Can we inspect & maintain vehicles ONLY when necessary? Can we do that without stopping traffic?

The Commercial Vehicle Safety Alliance (CVSA)
https://www.cvsa.org/news/future-video/

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Towards Data-Driven and Continuous Safety Inspection of Commercial Trucks and Trailers

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Industry Partners: CompuSpections, Truck-Lite

Introduction

Based on research provided by the National Highway Transportation Safety Administration (NHTSA), around 20 percent of all traffic accidents are caused in some way by poor maintenance or lack thereof.

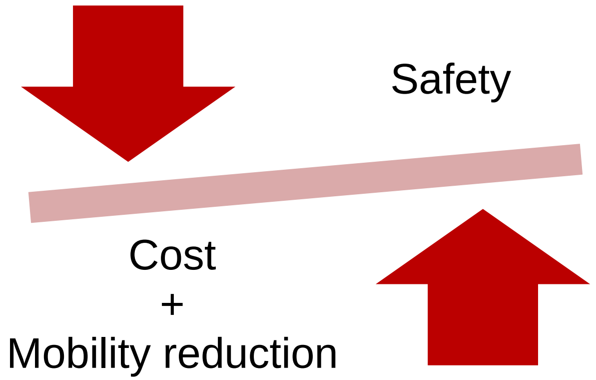
Vehicle Inspection and Maintenance Plan

Cost

- Financial expenses incurred by inspection and maintenance

Loss of Up-Time

- Vehicle operation time losses due to outages



Safety

- Vehicle violation
- Crash rates

Trade-off:

- More frequent inspection and maintenance would increase the cost and mobility reduction
- Less inspection would improve mobility but decrease the vehicles' operational safety

Introduction

The objective of motor carriers operating commercial fleets:
Make inspection and maintenance plans so that vehicles can operate safely with fewer costs, less idling time, and improved mobility

Research questions: what components are important that need more frequent inspection and maintenance?

- **Task 1:** What are the failure-prone components of specific types of vehicles?
- **Task 2:** What are the critical vehicles and risk-prone components for a given commercial fleet? Could we have priority queues?

Methodology - What are the failure-prone components of specific types of vehicles?

"Natural Language Processing" of vehicle inspection reports for identifying "clusters" of vehicles having similar failure trends and their critical vehicle components.

Vehicle Fleet → **Random Roadside Inspection** → **Topic Modeling Analysis**

Random Roadside Inspection

Historical Violation Description Report From MCMIS[1]

Topic Modeling Analysis

Eight Different Topics about heavy-duty trucks and trailer's failure mode (failure trends shared by many vehicles)

Description Analysis of topic modeling

- What make takes majority in each cluster?
- What DOT number takes majority in each cluster?

Real-time monitoring effectiveness check

Using distribution finding and the Markov method, we try to find out what are the failure-prone components of each cluster.

[1] The Federal Motor Carrier Safety Administration (FMCSA) maintains the **Motor Carrier Management Information System** (MCMIS). https://ask.fmcsa.dot.gov/app/mcmiscatalog/c_chap1

Methodology

Inspection Table

- INSPECTION_ID
- **INSP_DATE**
- INSP_START_TIME
- INSP_END_TIME
- INSP_LEVEL_ID
- **GROSS_COMB_VEH_WT**
- VEHICLE_VIOL_TOTAL
- VEHICLE_OOS_TOTAL

Unit Table

- INSPECTION_ID
- INSP_UNIT_MAKE
- **INSP_UNIT_VEHICLE_ID_NUMBER**

Violation Table

- **INSP_VIOLATION_ID**
- INSPECTION_ID
- **INSP_VIOLATION_CATEGORY_ID**
- OUT_OF_SERVICE_INDICATOR

Violation Supplement Table

- **INSP_VIOLATION_ID**
- **Supp_Desc**

- Select violation records from 2021 and generate a violation text record for each vehicle during this year.
  - The purpose is to see what's the major problem for each vehicle during the year 2021.
- Filter violation by category id from 15 – 30.
- Filter vehicles by gross combination vehicle weight heavier than 19500 lbs

Methodology

Input descriptions → Processed descriptions for topic analysis

INSP_UNIT_VEHICLE_ID_NUMBER	Supp_Desc	length	clean_msg	lower_msg	msg_tokenied	no_stopwords	msg_stemmed	msg_lemmatized
0V200000X192801NE	No Fire Extinguisher No warning devices No wor...	55	No Fire Extinguisher No warning devices No wor...	no fire extinguisher no warning devices no wor...	[no, fire, extinguisher, no, warning, devices,...	[fire, extinguisher, warning, devices, working...	[fire, extinguish, warn, devic, work, horn]	[fire, extinguish, warn, devic, work, horn]
101CCKLA04G004376	Axle 4 passenger side	21	Axle passenger side	axle passenger side	[axle, passenger, side]	[axle, passenger, side]	[axl, passeng, side]	[axl, passeng, side]
101CCKLA5RG003246	left tail lamp	14	left tail lamp	left tail lamp	[left, tail, lamp]	[left, tail, lamp]	[left, tail, lamp]	[left, tail, lamp]
101CCVLBXYG003865	Driver side measured 22.1%. Passenger side me...	59	Driver side measured Passenger side measured	driver side measured passenger side measured	[driver, side, measured, passenger, side, meas...	[driver, side, measured, passenger, side, meas...	[driver, side, measur, passeng, side, measur,]	[driver, side, measur, passeng, side, measur,]
101FR5327MG005241	3 single axle camper on trailer straps around ...	81	single axle camper on trailer straps around t...	single axle camper on trailer straps around t...	[, single, axle, camper, on, trailer, straps, ...	[, single, axle, camper, trailer, straps, arou...	[, singl, axl, camper, trailer, strap, around,...	[, singl, axl, camper, trailer, strap, around,...

