AN EMPIRICAL STUDY OF TRUCK PAYLOAD ALLOCATION

Areekamol Tor.Chaisuwan, Nakorn Indra-Payoong, Sarawut Jansuwan

Faculty of Logistics, Burapha University, Chonburi, Thailand 20131
E-mail: {areekamol, nakorn.ii }@gmail.com
Department of Civil and Environmental Engineering, Utah State University, Logan UT 84322
E-mail: sarawut.j@aggiemail.usu.edu

Abstract:
This study estimates the number of trucks by type and the level of service on the Interstate highway 15 (I-15) located in Utah. Since an increasing number of trucks affect the efficiency of the highway, providing the trips by truck types, body types and commodity types can be more clearly analyzed the relationship between density and delay on the highway. The predicted commodity flow data from the Freight Analysis Framework version 3 of the United Stated Department of Transportation in the year 2015 is derived. The truck allocation factors are modified to convert the commodity flow data to the annual average daily truck traffic (AADTT). The results have shown that the degree of saturation on the I-15 highway for the year 2015 approaches a full capacity, requiring a short-term transport solution.

Keywords: Freight analysis frame work, Truck trip allocation, Freight flow estimation, Average daily truck traffic, Highway network performance, Truck payload allocation

1. Introduction

The objective of this research is to represent a practical application to estimate the Annual Average Daily Truck Traffic (AADTT) in Utah, the United States. Because of Freight Analysis Framework FAF^3, the national commodity flow data does not provide AADTT directly, instead it is used for Vehicle Inventory and Use Survey (VIUS, 2002) to estimate AADTT by using commodity flows. According to the Federal Highway Administration (FHWA) and U.S. Department of Transportation (USDOT), the freight flow model was first released in 2002 based on 1998 commodity flow data. The FAF has been applied to a variety of transportation analysis including highway capacity and bottleneck assessments. In addition, the truck size and weight studies have applied the FAF for the evaluation of investments in transportation infrastructure, impacts of changes in road pricing policies, multimodal freight policy analysis, , and impacts on national freight movement of natural and manmade disasters. The current version is FAF version 3.

The commodity flow data was updated and enhanced by Oak Ridge National Laboratory (ORNL) for FHWA to estimate the dollar value and tons of shipments between freight origin-destination (O-D) including 123 regions 8 international zones 7 transport modes and 43 Standard Classification of Transported Goods (SCTG) in 2007, and those commodity flows were classified by the commodity types and modes of transport. The FAF^3 2007 is benchmarked as a base year and forecasted for every 5 years through 2040. The FAF^3 database is used to support various Federal needs related to policy and legislative issues for transport planning. In addition, the FAF^3 is used for several projects prepared for FHWA, State DOTs and metropolitan planning organizations (MPOs), and is also used to serve many public and private sectors for transportation planning proposes.

Battelle (2011) conducts a national highway freight analysis to estimate the base year 2007 and the 2040 forecasted FAF truck flow, and studies the congestion related to the highway network. The freight traffic analysis covers 7 areas is used to determine truck trips, payload and passenger car equivalent factor. According to a current truck payload equivalent factor, there is no direct source of information on the number of truck trips between origin and destination. For development of FAF^2 truck O-D matrix, they provide the procedures to convert the commodity flows (in tons) into the equivalent number of annual laden and empty trucks by using truck allocations with specified distance ranges and truck equivalent factors. The 2002 Vehicle Inventory and Use Survey (VIUS) data is used for estimation.

