible relationships between variables that had not been researched previously. For this reason, we wanted to be more inclusive and err on the side of including variables that may not truly have a relationship, rather than excluding variables that truly do have a relationship. In other words, we prioritized avoiding a type 2 data error where we fail to reject a false null hypothesis. This is also known as a false negative. Secondly, due to the nature of our analyses, we have aggregated many millions of data points into ~72 months or ~24 quarters. This data aggregation decreased the quality and so to balance this, we chose a more inclusive approach. Finally, for some of our analyses, we further sliced the data into corridors, further reducing the data available. As mentioned above, we wanted to include any possible true relationships.

3.9 Model 1 - Public LTL Metrics Correlation with TL Market Tension at a National Level

Our first model evaluated the relationships between public companies' LTL metrics and TL market tensions at a national level. This model took the widest scope possible by looking at U.S. national data for several large LTL companies. The wide-scope gave us a strong foundation to observe initial national results and then zoom into more narrowly defined datasets. We hypothesized that we would see statistically significant, positive correlations between TL market tension and public LTL data. However, we did not expect the correlation values to be very strong since we only analyzed 24 data points.

To create this model, we combined our (1) National LTL, with (3) TMC TL RGD, (4) DAT TL CPM, (5) DAT TL LTR, and (6) CHR Market Tension dataframes. This resulted in 24 observations. We also lagged and led the variables to see whether there were significant changes with a time delay.

3.10 Model 2 - CHR LTL Metrics Correlation with TL Market Tension at a National Level

Our second model evaluated the relationships between CHR LTL metrics and TL market tensions at a national level. This is similar to Model 1 in that the scope is national, but rather than using publicly available data, we used a richer dataset directly from C.H. Robinson. The drawback is that it introduces specific data to one company, rather than overall data from several large LTL companies. We hypothesized that we would see strong, statistically significant positive correlation, given the large amount of data underlying each observation.

To create this model, we combined our (2) CHR LTL, (3) TMC TL RGD, (4) DAT TL CPM, (5) DAT TL LTR, and (6) CHR Market Tension dataframes. We also lagged and led the variables to see whether there were significant changes with a time delay.

3.11 Model 3 - CHR LTL Metrics Correlation with TL Market Tension at a Corridor Level

Our third model evaluated the relationship between CHR LTL metrics and TL market tension metrics for five specific corridors, which were selected by C.H. Robinson. These were chosen to represent different market dynamics across the country. The market dynamics and corridors chosen were:

- Unbalanced Southeast: Atlanta to / from South Florida (Lakeland & Miami)
- Unbalanced Northeast: Boston to / from Harrisburg

- Balanced Longhaul: Southern California (Ontario & Los Angeles) to / from Chicago (Chicago & Joliet)
- Balanced Shorthaul: Southern California (Ontario & Los Angeles) to / from Dallas (Dallas & Ft. Worth)
- Intra State: Southern California (Ontario & Los Angeles) to / from Northern California (San Francisco & Stockton)

After we evaluated correlations between TL market tension and public LTL data on a national level, we hypothesized that the same statistically significant and positive correlations exist on a corridor level between different states (inbound and outbound) as well as intra-state.

To create this model, we combined our (2) CHR LTL, (3) TMC TL RGD, (4) DAT TL CPM, and (6) CHR Market Tension dataframes, and filtering for specific key market areas. Unlike for models discussed at national level, we were not able to include load to truck ratio on a corridor level as the geographic granularity of the data for this indicator does not match the required level needed for the analysis.

3.12 Model 4 - CHR LTL Metrics and TL Market Tension Correlation with PMI at a National Level

Our final model evaluated the relationship between CHR LTL metrics, key TL market tension metrics, and the PMI. We had two hypotheses: first, we hypothesized that there is a positive, statistically significant correlation between the PMI and LTL volumes. In other words, if industrial output is expected to decline, we expect that LTL Volumes will also decline and vice versa. Second, we hypothesized that the PMI is positively correlated with TL cost per mile. We reasoned that as the sentiment for the economy improves, shippers need to send more loads and thus the TL market experiences increased demand. To create this model, we combined the (7) PMI together with (2) CHR LTL, (3) TMC TL RGD, (4) DAT TL CPM, and (5) DAT TL LTR dataframes.

4. RESULTS

This chapter describes the specific results of each of the 4 models we considered: Model 1 - Public LTL Metrics Correlation with TL Market Tension at a National Level, Model 2 - CHR LTL Metrics Correlation with TL Market Tension at a National Level, Model 3 - CHR LTL Metrics Correlation with TL Market Tension at a Corridor Level, and Model 4 - CHR LTL Metrics and TL Market Tension Correlation with PMI at a National Level.

4.1 Model 1 - Public LTL Metrics Correlation with TL Market Tension at a National Level

In the correlation analysis for the entire six years, Table 8 demonstrates that cost per mile and route guide depth were positively and significantly correlated with many LTL metrics such as average revenue per CWT, total tonnage (cost per mile only), average revenue per shipment, and average weight per shipment. The six-year analysis is useful as a general guide if C.H. Robinson and other market players are unsure of which market tension they are currently in.