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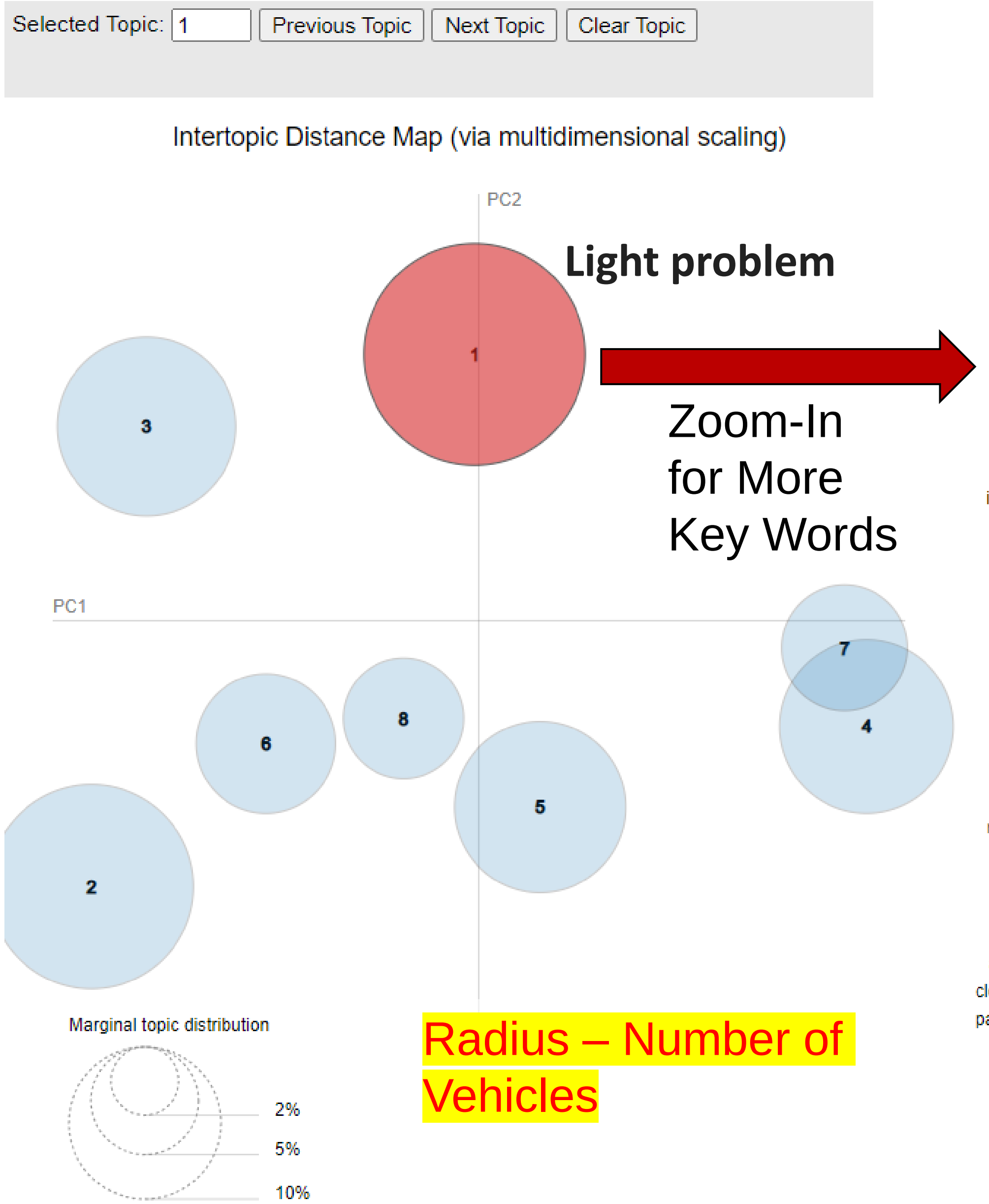
Methodology

Top 8 topics:

Topic	Top 10 words and weights										Related violation
1	0.051*"inop"	0.045*"**lamp**"	0.034*"inoper"	0.031*"rear"	0.030*"**turn**"	0.029*"**signal**"	0.026*"front"	0.026*"right"	0.026*"left"	0.025*"**light**"	**Light problem**
2	0.034*"**air**"	0.024*"**leak**"	0.024*"axl"	0.021*"**brake**"	0.019*"hose"	0.016*"x"	0.015*"l"	0.014*"chamber"	0.014*"r"	0.013*"v"	**Brake Air Leak problem**
3	0.051*"**tire**"	0.050*"axl"	0.036*"psi"	0.035*"right"	0.031*"left"	0.027*"side"	0.026*"insid"	0.021*"outsid"	0.021*"inop"	0.021*"**flat**"	**Tire problem**
4	0.027*"**display**"	0.026*"number"	0.025*"name"	0.024*"usdot"	0.023*"dot"	0.022*"carrier"	0.022*"lb"	0.017*"vehicl"	0.016*"compani"	0.015*"truck"	**USDOT number display problem**
5	0.021*"none"	0.020*"**trailer**"	0.019*"secur"	0.019*"chain"	0.018*"**breakaway**"	0.016*"cabl"	0.015*"unit"	0.015*"**attach**"	0.013*"strap"	0.012*"**connect**"	**Trailer Attachment problem**
6	0.016*"**oil**"	0.015*"miss"	0.014*"**leak**"	0.014*"rear"	0.014*"**engin**"	0.012*"right"	0.012*"side"	0.011*"left"	0.010*"inop"	0.009*"cover"	**Engine oil leak problem**
7	0.049*"**expir**"	0.035*"""	0.034*"**registr**"	0.019*"current"	0.016*"**plate**"	0.016*"inspect"	0.014*"proof"	0.014*"**insur**"	0.013*"card"	0.013*"display"	**Insurance proof problem**
8	0.027*"**window**"	0.024*"**windshield**"	0.023*"tint"	0.021*"fluid"	0.018*"washer"	0.017*"measur"	0.016*"crack"	0.016*"driver"	0.014*"side"	0.013*"adjust"	**Windshield problem**

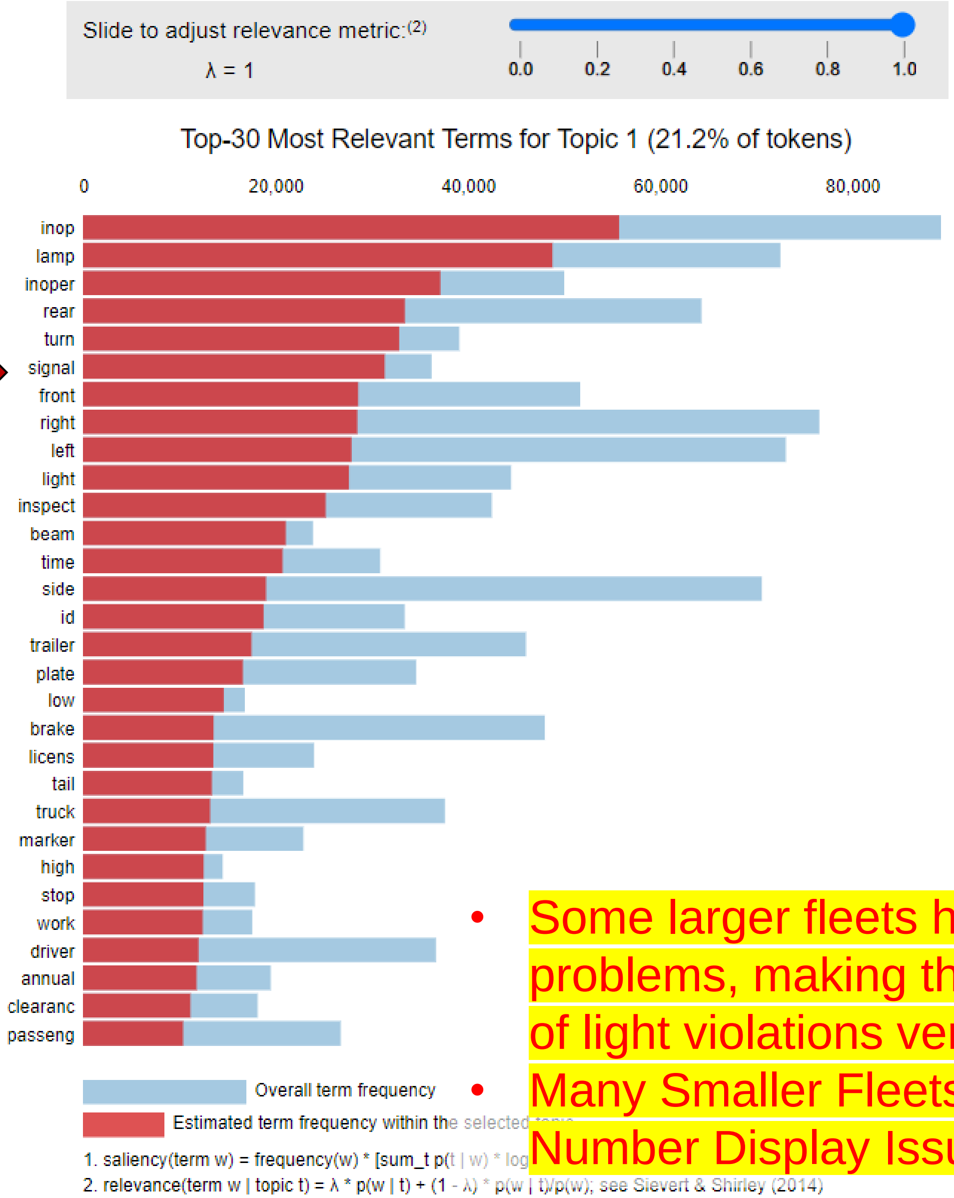
Results –Topic display interface



Light problem

Zoom-In for More Key Words

Radius – Number of Vehicles



1	Light problem
2	Brake Air Leak problem
3	Tire problem
4	USDOT number display problem
5	Trailer Attachment problem
6	Engine oil leak problem
7	Insurance proof problem
8	Windshield problem