Gillett (2011) calculates a delay cost for long haul single unit and combination trucks to assess the highway performance by identifying the congested locations where current or future delay are likely to occur. An Interstate-75, 160 miles from Macon to the Georgia-Florida border is studied. The delay cost is calculated by taking speed, volume, distance, types of truck, and types of commodity into account. In order to obtain the value of freight by truck and commodity types, the FAF^3 is used as the data source together with the average truck speed surveyed by American Transportation Research Institute (ATRI)and traffic volume collected by Georgia Department of Transportation (GDOT). To calculate the delay cost, the commodity values moved by truck from 43 SCTG commodities are grouped into 3 categories: high, moderate and low time sensitive. The tons of commodities are converted to the number of trucks by the truck equivalent factors similar to Battelle (2011), in order to estimate the number of trucks by single and combination types moved through the corridor. In the study area, the range of 101-200 miles travel distance is considered. Truck trips derived from the above database are assigned to freight transportation network. The critical links are then identified and prioritized for the future improvement scheme. Virginia Department of Transportation (VDOT, 2005) studies the freight trucks from I-81 that are diverted to rail by using the Intermodal Transportation and Inventory Cost model. The truck movement in I-81 is forecasted using Truck Trip Analyzer (TTA) model. Two types of survey questionnaires are compared with freight forecasting model. The truck trip estimation is developed using a variety of data sources including 1997 VIUS, 1998 TTA and 1998 VDOT freight flow data. The standard commodity flow data is allocated to traffic analysis zones. Then, sets of different load factors are used to convert tonnage to truck trips. They also create the adjustment factor that reflects empty truck movement. The economic input-output techniques are used to identify link production and supply center with local consumption. Mesa-Arango *et al.* (2010) evaluate the economic impact of disruption for transportation policy decisions. The study areas include: the northeastern part of Illinois, the northern part of Indiana, and the small part of southwestern Michigan, resulting to 467 zones. The consequences of network disruptions are in various forms including fatalities, infrastructure destructions, and economic losses. To quantify the consequences of disruption, they evaluate the economic impact from the commodity movement data. The purposed model is based on the state of the art in economic concepts that quantify the impacts at a regional level. A framework is based on four input data sources: FAF^3, Transportation Analysis Zones (TAZs), a disruption scenario, and vehicle operational cost and value of time. Jin (2011) uses 2007 CFS (Commodity Flow Survey) data of Utah's state highway network for predicting truck freight flow on state truck routes. A state-wide truck freight demand model is developed for estimating truck traffic at any point on its highway. The assumption and the developed model are set that freight trips are the same behavioral mechanism as passenger trips. The county-level multiple regression models are developed using GIS and statistical data: a physical distance, Euclidean distance, and population and employment data. The commodity flow are also converted to truck trips using the $FAF^{2.2}$ estimation method (FHWA, 2006), and assigned to Utah's truck routes using all-or-nothing assignment in TransCAD together with a modified genetic algorithm. The results indicate that using freight flow and land use data could be practical for modeling truck traffic demand on a state-wide truck route.

ULTRANS (2011) develops a model to forecast long-haul commercial vehicles (greater than 50 miles on travelling distance). The development of the Long Distance Commercial Vehicle Model is based on California spatial economic data: Production, Exchange and Consumption Allocation System (PECAS) modeling framework. It uses an aggregate, equilibrium structure with separate flows of exchanges, i.e. goods, service, labor and space going from production and consumption based on coefficients and market prices conversion of the year 2000 PECAS commodity flow to weekday truck flow. The 2002 FAF data is a primary source of factors to convert PECAS from dollar flows to truck flows. The appropriate weight derived from IMPLAN data is also used to convert the truck flows classified using Standard Transportation Commodity Classification (STCC) codes to PECAS commodity categories. The estimated ranges of truck trip by commodity are compared with the observed trip lengths. To convert the commodity flow data to ADTT, it requires the number of truck trips passing through a particular highway section between freight O-D pairs. Currently, the indirect method to estimate the truck trips between state-wide O-D pairs is provided by FHWA (Alam, 2010) and a truck payload equivalent factor is introduced by using 2002 VIUS database.

In our study, the process to convert FAF^3 commodity flow data to ADTT is shown in Figure 1. To allocate ADTT by commodity types and percentage share in Utah, the driving distance of trucks is determined. The truck movement within Utah is limited to 201-500 miles, and from-to Utah commodity flow is greater than 500 miles. Once the distance ranges have been specified, the ADTT by truck and body types can be allocated. Table 1 and 2 show FAF^3 truck configuration (Truck types) and truck body types. For the truck allocation factors, we follow the VIUS2002 as shown in Table 3.

To obtain the number of truck trips from FAF^3 commodity in tonnage on highway for a specific O-D pair, the distance range is defined. For example, if O-D travel distance is 245 miles, the distance range 201-500 miles is considered. Then, each commodity type is proportioned to each type of truck using the allocation number in Table 3. After that, truck equivalent factors will be used to allocate the commodity weight to the number of trucks by specific body type.