Table 8
Correlations for National LTL Carriers Across 6 Years

	Variable	Average Revenue Per CWT	Total Tonnage	Total Shipments	Average Revenue Per Shipment	Average Weight Per Shipment
1.	DAT Load to Truck Ratio	.29	.35	.30	.24	.28
2.	DAT Cost Per Mile	**.40****	**.38***	.15	**.42****	**.56*****
3.	TMC Route Guide Depth	**.43****	.80	-.80	**.36***	**.39***

*** p <.01, ** p <.05, * p <.1. Statistically significant results are highlighted in Bold.

Table 9 shows the correlation results for loose market tension. Route guide depth results were higher than cost per mile with average revenue per CWT and average revenue per shipment - both in terms of coefficient correlation and statistical significance. The correlation for RGD and average revenue per CWT was .78 (p <.01) and average revenue per shipment at .67 (p <.05). Average weight per shipment was correlated to cost per mile and route guide depth across the 6 years, but this relationship was not statistically significant during loose markets.

Table 9

Correlations for National LTL Carriers During Loose Market Tension Periods

Variable	Average Revenue Per CWT	Total Tonnage	Total Shipments	Average Revenue Per Shipment	Average Weight Per Shipment
1. DAT Load to Truck Ratio	**.51***	.03	.03	.42	-.06
2. DAT Cost Per Mile	**.55***	.05	-.13	**.51***	.47
3. TMC Route Guide Depth	**.78*****	-.11	-.16	**.67****	.16

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

Finally, Table 10 depicts our results for correlations during tight market tension. In this analysis, route guide depth was statistically correlated to total tonnage and average weight per shipment at the p <.10 level. In the previous analysis over the 6 years, route guide depth was statistically significant for average revenue per CWT and average revenue per shipment, at the p<.01 and p<.05 level respectively, but these relations were not statistically significant under the loose market tension analysis. However, cost per mile was positively and statistically significantly correlated with every LTL metric, most notably with total tonnage and total shipments. Interestingly, load to truck ratio was correlated with variables it was not correlated with across the 6 year nor loose market tension analysis.

Table 10
Correlations for National LTL Carriers During Tight Market Tension Periods

Variable	Average Revenue Per CWT	Total Tonnage	Total Shipments	Average Revenue Per Shipment	Average Weight Per Shipment
1. DAT Load to Truck Ratio	.26	**.58***	**.55***	.34	.39
2. DAT Cost Per Mile	**.57***	**.83*****	**.75*****	**.65****	**.64****
3. TMC Route Guide Depth	.45	**.55***	.47	.49	**.51***

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

While DAT load to truck ratio was not correlated with LTL metrics when looking at data in simultaneous time periods, it was very correlated when we lagged the variable. Table 11 contains the results of our lag analysis with load to truck ratio. It had the highest correlation and most statistically significant two to three quarters before LTL metrics. Notably, total tonnage's correlation coefficient was largest, and thus most correlated when lagged four quarters - a complete year. Given the relatively weak coefficient and statistical significance at p < .1, it is likely this relation is not as strong as other LTL metrics, such as average weight per shipment, which have larger coefficients (.64 vs. 38) and more statistically significant results (p <.01 vs. p <.1). The variables lagged over several periods show that a positive correlation exists up until even 5 quarters away but reach their maximum typically at 2-3 time period lag. This indicates that there is some level of correlation for many prior periods and that it grows up until that maximum point, with the correlation again becoming weaker when moving towards simultaneous time period analysis.

Table 11
Correlations for National LTL Carriers with Lagged DAT Load to Truck Ratio

Variable	Average Revenue Per CWT	Total Tonnage	Total Shipments	Average Revenue Per Shipment	Average Weight Per Shipment
1. No Lag	.29	.15	.03	.24	.28
2. Lag 1 Quarter	**.49****	.32	.09	**.49****	**.53****
3. Lag 2 Quarters	**.59*****	**.37***	.10	**.59*****	**.64*****
4. Lag 3 Quarters	**.52****	**.38***	.11	**.58****	**.64*****
5. Lag 4 Quarters	**.28****	**.44***	.24	**.4****	**.46*****
6. Lag 5 Quarters	**.04****	**.38***	.27	**.29****	**.28*****

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

When looking at cost per mile, correlations were highest and most statistically significantly correlated when lagged one to two quarters, as shown in Table 12. For total tonnage, in contrast to load to truck ratio analysis above, which observed the maximum correlation at 4 quarter lagged, the maximum correlation for cost per mile was found at 2 quarter lag.