Number of Motor Carriers

Topic	DOT_NUMBER
1	8,430
2	22,381
3	7,744
4	28,865
5	7,938
[illegible]	13,120
[illegible]	5,297
[illegible]	13,449

- Some larger fleets have light problems, making the total number of light violations very large
- Many Smaller Fleets have USDOT Number Display Issues

Results - Failure-Prone Components

INSP_UNIT_MAKE	1	2	3	4	5	6	7	8	Maximum	Second_Maximum	Third_Maximum
BIGT	478	228	347	2501	534	1762	639	1229	4	6	8
FRHT	7167	36879	6324	13643	5964	5888	14311	13980	2	7	8
GDAN	441	1528	446	722	235	289	656	880	2	8	4
GMC	458	391	264	1789	360	846	851	519	4	7	6
HINO	1146	1690	1111	3932	1281	1407	2198	1325	4	7	2
INTL	3272	19160	2812	9052	2852	3626	7650	6111	2	4	7
KW	2685	14197	2373	4468	2604	3227	6829	5053	2	7	8
MACK	1096	3571	1064	2402	1386	2063	3227	2634	2	7	8
OTHR	481	799	456	2332	701	1322	1091	1032	4	6	7
PTRB	2251	9277	2359	3742	2407	2862	4414	4276	2	7	8
RAM	533	284	418	1806	509	1451	616	1077	4	6	8
TRLR	817	899	806	4310	794	2535	1133	1707	4	6	8
UNK	457	462	369	2058	380	1179	593	828	4	6	8
UTIL	705	2450	691	1263	490	511	1046	1442	2	8	4
VOLV	1152	6793	1218	1878	867	881	2136	2751	2	8	7

Vehicle Make/Brand

Different vehicle makes have different “failure modes”

1	Light problem
2	Brake Air Leak problem
3	Tire problem
4	USDOT number display problem

5	Trailer Attachment problem
6	Engine oil leak problem
7	Insurance proof problem
8	Windshield problem

Methodology - What are the critical vehicles and risk-prone components for a given commercial fleet?

Simulate the deterioration trends of a fleet and prioritize vehicles/components

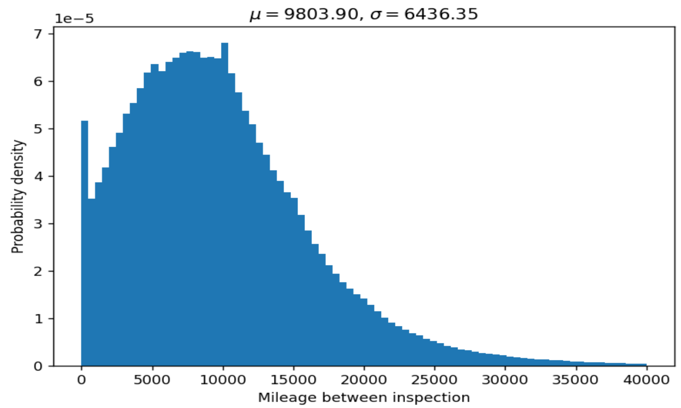
Fleet

Current Annual Inspection

Brake pad thickness

Tire tread depth

- **Given a Certain Mileage – after a Certain Mileage**
- **Simulate a Potential Annual Mileage – after One Year**



Brake Pad Thickness/Tire Tread Depth Deterioration Prediction Model

Predicted Next Annual Inspection

Predicted Brake pad thickness

Predicted Tire tread depth

Risky Cases

Cases where the predicted values are less than 2/32 inch

Probability of transition to risky states (under 2/32 inch)

Ranking of risky components in a fleet

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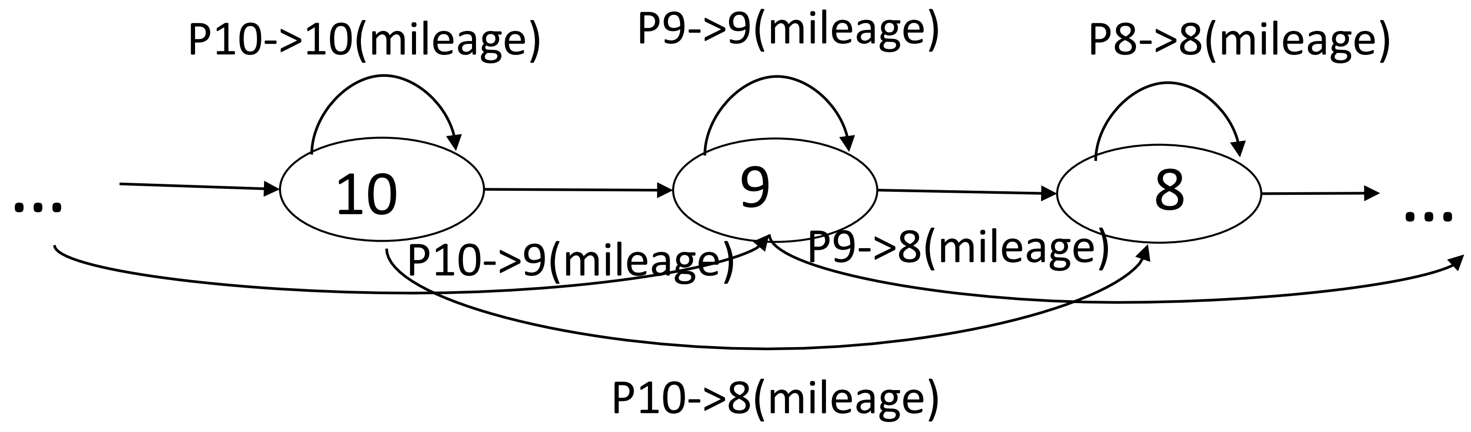
Methodology – Markovian Deterioration Prediction