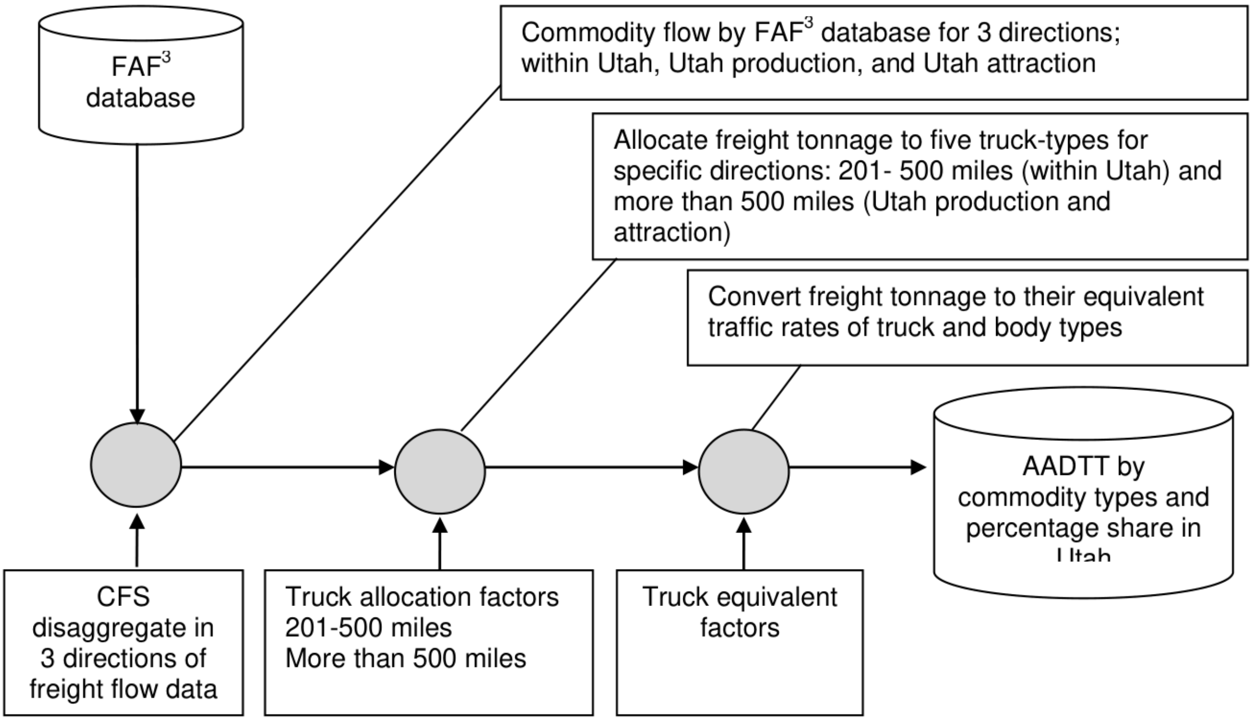

Figure1 Truck payload allocation diagram (Battelle, 2011)

Table1 FAF^3 truck configuration

Group	Abbreviation	Description
1	SU	Single unit truck
2	TT	Truck plus trailer combination
3	CS	Tractor plus semi-trailer combination
4	DBL	Tractor plus double trailer combination
5	TPT	Tractor plus triple trailer combination

Table 2 FAF^3 truck body types

Body	Truck Fleet	Description
1	37.72%	Dry van
2	24.37%	Flat bed
3	14.73%	Bulk
…	…	…
9	2.33%	Others

Table 3 FAF^3 truck allocation factors

Min. Range (miles)	Max. Range (miles)	SU	TT	CS	DBL	TPT
0	50	0.793201	0.070139	0.130465	0.006179	0.0000167
51	100	0.577445	0.058172	0.344653	0.019608	0
101	200	0.313468	0.045762	0.565269	0.074434	0.000452
201	500	0.142467	0.027288	0.751628	0.075218	0.002031
501	10000	0.064660	0.014900	0.879727	0.034143	0.004225

2. Data collection

The state of Utah is a case study of our research; it is bordered by Colorado on the east, Wyoming and Idaho on the North, Arizona on the South and Nevada on the west as shown in Figure 2. In Utah, the freight transport demand has been rising steadily and the forecast shows the continued growth for the next two decades (Jansuwan *et al.*, 2010). According to FAF[3] the top five commodity tonnages in 2007 are: non-metal, mineral products, gravel, coal waste/scrap, and gasoline, and these commodities account for almost two-third (i.e. 63.48%) of total commodity flow in the State of Utah.