Table 12
Correlations for National LTL Carriers with Lagged Cost Per Mile

Variable	Average Revenue Per CWT	Total Tonnage	Total Shipments	Average Revenue Per Shipment	Average Weight Per Shipment
1. No Lag	**.40***	**.38***	.15	**.42****	**.56*****
2. Lag 1 Quarter	**.47****	**.47****	.17	**.54****	**.70*****
3. Lag 2 Quarters	**.42***	**.51****	.25	**.52****	**.61*****
4. Lag 3 Quarters	.27	**.47****	.29	**.43***	**.41***
5. Lag 4 Quarters	.02	**.38****	.29	**.23***	**.18***
6. Lag 5 Quarters	-.15	**.2****	.20	**.04***	**-.02***

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

Finally, route guide depth was more positive and statistically significant correlation when it lagged one to two quarters (same pattern as cost per mile), as depicted in Table 13. The exception again being total tonnage, which took three to four quarters to reach maximum correlation, similar to load to truck ratio.

Table 13
Correlations for National LTL Carriers with Lagged Route Guide Depth

Variable	Average Revenue Per CWT	Total Tonnage	Total Shipments	Average Revenue Per Shipment	Average Weight Per Shipment
1. No Lag	**.43****	.08	-.08	**.36***	**.39***
2. Lag 1 Quarter	**.53****	.23	-.04	**.53****	**.66*****
3. Lag 2 Quarters	**.53****	**.40***	.10	**.56****	**.72*****
4. Lag 3 Quarters	**.42***	**.49****	.22	**.49****	**.62*****
5. Lag 4 Quarters	**.15***	**.47****	.28	**.32****	**.43*****
6. Lag 5 Quarters	**-.08***	**.41****	.31	**.14****	**.23*****

*** $p < .01$, ** $p < .05$, * $p < .1$ Statistically significant results are highlighted in Bold.

To better compare the lagged results of the truckload market tension metric variables, we compared the lagged results to each other on the two LTL variables that were showing consistently high correlations: average revenue per shipment and average weight per shipment. For average weight per shipment, we see load to truck ratio and route guide depth perform similarly with positive, statistically significant correlations identified 5 quarters lagged but that the correlations gradually build until their maximum 2 quarters lagged. This contrasts with cost per mile, which has virtually no correlation 5 quarters lagged and instead builds very quickly to its maximum at a 1 quarter lag.

Table 14
Correlations for National LTL Carriers Average Weight Per Shipment lagged with TL Market Tension Metrics

Variable	5 Quarters Lag	4 Quarters Lag	3 Quarters Lag	2 Quarters Lag	1 Quarter Lag	No Lag
1. DAT Load to Truck Ratio	**.28*** **	**.46*** **	**.64*** **	**.64*** **	**.53** **	.28
2. DAT Cost Per Mile	**-.02* **	**.18* **	**.41* **	**.61*** **	**.70*** **	**.56*** **
3. TMC Route Guide Depth	**.23*** **	**.43*** **	**.62*** **	**.72*** **	**.66*** **	**.39* **

**** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

The results were similar when making the comparison for average revenue per shipment, as shown in Table 15. Once again load to truck ratio and route guide depth have a small, but statistically significant correlation beginning 5 months lagged and it gradually builds until it peaks at 2 quarters lagged. In contrast, cost per mile starts at a statistically significant no correlation at 5 quarters, but quickly builds to a similar correlation coefficient and peaks at 1 quarter lag.

Table 15
Correlations for National LTL Carriers Average Revenue Per Shipment lagged with TL Market Tension Metrics

Variable	5 Quarters Lag	4 Quarters Lag	3 Quarters Lag	2 Quarters Lag	1 Quarter Lag	No Lag
1. DAT Load to Truck Ratio	**.29** **	**.40** **	**.58** **	**.59*** **	**.49** **	.24
2. DAT Cost Per Mile	**.04* **	**.23* **	**.43* **	**.52** **	**.54** **	**.42** **
3. TMC Route Guide Depth	**.14** **	**.32** **	**.49** **	**.56** **	**.53** **	**.36* **

**** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

4.2 Model 2 - CHR LTL Metrics Correlation with TL Market Tension at a National Level

Our results show a statistically significant, positive correlation between CHR LTL volume and DAT truckload cost per mile. This was true for the entire time period, as well as looking within high and low market tensions. As above, the relationship was stronger during high market tensions. This overview is shown in Table 16.

*Table **16***
Correlations for C.H. Robinson Across 6 Years, High and Low Market Tensions

Variable	Overall (Entire Time Period)	Low Market Tension	High Market Tension
1. DAT Load to Truck Ratio	.18	.14	.27
2. DAT Cost Per Mile	**.44*****	**.29*****	**.62*****
3. TMC Route Guide Depth	**.30****	**.24****	**.54****

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

As we saw above for load to truck ratio, once we lagged the variable, we observed positive and statistically significant correlation, with the maximum being one to two months lag. DAT cost per mile similarly increased its statistical significance with a 1–3-month lag. Finally, route guide depth also became more correlated with a 2-3 month lag. These results are shown in Table 17.