Brake Pad Thickness/Tire Tread Depth Deterioration Model – Percentages of Transitions from One State to Another in the Historical Inspection Reports

Historical data

Last state (/32in)	Mileage in one year	Next state (/32in)
4	83	4
6	753	5
…	…	…

Transition probability



Example: transition from 10

$$P10\_10(mileage) = \frac{\#(10\_10, mileage \pm 200)}{\#(10\_(10, 9, 8, ...2), mileage \pm 200)}$$

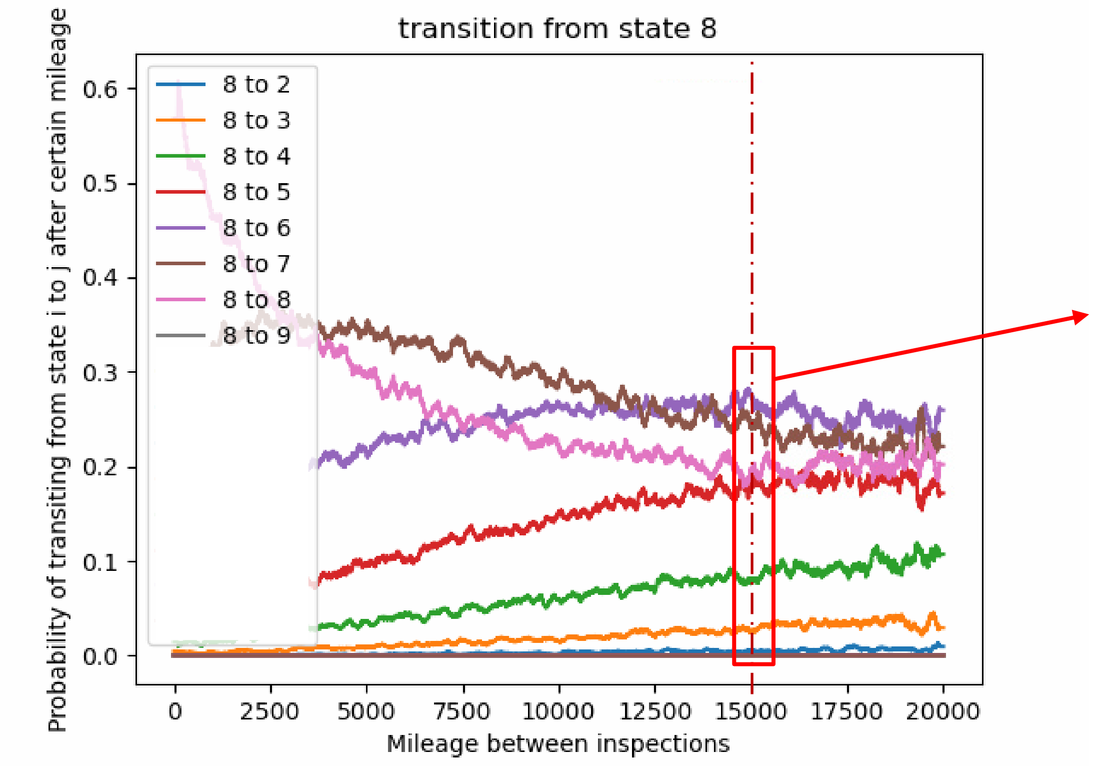
$$P10\_9(mileage) = \frac{\#(10\_9, mileage \pm 200)}{\#(10\_(10, 9, 8, ...2), mileage \pm 200)}$$

……

$$P10\_2(mileage) = \frac{\#(10\_2, mileage \pm 200)}{\#(10\_(10, 9, 8, ...2), mileage \pm 200)}$$