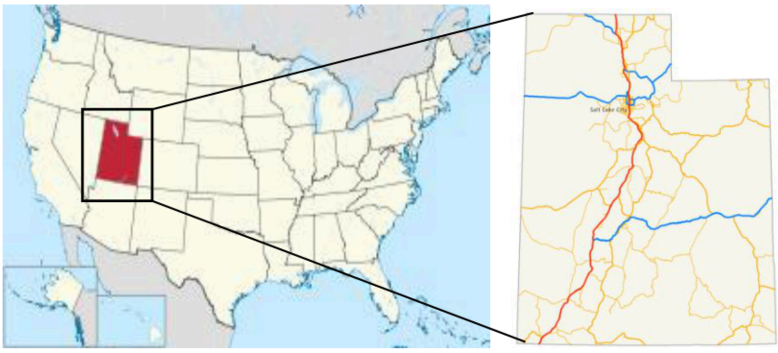

Figure 2 The U.S. Interstate-15 in the study area (i.e., red line)

According to FAF[3] database, we can derive a percentage share of transport modes in Utah. The largest modal share in Utah is truck (63.67% in base year 2007) and its trend has been increasing continuously (See Figure 3). Considering freight tonnage by the direction of truck movement, the commodity flow within Utah is accounted for 105.49 million tons, from Utah to other states (Utah production) is 18.21 million tons, and from other states to Utah (Utah attraction) is 20.89 million tons as shown in Figure 4.

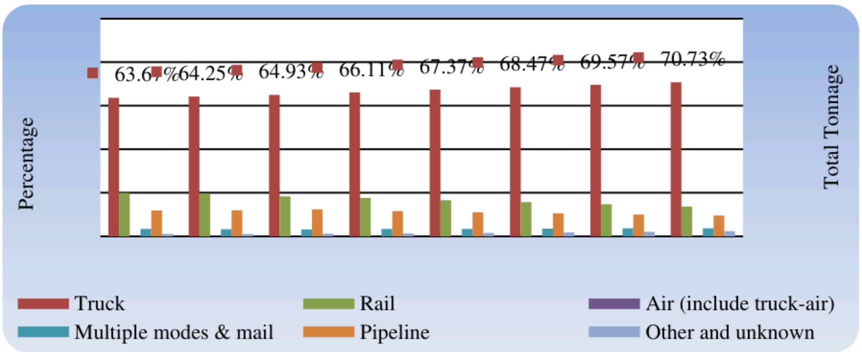

Figure 3 Projection of commodity flow and modal share by volume in Utah from 2007 to 2040

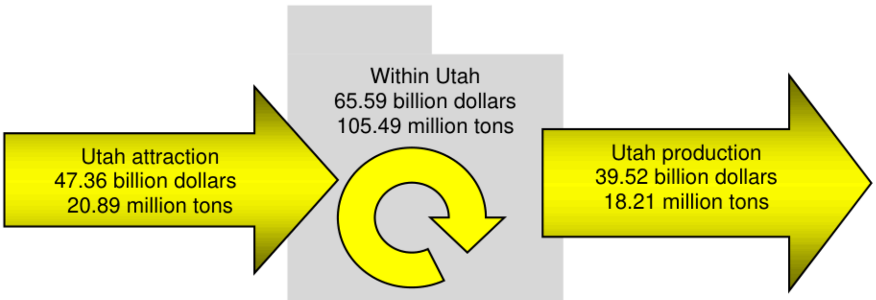

Figure 4 Direction of truck movement in Utah by dollar value and tonnage (2015)

Table 4 FAF[3] Utah commodity flow survey attraction (2015)

Ranking No.	SCTG Code	Commodity Type	Tonnage 2015 (x1000 tons)			Total
			Within Utah	Utah Production	Utah Attraction	
1	31	Nonmetal min. prods.	16,442.38	947.49	1,164.71	18,554.57
2	15	Coal	18,181.49	156.36	3.67	18,341.52
3	41	Waste/scrap	12,338.83	88.19	1,293.09	13,720.10
…		…	…	…	…	…
43	09	Tobacco prods.	7.70	0.05	1.99	9.74
		Total	105,489.95	18,214.08	20,889.02	144,593.95

Table 4 shows the commodity survey (CFS), forecasted to the year 2015 and extracted to specific areas, using FAF data tabulation tool.