Table 17
Correlations for TL Market Tension Metrics Lagged against C.H. Robinson LTL Volume

	Variable	3 Months Lag	2 Months Lag	1 Month Lag	No Lag
1.	DAT Load to Truck Ratio	**.31****	**.41*****	**.38*****	.18
2.	DAT Cost Per Mile	**.45*****	**.46*****	**.47*****	**.44*****
3.	TMC Route Guide Depth	**.45*****	**.38*****	**.35*****	**.30****

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

However, it should be noted that the cost per mile variable is also similarly correlated when it is pushed into the future. In other words, based on this result, LTL volume seems to impact cost per mile 1, 2, and 3 months into the future as well, as depicted in Table 18. The other two TL market tension metrics did not have this curious result.

Table 18
Correlations for C.H. Robinson LTL Volume Lagged against TL Market Tension Metrics

	Variable	No Lag	1 Month Lag	2 Months Lag	3 Months Lag
1.	DAT Load to Truck Ratio	.18	.08	.07	.03
2.	DAT Cost Per Mile	**.44*****	**.36*****	**.31****	**.28****
3.	TMC Route Guide Depth	**.30****	**.23***	.18	.12

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

4.3 Model 3 - CHR LTL Metrics Correlation with TL Market Tension at a Corridor Level

Overall, we find that cost per mile is positively correlated to LTL volume and statistically significant for 5 out of 10 lanes considered, while for RGD, we were only able to confirm a positive and statistically significant correlation in 2 lanes. Notably, neither CPM nor RGD, were correlated for the balanced longhaul from Southern California to Chicago - the only lane that did not display any statistical significance for either variable in either direction. Recall, load to truck ratio cannot be considered when performing the analysis on a corridor level as this indicator is missing the required geographical granularity. Presented below in Table 19 is an overview of results on a corridor level, followed by corridor level results in Tables 20 through 24.

Table 19
Correlations for CHR LTL Volume to Key TL Metrics

Variable	TL RGD	TL CPM
1. LTL Volume South California to Texas	-.07	**-.22****
2. LTL Volume Texas to South California	**.44*****	**.46*****
3. LTL Volume South California to Chicago	.03	.03
4. LTL Volume Chicago to South California	.11	.07
5. LTL Volume Boston to Harrisburg	.05	.01
6. LTL Volume Harrisburg to Boston	**.44*****	**.53*****
7. LTL Volume Atlanta to South Florida	**-.19***	**.8*****
8. LTL Volume South Florida to Atlanta	.04	**.38*****
9. LTL Volume California South to North	-.16	-.14
10. LTL Volume California North to South	.09	**.22***

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

Balanced (California to Texas)

Table 20 shows a positive correlation for LTL volume to CPM from Texas to South California while a negative correlation in the opposite direction. This is notable as we recorded a statistically significant negative correlation only twice and our hypothesis is that results would indicate a positive correlation. While significant at the .05 level, it is possible this is simply a case of a Type 1 error (False-positive), where the null hypothesis that the value is equal to 0 is rejected, when it should be accepted.

Table 20

Correlations for CHR LTL Volume to Key TL Metrics: Balanced Corridor

	Variable	TL RGD	TL CPM
1.	LTL Volume South California to Texas	-.07	**-.22***
2.	LTL Volume Texas to South California	**.44*****	**.46*****

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

Balanced Longhaul (South California to Chicago)

It was not possible to identify any statistically significant correlation in the balanced longhaul segment for both directions, as depicted in Table 21. In the discussion section, we formulated hypotheses of what could drive these results.

Table 21

Correlations for CHR LTL Volume to Key TL Metrics: Balanced Longhaul

	Variable	TL RGD	TL CPM
1.	LTL Volume South California to Chicago	.03	.03
2.	LTL Volume Chicago to South California	.11	.07

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

Unbalanced Northeast (Boston to Harrisburg)

When it comes to unbalanced northeast, we found no statistically relevant correlation between any key metrics in the Boston to Harrisburg lane but statistically valid correlations across 2 key metrics in the Harrisburg to Boston lane. In particular CPM and RGD show a strong positive correlation. These are shown in Table 22.

Table 22

Correlations for CHR LTL Volume to Key TL Metrics: Unbalanced Northeast

Variable	TL RGD	TL CPM
1. LTL Volume Boston to Harrisburg	.05	.01
2. LTL Volume Harrisburg to Boston	**.44*** **	**.53*** **

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

Unbalanced Southeast (Atlanta to South Florida)

The Unbalanced Southeast corridor results had a strong positive and statistically significant correlation between CPM and LTL volumes in both directions while we were not able to confirm a strong and significant correlation between RGD and LTL volumes. We again observed a surprising finding or a potential Type 1 error, with LTL volume being negatively correlated with TL RGD from Atlanta to South Florida. These results are shown in Table 23.