Methodology – Markovian Deterioration Prediction

Transition probability example



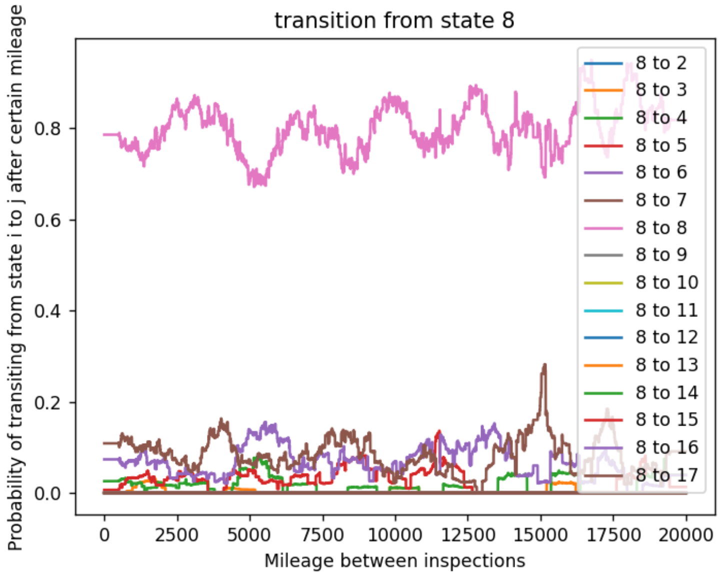
Predict the state by sampling according to percentages

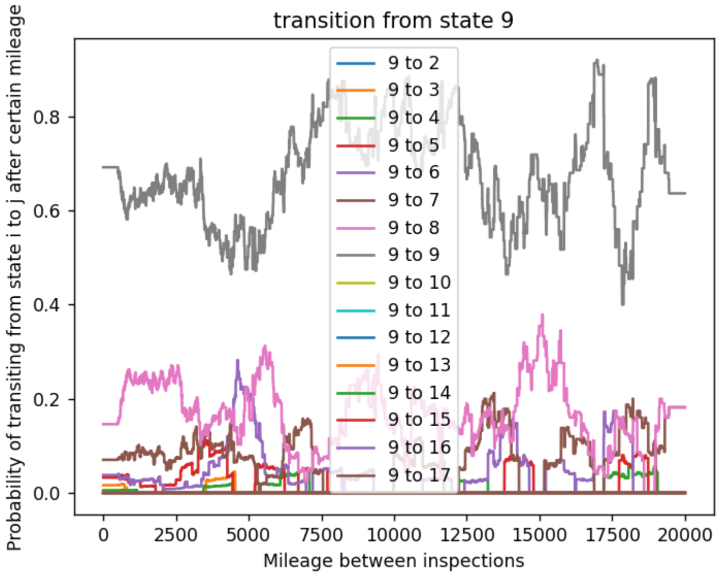
For each vehicle in a fleet, given current inspected component state and the potential operating mileage, the prediction model can calculate the probability of state in the future. The next state is predicted by sampling according to the probability.

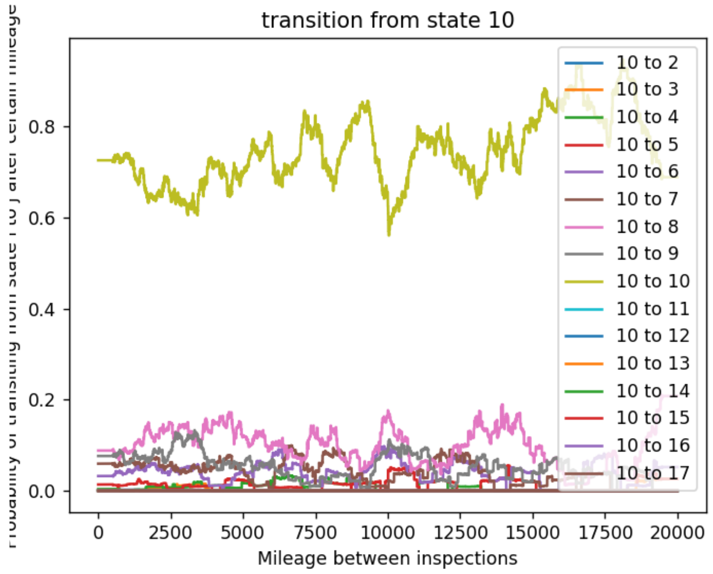
Deterioration Modeling and Prediction Results

Brake’s Markovian Deterioration Prediction Model for Heavy Trucks and Trailers

Transition probability examples -Training dataset: 49,604







Deterioration Modeling and Prediction Results

Brake's Markovian Deterioration Prediction for Heavy Trucks and Trailers

Testing results -Testing dataset: 1,000

- Test on the state prediction after operating a certain mileage
  - Accuracy: 48.3%
  - Soft accuracy: 63.6%
- Test on the state prediction after operating one year
  - Accuracy: 49.4%
  - Soft accuracy: 63.1%

$$\text{Accuracy} = \frac{\#(y_{pred} == y_{true})}{\# y_{pred}}$$

$$\text{SoftAccuracy} = \frac{\#(y_{pred} == (y_{true} \pm 1))}{\# y_{pred}}$$

Brake states' distribution in a heavy-duty fleet with 1,000 vehicles after one year

State(32/in)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Current Inspection	0.0%	0.0%	0.1%	0.1%	1.1%	1.8%	4.4%	5.7%	10.6%	4.6%	13.9%	4.3%	16.7%	4.0%	12.4%	9.4%	8.7%	2.2%
Next Inspection -after one year (ground truth)	0.0%	0.0%	0.4%	0.3%	2.5%	3.2%	6.9%	8.9%	13.9%	4.7%	16.6%	3.5%	14.1%	3.3%	9.3%	6.2%	5.5%	0.7%
Next Inspection -after one year	0.0%	0.0%	0.3%	0.2%	2.1%	3.6%	7.0%	7.3%	13.0%	5.5%	17.2%	3.9%	13.3%	4.0%	10.4%	5.6%	5.9%	0.7%