3. Truck payload allocation

In our paper, the AADTT by truck types, body types, and commodity types is estimated using the FAF[3] freight analysis framework. The VIUS 2002 with Truck Payload Equivalent (TEP) is also used for model calibration as described in equations below:

Notations:

Y_j : the number of trucks in type j, where j =1, 2,...,5

X_i : tonnage of commodity i, where i =1, 2,…,43

β_{ijk} : fraction of commodity i moved by truck type j with body type k, where k = 1, 2,…,9

ω_{ijk} : mean payload of moving commodity i by truck type j with body type k

$X_i\beta_{ijk}$: tonnage of commodity X_i carried by truck type j and body type k

$X_i\beta_{ijk} / \omega_{ijk}$: the number of trucks j with body type k required to move $X_i\beta_{ijk}$ tons

For example, the number of trucks, type $Y_{j=1}$ (i.e., Single unit truck: SU) and $Y_{j=2}$ (i.e. Trucks plus trailer combination: TT) used to move $X_i\beta_{ijk}$ tons of commodity disaggregate direction $X_{i=1}$ (i.e. Live animals/fish, Cereal grains, etc.) by all body types (i.e. Dry van, Flat bed, Bulk, etc.) are calculated as:

$$Y_{j=1} = \frac{X_i\beta_{i11}}{\omega_{i11}} + \frac{X_i\beta_{i12}}{\omega_{i12}} + \frac{X_i\beta_{i13}}{\omega_{i13}} + ... + \frac{X_i\beta_{i19}}{\omega_{i19}} = \sum_{k=1}^{k=9} \frac{X_i\beta_{i1k}}{\omega_{i1k}}$$

(1)

The total number of trucks assigned to move commodity X_i and the total number of trucks assigned to move all commodities are given by equations

$$Total\_Trucks = \sum_{i=1}^{i=43} X_i \sum_{j=1}^{j=5} \sum_{k=1}^{k=9} \frac{\beta_{ijk}}{\omega_{ijk}}$$

(2)

The tonnage to truck conversion factor or truck equivalent factor is therefore given by:

$$TEF_{ijk} = \frac{\beta_{ijk}}{\omega_{ijk}}$$

(3)

where: TEF_{ijk} is the factor that converts tons of commodity to equivalent number of trucks classified by truck type (configuration), body type, and commodity type.

Example: Truck conversion 2015
The example for converting FAF[3] data uses the largest commodity flow (type 31- nonmetal min. prod) within Utah in the year 2015. The result shows the number of trucks in a single unit type ($Y_{j=1}$).

Table 5 FAF[3] calculation data

Data	Value
Direction of commodity	Within
SCTG code-Commodity	31-Nonmetal mineral products
Tonnage ($X_{i=31}$)	16,442,376.06 Tons
Distance range	201-500 miles

Table 6 Tonnage Alllocated to the five truck types of range 201-500

		Allocation Factor (ω_{ijk})	Value (tons)
Single unit	SU	0.142467	2,342,495.99
Truck trailer	TT	0.027288	448,679.56
Combination semitrailer	CS	0.751628	12,358,550.23
Combination double	DBL	0.075218	1,236,762.64
Combination triple	TPT	0.002031	33,394.47

Table 7 Truck equivalent factor for nonmetal min. products, $i = 31$

Body Type (k)	Truck Equivalent Factor (β_{ijk})				
	SU	TT	CS	DBL	TPT
Dry van	0	0	0	0	0
Flat bed	0	0	0	0	0
Bulk	0.00404	0.0194	0.00288	0.00429	0.02181
…	…	…	…	…	…
Other	0.01456	0.01178	0	0	0