Table 23

Correlations for CHR LTL Volume to Key TL Metrics: Unbalanced Southeast

Variable	TL RGD	TL CPM
1. LTL Volume Atlanta to South Florida	**-.19***	**.80*** **
2. LTL Volume South Florida to Atlanta	.04	**.38*** **

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

Instra-State (California South to North)

The Intra-State corridor shows a statistically significant and positive correlation between CPM and LTL volumes in the lane from Northern to Southern California. It was not possible to confirm any statistically significant correlation between RGD and LTL Volume. These results are shown in Table 24.

Table 24

Correlations for CHR LTL Volume to Key TL Metrics: Intra State

Variable	LTL RGD	TL CPM
1. LTL Volume California South to North	-.16	-.14
2. LTL Volume California North to South	.09	**.22***

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

4.4 Model 4 - CHR LTL Metrics and TL Market Tension Correlation with PMI at a National Level

This model showed a statistically significant and positive correlation between the PMI and the TL cost per mile, CHR LTL volume, and CHR cost per CWT. The model shows a weak positive and statistically significant correlation between PMI and LTL volume. The results were a strong positive and statistically significant correlation between PMI and TL CPM, as shown in Table 25.

Table 25
Correlations for PMI to Key Metrics

Variable	LTL Volume	LTL CWT	DAT Load to Truck Ratio	TL CPM	TL RGD
1. PMI	**.02*** **	**.20*** **	**.62***	**.54*** **	.80

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

In table 26 we provide results of a lag analysis while in Table 27 we provide results of a lead analysis.

Table 26
Correlations for Lagged PMI to Key LTL and TL Metrics

Variable	LTL Volume	LTL CWT	DAT Load to Truck Ratio	TL CPM	TL RGD
1. No Lag	**.02*** **	**.20*** **	**.62***	**.54*** **	.80
2. Lag 3 Months	-.08	.11	**.56*** **	**.34*** **	**.8*** **
3. Lag 6 Months	-.14	.01	**.37*** **	.10	**.63*** **

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

Table 27
Correlations for PMI to Lagged Key LTL and CHR TL Metrics

Variable	LTL Volume	LTL CWT	DAT Load to Truck Ratio	TL CPM	TL RGD
1. No Lag	**.02*** **	**.20*** **	**.62***	**.54*** **	.80
2. Lead 3 Months	.11	**.20***	**.45*** **	**.58*** **	**.54*** **
3. Lead 6 Months	.19	**.29** **	**.25** **	**.48*** **	**.21***

*** p <.01, ** p <.05, * p <.1 Statistically significant results are highlighted in Bold.

Both tables show positive and statistically significant correlations. This means that when we either lag or lead the series of data, the correlations remain significant. Although it is possible for two time series to remain positively correlated during lead and lag analysis, this could also be an indication of a different underlying relationship between the two series. This relationship should be further researched. Based on this preliminary analysis, we are not considering the PMI as a good indicator of freight migration between the different modes, at least with regards to C.H. Robinson LTL volume.

5 DISCUSSION

5.1 Synthesis of Results Across Models

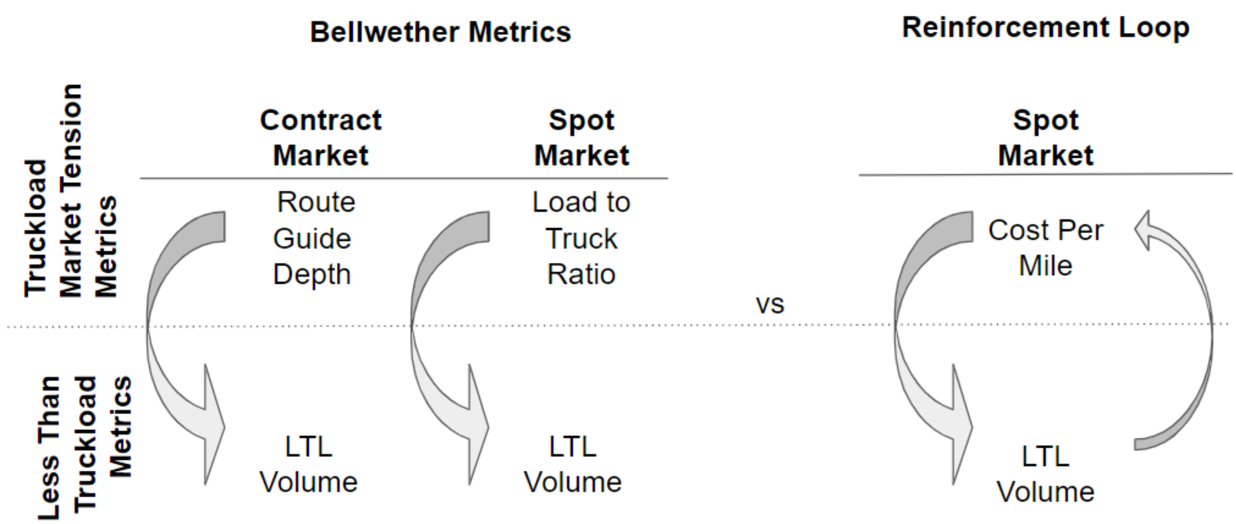
Overall, our results showed a positive correlation between LTL variables and lagged TL market tension metrics for both the spot market and contract market through load to truck ratio and route guide depth, respectively. More specifically, we found that both load to truck ratio and route guide depth were positively correlated for Public LTL and C.H. Robinson LTL data, though this relationship was absent at the corridor level. This may be because both Model 1 and Model 2 included lag analysis, but Model 3 did not. We further tested whether LTL volume impacts future load to truck ratio and route guide depth, and found those values were not correlated. For this reason, they are effective bellwether[2] variables. Figure 5 depicts the general relationships across our models. We found that lagging our truckload market tension variables increased the correlation and increased the statistical significance. The exact lag varied for each correlation pair but was generally 1-2 quarters for Public LTL and 1-3 months for C.H. Robinson. Notably, each of these variables can be considered a metric that captures service level within the shipping industry. Route guide depth is an indicator of service as you want to utilize your preferred shipping vendor when moving freight. Anything below your first choice means that you are using more time and resources to move your freight. Load to truck ratio captures service because when it is high, a given load has lots of competition to secure a truck. It may