Component's Ranking

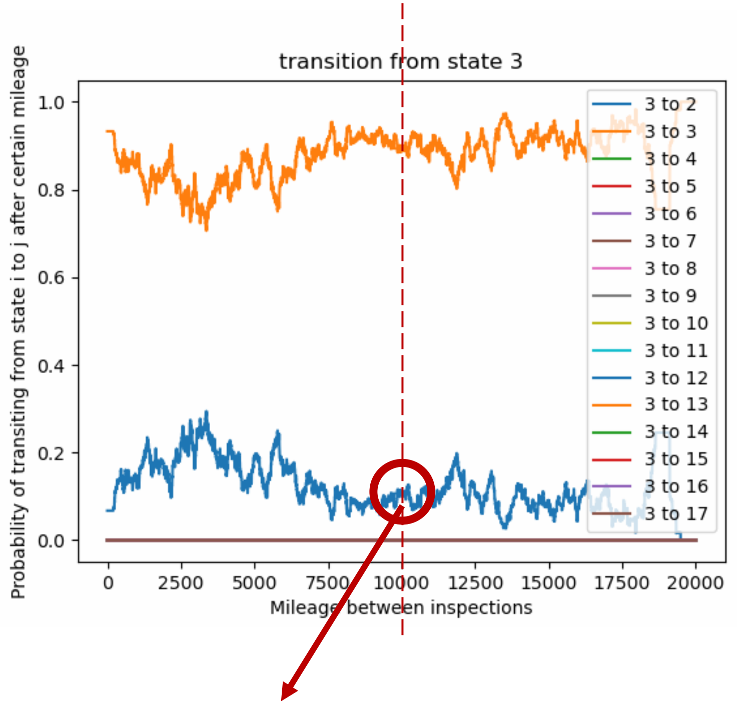
Rank according to the probability that the component transition to state 2 (2/32in)

Ranking of 1,000 brakes – after given certain mileages

Ranking	1	2	3	4	5	6	7	…
Component ID	200	470	608	729	709	532	275	…
Probability	100.00%	100.00%	8.33%	1.41%	1.08%	1.06%	1.05%	0

Ranking of 1,000 brakes –after one year

Ranking	1	2	3	4	5	…
Component ID	200	470	626	783	188	…
Probability	100.00%	100.00%	5.71%	1.12%	1.00%	0



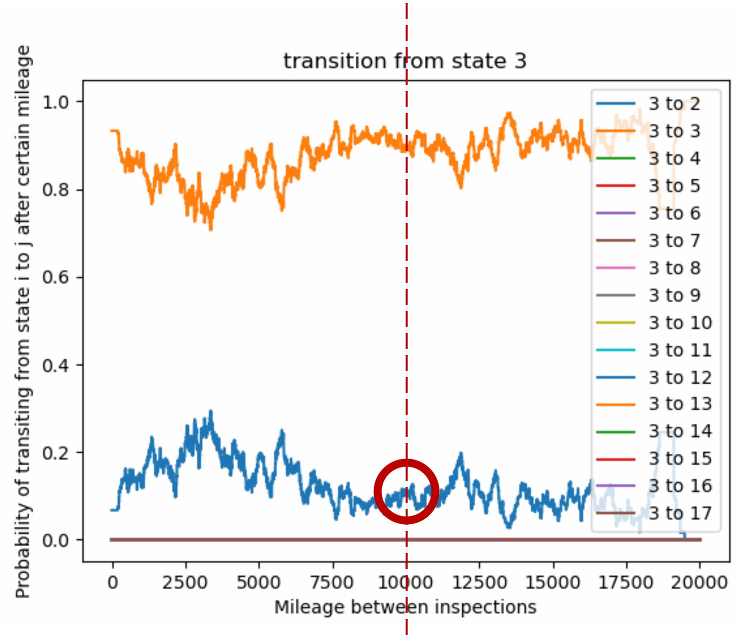
Probability that the component transition to state 2 (/32in)

Prioritizing Vehicles based on their Predicted Brake States

Rank according to the probability that the component transition to state 2 (/32in)

Ranking of brake states – after given certain mileages (10,000 miles in this case)

	1	2	3	4	5	6	7
Vehicle ID	200	470	608	729	709	532	275
Probability	100.00%	100.00%	8.33%	1.41%	1.08%	1.06%	1.05%



Ranking of brake states – after one year

	1	2	3	4	5
Vehicle ID	200	470	626	783	188
Probability	100.00%	100.00%	5.71%	1.12%	1.00%