Table 8 Annual truck traffic within Utah for nonmetal min. products

	SU	TT	CS	DBL	TPT
Dry van	0	0	0	0	0
Flat bed	0	0	0	0	0
Bulk	31.55	29.01	118.64	17.69	2.43
…	…	…	…	…	…
Other	113.69	17.62	0	0	0
Total truck (Y_j)	227.85	72.16	1,410.52	95.81	2.43

$Y_{j=1}$ = ((16,442,376.06)(0.142467)(0)+ (16,442,376.06)(0.142467)(0)+…+(16,442,376.06) (0.142467)(0.01456))/300 = 227.85 SU trucks

To calculate all types of trucks for commodity nonmetal mineral products, We follow the procesing steps as shown in Table 5 to 8. The results of AADTT allocated by truck types, body types, and commodity types are presented in the following section.

4. Empirical results

Apart from FAF[3] database that shows only freight tonnage, our results represent 2015 AADTT allocated by truck types, body types, and commodity types (see Table 9 - 11). In Utah, a majority of truck type used to transport the top five products is a tractor plus semi-trailer combinations (CS) as shown in Figure 5, along with the direction of freight movement shown in Figure 6. The AADTT by body types and commodity types is shown in Table 12. The projected commodity flow data in Utah for the year 2015 is estimated to 5,429 thousand trucks. The percentage share of single unit truck (SU) within Utah is the largest proportion accounted for 16.70% while the SU for production and attraction are more or less the same, about 10%. The average percentage share of single and combination trucks in all three directions is approximated 12.90% and 87.10%.

Table 9 AADTT by truck and commodity types within Utah

SCTG	Commodity	AADTT within Utah (trucks/day)				
		SU	TT	CS	DBL	TPL
1	Live animals/fish	0.28	3.77	30.46	2.53	-
2	Cereal grains	74.26	15.93	370.81	28.05	-
3	Other agricultural products	47.97	15.13	181.23	16.00	-
...	...	...	...	...	...	...
43	Unknown	89.15	26.82	200.72	21.35	0.33
		2,141.24	771.95	9,134.06	772.20	5.14

Table 10 AADTT by truck and commodity types for Utah production

SCTG	Commodity	AADTT for Utah Production (trucks/day)				
		SU	TT	CS	DBL	TPL
1	Live animals/fish	4.74	2.11	36.62	1.18	-
2	Cereal grains	0.23	0.06	2.99	0.09	-
3	Other agricultural products	0.85	2.60	66.69	2.28	-
...	....	...	...	...	...	...
43	Unknown	0.28	0.10	1.62	0.07	0.00
		267.60	148.99	1,953.91	104.53	0.40

Table 11 ADTT by truck and commodity types for Utah attraction

SCTG	Commodity	AADTT for Utah Attraction (trucks/day)				
		SU	TT	CS	DBL	TPL
1	Live animals/fish	0.30	0.13	2.34	0.08	-
2	Cereal grains	8.00	2.06	103.00	3.02	-
3	Other agricultural products	4.35	1.65	42.42	1.45	-
...	...	...	...	...	...	...
43	Unknown	0.74	0.27	4.28	0.18	0.01
		283.08	154.82	2,261.06	96.94	0.48