[2] In economics, a 'bellwether' is a leading indicator of a change that may occur in the broader system.

not secure that truck right away. So, our findings are applicable across the spot and contract market and point to a strong impact of service metrics on future LTL variables.

Figure 5

Overview of TL Market Tension Relationship to Public LTL and CHR LTL Metrics based on Models 1-3



By analyzing the lag analyses, we were able to identify which truckload market tension metrics were showing strong correlations with future LTL variables earliest and which metrics were strongest correlated. Understanding these two data points can be particularly useful for C.H. Robinson and the LTL community. For Model 1, we saw strong, statistically significant positive correlations for load to truck ratio (.46***) and route guide depth (.43***) beginning at 4 quarters lag. This is quite an early indicator, and it strengthens at 3 quarters and 2 quarters. The strongest correlation was 2 quarters lag for route guide depth (.72***). These correlation values were very high for average weight per shipment. In Model 2, the strongest early indicator we observed strong correlation values at a 3 month lag for route guide depth (.45***) on C.H. Robinson LTL Volume, while the strongest overall correlation was for cost per mile at 1 month lag (.47***). From this, we also observed stronger correlations for the public LTL data than for C.H. Robinson. This indicates that the theory behind the market freight movement holds truer for the entire industry than it does for C. H. Robinson.

While our overall results showed a positive correlation between LTL variables and TL cost per mile, as indicated in our Model 1, Model 2, and 5 of the 10 corridor pairs in Model 3, we believed this relationship to be more complex and less useful for the LTL community and C.H. Robinson. Recall this positive correlation means that as TL cost per mile increases, so do LTL volumes. Our hypothesis is that because of the increase in price of TL rates, more freight is being moved to other means such as LTL. But when the prices for TL drop, then LTL volume shifts back to the most convenient and quickest shipping option. However, the lag and lead analysis showed unexpected results that LTL volume was also correlated to future TL cost per mile. We were unable to identify the business process that would explain this in reality. For this reason, it may not be an effective bellwether variable. One way to imagine this relationship is a cycle, where one variable impacts the other, which impacts the original variable. In other words, a reinforcing feedback loop. Figure 5 represents the relationships we observed. Cost is the variable that leads to the quickest (shortest lag) because it directly impacts shippers' bottom line, and they will respond quickly to changes there. While cost per mile had the largest correlation to LTL volumes, LTL volume was also correlated to CPM, which we did not observe on the other variables. Table 28 summarizes the effectiveness of each truckload market tension metric based on the various tests we conducted.

Table 28
The Best Bellwether: Overview of Tests Performed on TL Market Tension Metrics

Variable	Test 1: Statistically Significant Correlation	Test 2: TL Market Tension leads LTL Variable	Test 3: LTL Variable does NOT lead TL Market Tension
1. DAT Load to Truck Ratio	Yes	Yes	No
2. DAT Cost Per Mile	Yes	Yes	Yes
3. TMC Route Guide Depth	Yes	Yes	Yes

One interesting take-away was that the LTL variable most correlated with TL market tension metrics changed from Model 1 to Model 2. For Model 1, we displayed results from average revenue per CWT, total tonnage, total shipments, average revenue per shipment, and average weight per shipment. Total shipments were not correlated in any of our analyses in Model 1 and total tonnage was the second least correlated variable. However, in Model 2, we mainly used C.H. Robinson LTL volume, and found numerous statistically significant positive correlations. This would be the same as Public LTL total shipments. We believe that the different LTL variables showing the strongest strength with TL market tension metrics across Models demonstrated the strength of the overall relationship between TL market tension and the LTL business.