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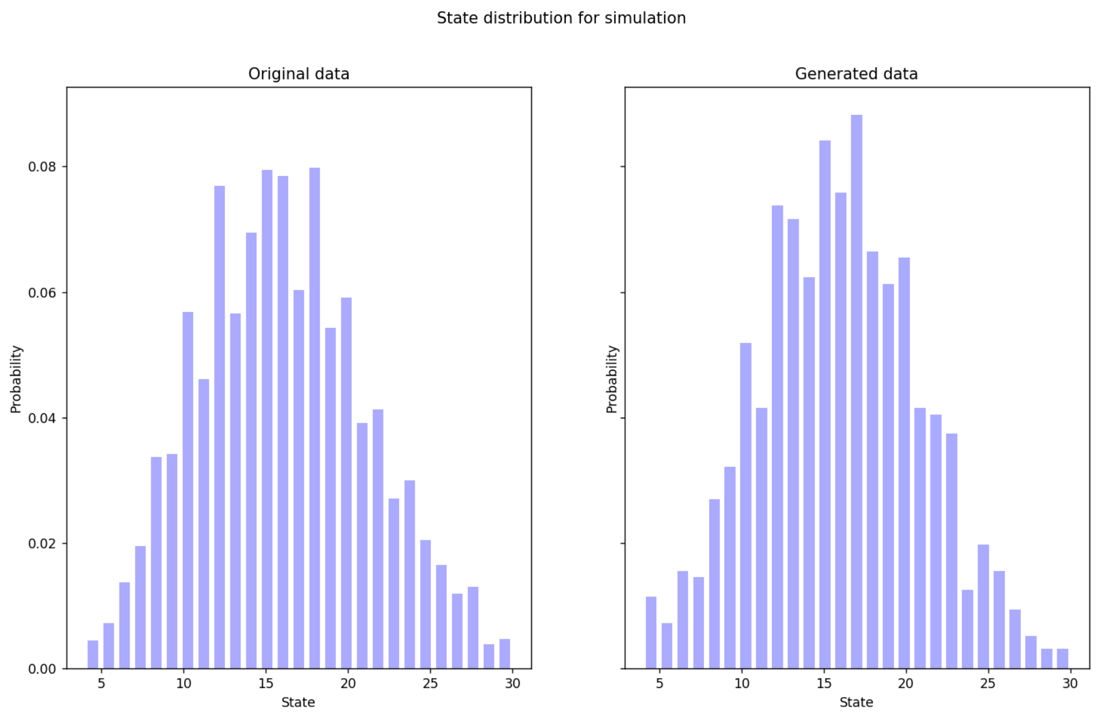
Results –test on simulated tire states

Simulated tire distribution



Training dataset (heavy trucks and trailers): 49,604
Test dataset (heavy trucks and trailers): 1,000

Model based on heavy trucks and trailer

Prediction Models	Prediction states after a certain mileage		Prediction states after one year	
	Accuracy	Soft accuracy	Accuracy	Soft accuracy
Deterioration rate model	21.2%	44.3%	4.7%	13.1%
Markov deterioration model	44.7%	60.8%	5.9%	15.1%

Results –test on simulated tire states

A heavy-duty fleet with 1,000 operating brake components

State (/32in)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Current Inspection	0.0%	0.0%	0.0%	0.0%	0.9%	1.2%	2.6%	3.2%	5.0%	5.0%	9.5%	5.3%	12.2%	8.2%	8.6%	7.5%	6.2%	4.8%	5.7%	4.3%	4.2%	2.7%	1.7%	0.2%	0.6%	0.1%	0.2%	0.0%	0.1%	0.0%	0.0%
Next Inspection -after one year (Markovian)	0.0%	0.0%	0.3%	0.6%	1.6%	1.4%	2.9%	2.4%	5.4%	5.6%	6.2%	4.9%	8.9%	6.6%	7.7%	6.7%	5.7%	6.8%	5.8%	4.8%	4.2%	3.4%	2.5%	1.6%	1.9%	0.7%	0.5%	0.4%	0.3%	0.2%	0.0%

State (/32in)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Current Inspection	0.0%	0.0%	0.0%	0.0%	0.8%	1.2%	2.6%	3.2%	5.1%	5.0%	9.5%	5.3%	12.2%	8.2%	8.6%	7.5%	6.2%	4.8%	5.7%	4.3%	4.2%	2.7%	1.7%	0.2%	0.6%	0.1%	0.2%	0.0%	0.1%	0.0%	0.0%
Next Inspection -after one year(DR)	18.7%	1.2%	2.0%	2.9%	1.6%	3.1%	3.3%	4.8%	2.9%	3.7%	4.7%	4.7%	5.6%	4.4%	4.8%	4.6%	5.4%	4.3%	3.1%	3.4%	3.0%	2.0%	1.5%	1.1%	0.9%	1.3%	0.8%	0.2%	0.0%	0.0%	0.0%

The prediction using the Markovian deterioration model is closer to the ground truth.

The prediction using the DR model is more pessimistic than using the Markovian deterioration model.

Conclusion

- The topic analysis based on violation descriptions can identify failure-prone components of specific brand/make/type of vehicles.
    - Such identified failure-prone components are those that need more attention from fleet managers in their life cycle considering the vehicle type.
- The component risk ranking method can predict the probabilities that components transition to risky (violation) states (under 2/32 inches) in the future and rank the risky components in terms of their predicted states as inspection/maintenance priority queues.
    - Such ranking can help fleet managers decide what vehicle components need inspection and maintenance most in the following days considering vehicles' current states.
- The Markovian deterioration prediction model is validated to have a higher prediction accuracy compared with the prediction model using the linear-milage deterioration rates.


Thank you!