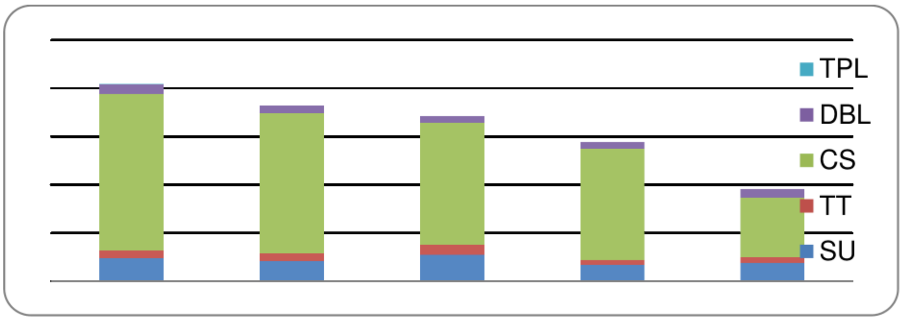

Figure 5 Top five commodities allocated by truck types

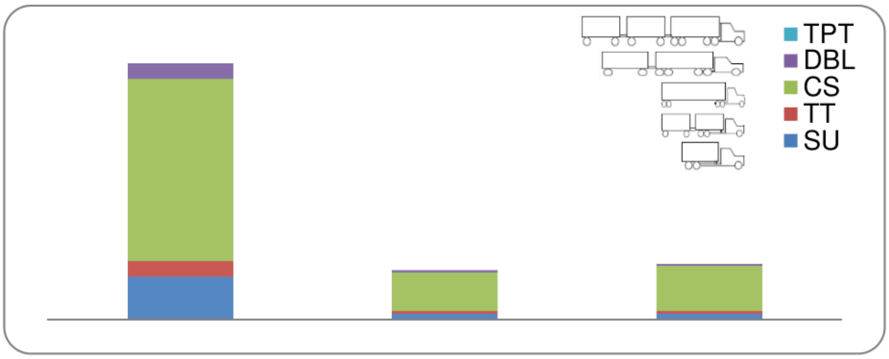

Figure 6 Utah freight flow allocated by truck types

Table 12 Utah commodity flow allocated by truck types

Direction Flow	Truck trips (trucks/day)						Percentage (%)	
	SU	TT	CS	DBL	TPT	Total Trucks	SU	Combination
Within	2,141.24	771.95	9,134.06	772.20	5.14	12,824.59	16.70	83.30
Production	267.60	148.99	1,953.91	104.53	0.40	2,475.42	10.81	89.19
Attraction	283.08	154.82	2,261.06	96.94	0.48	2,796.38	10.12	89.88
Total	2,691.91	1,075.76	13,349.04	973.66	6.01	18,096.39	12.90	87.10

Table 13 Percentage changes of truck trips within Utah from 2007 to 2015

Year	Truck trips within Utah (trucks/day)						Degree of Saturate
	SU	TT	CS	DBL	TPT	Total Trucks	
2007	1,875.98	676.36	8,110.24	678.78	5.45	11,346.81	0.8832
2015	2,141.24	771.95	9,134.06	772.20	5.14	12,824.59	0.9982
(%)change	14.14%	14.13%	12.62%	13.77%	-6.10%	13.02%	

From Table13, the I-15 corridor has substantially increased in almost all truck types except the tractor plus triple trailer combinations (TPT), which the number is not significant. The percentage change classified by truck type is useful to analyze the capacity of highway network. The degree of saturation delay is estimated by (Akcelik and Rouphail, 1993)

$$x = q / c$$

where: x is the degree of saturation related to truck volume and capacity of lane, q is the demand flow rate during the specified period in vehicles per hour, c is the capacity of truck under the specified flow conditions in vehicles per hour.

Attempt to find out the vehicle capacity on highway according to Arizona Department of Transport (2012) estimates 2,000 vehicles per hour per lane. Combining with truck average volume in urban areas studied by Daigre (2011) states that the average percentage of truck traffic on I-15 in Utah is accounted for 22% of total vehicles, i.e. 440 vehicles per hour. The total trucks are then divided by 365 days per year and 24 hours per day to obtain the volume of demand per hour. The degree of saturation delay in year 2007 and 2015 is: x_{2007} = (3,404,040/ 365 * 24))/ 440 = 0.8832, and x_{2015} = (3,847,380/ 365 * 24)/ 440 = 0.9982, almost exceeding a capacity of highway network.

5. Conclusions

An increase in the number of trucks will affect traffic volume on a transportation network and due to capacity and infrastructure of pavement. Identifying the type of truck-specific commodity raises the awareness to construct the critical link. Although this study shows illustrative example, it will be used for applying in the further step of study in delay time cost referred to the percentage of single unit and total combination unit of truck. The findings can be useful for other studies to get more information clearly point of view with the number in specific type of trucks. To more accurately calculate the delay, the disaggregate type of truck along I-15 in Utah and the volume of truck by UDOT can be combined with FAF^3 commodity flow data in percentage type of truck to obtain the truck profiles along the corridor. In addition, to correct the distribution of FAF^3 volumes by truck type on specified links in the next study, the U.S. DOT data will be used to split the truck volume for each link while the proportion of FAF^3 volumes by truck type could be determined the split for each type of truck on each link.

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