5.2 Model 1 - Public LTL Metrics Correlation with TL Market Tension at a National Level

Model 1 results found that TL market tension metrics were positively and statistically correlated with national public LTL data. This is an important relationship to evaluate because it is our largest geographic and LTL coverage. Interestingly, we do not find strong relationships with total tonnage and no correlation with total shipments; but instead find strong positive correlations with average revenue per CWT, average revenue per shipment, and average weight per shipment.

We were surprised that the correlations held up so clearly despite the relatively small number of observations. Recall, the state of the art recommends 25 data points minimum for Pearson's correlation and our model only had 24, with 0 lags. We believe the model is helped by including a built-in, effective lag of 1 month, as depicted in Table 29. Because the data is aggregated at a quarterly level, it means that within each quarter, there were values for 3 months within each observation. The 3rd month effectively included a lag of 2 months, and the 2nd month basically includes a lag of 1 month. When averaged out with the 1st month having 0 lagged months, the weighted average was 1 month.

Table 29
How Quarterly Analysis Includes 1 Month of Lagged Variables

Quarter	Month	Y (LTL Variable)	X	Effective Lag When Grouped Quarterly
1	January	#	#	0
1	February	#	#	1 (Jan)
1	March	#	#	2 (Jan & Feb)
			Total	(.33 x 0) + (.33 x 1) + (.33 x 2) = 1

5.3 Model 2 - CHR LTL Metrics Correlation with TL Market Tension at a National Level

Model 2 results found that TL market tension metrics were positively and statistically correlated with C.H. Robinson LTL data. This validated that C.H. Robinson business is large and moves in sync with the larger LTL business cycles. However, we did find that the relationship was less strong, compared to Model 1, in terms of correlation values. Further, the variables that were correlated were different: LTL volume was now statistically and positively correlated, whereas it was not in Model 1. We believe this shows the unique business that C.H. Robinson has built. The results of this model also provided an unexpected result that LTL volume was correlated with future cost per mile. We were unable to find any solid business intuition or hypotheses that would explain this positive reinforcement cycle. Potentially, it could be disproportionately driven by the high-tension period during COVID-19.

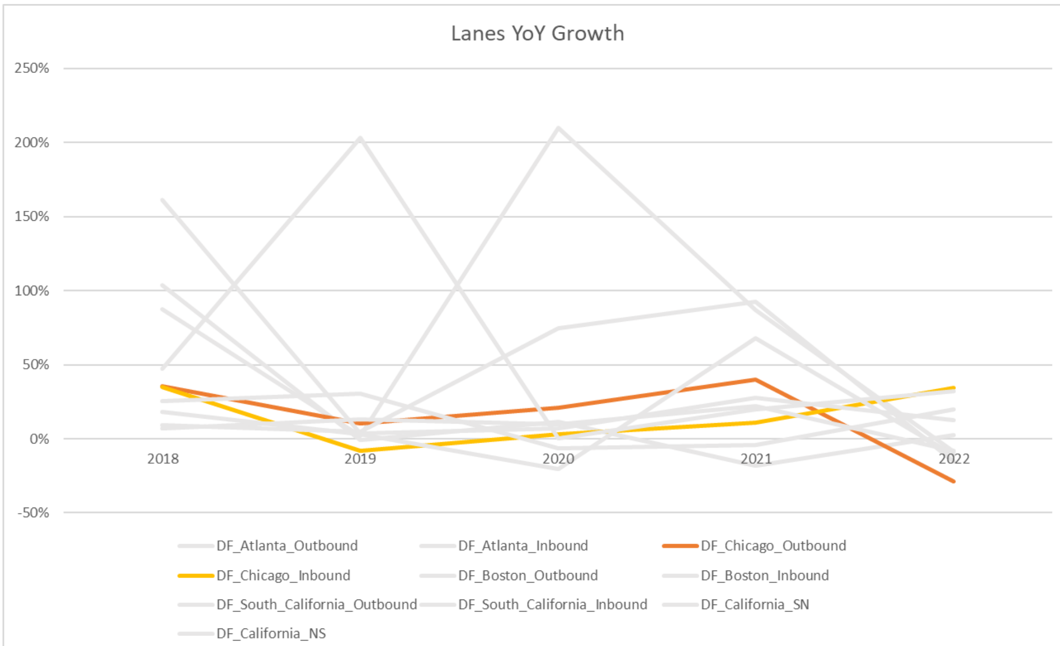
5.4 Model 3 - CHR LTL Metrics Correlation with TL Market Tension at a Corridor Level

Model 3 results found, interestingly, that what is true at the national level, is not necessarily true at the lane level. Recall, this model is unable to evaluate load to truck ratio. Route guide depth was positively and significantly correlated on only two of the ten directions of the five corridors, while negatively correlated on one. Cost per mile was positively and significantly correlated on five of the ten corridors, while negatively correlated on one of the ten corridors.

Since we observed cost per mile positive and statistically significant correlation in at least one direction on four of the five corridors, we investigated further that happened on the one corridor. From private discussions with C.H. Robinson (2023) and exploration of the data, we had several hypotheses why the balanced longhaul from Southern California to Chicago does not demonstrate any statistically significant correlations in either direction, while the other four corridors do. First, it is possible that this corridor is better served by rail modal than the other lanes. This would make the relationship between TL and LTL modals weaker. Secondly, this corridor may have more suppliers able to pick up excess capacity, thus reducing the relationship between the modes. From personal conversations with C.H. Robinson (2023), these two theories are mostly likely. Thirdly, it is possible that this corridor has grown more significantly than the other four lanes. This means that when we made the data stationary by removing the trend, we removed more of the variation in this lane than experienced in the other lanes. We were able to test this hypothesis, by graphing year over year growth of each corridor and no longer believe this to be a reasonable theory; as shown in Figure 6, the Chicago-South California inbound and outbound growth rate are not outliers.

Figure 6

Lanes Year Over Year Volume Growth



Finally, it is possible the underlying relationship holds true here, only that the lag between TL market tensions and LTL volume were longer here than the other lanes. For this theory, instead of TL market tension moving 1-2 months prior to LTL, and thus still having a statistically significant correlation during the present time evaluation, perhaps the true relationship would be strongest 3-4 months and thus the positive correlation fades by the time of our evaluation.

4.5 Model 4 - CHR LTL Metrics Correlation and TL Market Tension with PMI at a National Level

Model 4 results found that the PMI is positively and statistically significantly correlated with key TL market tension metrics, but less so with C.H. Robison LTL variables. The PMI is widely used in the trucking industry for monitoring the sentiment of the economy and to estimate the future direction of the trucking economy. While it is generally accepted within the industry that the PMI positively correlated with LTL volumes, the model showed a weak correlation between CHR data and the PMI. The model was able to confirm a strong correlation between the PMI and TL cost per mile.

Our research also performed a lead and lag analysis on this indicator but in both cases the analysis showed a strong correlation. This is the same evaluation done in Model 2 to test whether the indicator is a good bellwether indicator. This pattern should be further explored before concluding that the PMI predicts any TL or LTL metric. Similarly, these results should be tested for National LTL carriers, rather than only C.H. Robinson LTL data. Therefore, we do not consider the PMI as a good indicator of freight migration between the different modes, at least with regards to C.H. Robinson LTL volume.

6 CONCLUSION

6.1 Insights and Management Recommendations

Our research found a positive, statistically significant correlation for key truckload market tension metrics, including from the contract market (route guide depth) and the spot market (cost per mile and load to truck ratio), especially when lagged 1-3 months. We found this relationship to be true for National Public LTL Carrier data as well as private C.H. Robinson data. However, because the cost per mile data is correlated with future LTL volume and LTL volume is correlated with future cost per mile, we believe route guide depth and load to truck ratio to be better bellwether indicators. Only cost per mile is reliably correlated when zooming into five specific corridors, but we have reservations about it given the unique LTL-relationship property mentioned above. We believe the national findings did not apply to corridors simply because each corridor represents a unique mix of transportation modes (TL, LTL, Rail), with a different amount of capacity, and with a different amount of total freight. We then evaluated the PMI as it is generally accepted that this correlates with TL and LTL Volumes. Although our research has found a positive correlation with TL CPM, we did not find a relationship with CHR LTL data.

There are several business applications of this research. C.H. Robinson can monitor load to truck ratio and route guide depth and given the 1–3-month lag time, alert clients to coming market tension in LTL and advise clients to secure capacity. Similarly, they can alert customers to potential cost savings opportunities coming into the LTL market. Often freight brokerages are asked when the best time is to run a tender. Given this research, C.H. Robinson can advise that within 1-3 months of the TL freight market tension decreasing is when the impact on LTL carriers will be felt. Given that the tender process often takes at least two months, shippers should begin the tender approximately 1 month after the TL market tension decreases. Our results suggest that this would be the best time to run a tender as they would likely offer competitive pricing. Finally, C.H. Robinson can demonstrate thought leadership in the unique predictive power of TL market tension when helping clients design freight transportation. For instance, potentially beginning to reframe the PMI as a leading TL indicator rather than leading C.H. Robinson LTL indicator. C.H. Robinson should instead use TL market tension as the superior C.H. Robinson LTL leading indicator.

6.2 Future Research

While this research has found support that truckload market tension metrics are positively correlated with key LTL business metrics usually with a lead time of 1 to 2 months, there have been new additional questions raised. First and foremost, researchers could build upon this work by incorporating lagged truckload market tension metrics into a forecasting model for LTL business outcomes. The LTL community could benefit in understanding if there is a tipping point for TL market tension, that once they pass a certain value, then the correlation values really improve. To quantify this relationship, they could use a partial dependence plot, which is a methodology employed to understand how a model's predictions change as a selected feature of the model is varied while all other features are kept fixed. And finally, due to the market changing over the past few years, is the relationship between these variables getting stronger or weaker?

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