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SNOW ROUTE OPTIMIZATION

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16. Abstract
Route optimization is a method of creating a set of winter highway treatment routes to meet a range of targets, including service level improvements, resource reallocation and changes to overriding constraints. These routes will allow the operator clear the pavement in a timely and efficient manner, reducing wastage and utilizing resources to their best effect.

Implementation
The implementation of a route optimisation exercise will be determined by the Boulder maintenance area. The final decision on whether a route optimization exercise could be of valuable to CDOT operations will be made in conjunction with the decision-makers prior to any regional or statewide implementation plan. Vaisala has advised on potential route strategies together with weather station locations based on the Thermal Map findings which would complement the current setup.

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CHAPTER 1

BACKGROUND

This report has been commissioned by The Colorado Department of Transportation (CDOT), which has appointed Vaisala Inc. to examine current Winter Service practices across a designated section of patrol routes within Region 4, in the State of Colorado. The main objective of this research project is to review and understand current CDOT snow removal practices and provide operational recommendations. These recommendations shall aim to improve snow removal efficiency in a cost-effective manner while also reducing winter weather related road incidents along CDOT routes. This is to be achieved while keeping to the current treatment criteria which are outlined below.

Vaisala will also investigate whether there is an option for route reduction under the current criteria (without compromising current levels of service) via a Route Optimization exercise across CDOT's treatment network. This report will not address any other winter treatment options such as changes to depots (number and location), requirements to meet specific treatment times, etc.

This review will be completed using a series of desk-based exercises, with no actual route design taking place at this stage of the project. Any places where exact data was not available from CDOT assumptions have been made and are highlighted as appropriate throughout the report.

All calculations within this report are based on average figures. To try to address all scenarios would require a larger platform than available here.

Finally, Vaisala would like to acknowledge and thank the following CDOT Study Panel members:

David Reeves; Mark Eike; Eddie Gentry; Kyle Lester; Matthew Rickard; Thomas Aguilar; Timothy Miles; Amanullah Mommandi; David Wieder.

CHAPTER 2

SOURCES OF INFORMATION

In order to undertake this study, information on CDOT's current treatment regimen, resources, and constraints needed to be sourced. Additionally, information on areas of further investigation, future options, etc., also needed to be identified. This was achieved as follows:

- Initial discussions, meetings and e-mail exchanges of headline information between CDOT and Matt Krueger, Rose Mooney, Colin Walsh, Tony Coventry, Bert Murillo and Matt Harley of Vaisala.

- Current treatment operation figures and the current level of service in the form of emails and telephone conversations with but not exclusively Arnold Lopez of CDOT. GIS networks were supplied to Vaisala by David Reeves of CDOT.

Actions generated from the meeting initiated further e-mail discussions, clarifications and information-gathering exercises.

CHAPTER 3

SCOPE OF REPORT

CDOT has asked for the number of routes and therefore the number of trucks to be investigated with regards to route numbers. There is no set time limit to the treatment of the roads but rather a consideration of the Level of Service (LOS) in the Snow and Ice Maintenance Program Area of the manual. This report shall investigate the treatment within a Designated Patrol Section in CDOT Region 4; this section lies to the north of Denver and encompasses the City of Boulder. Details of the Designated Patrol Section are expanded on in Chapter 4.

1 - Potential to Increase Route Performance

Route performance will be investigated in two ways:

- **Review & Analysis of Current Treatment Methodology**: This report will identify opportunities within the current treatment methodology to reduce route numbers by maximizing the performance of the existing routes within their limiting constraints (i.e. are the current routes making the best use of available treatment time and treatment range?).

- **Review & Analysis of Current Resources and Winter Maintenance Operations**: This report will investigate whether changes to the current resources will help improve efficiencies and maximize resource deployment. The report will also look at other areas of winter maintenance operations and address any issues raised during the face-to-face meetings with department personnel from the Designated Patrol Section or CDOT Region 4.

CHAPTER 4

CURRENT SITUATION

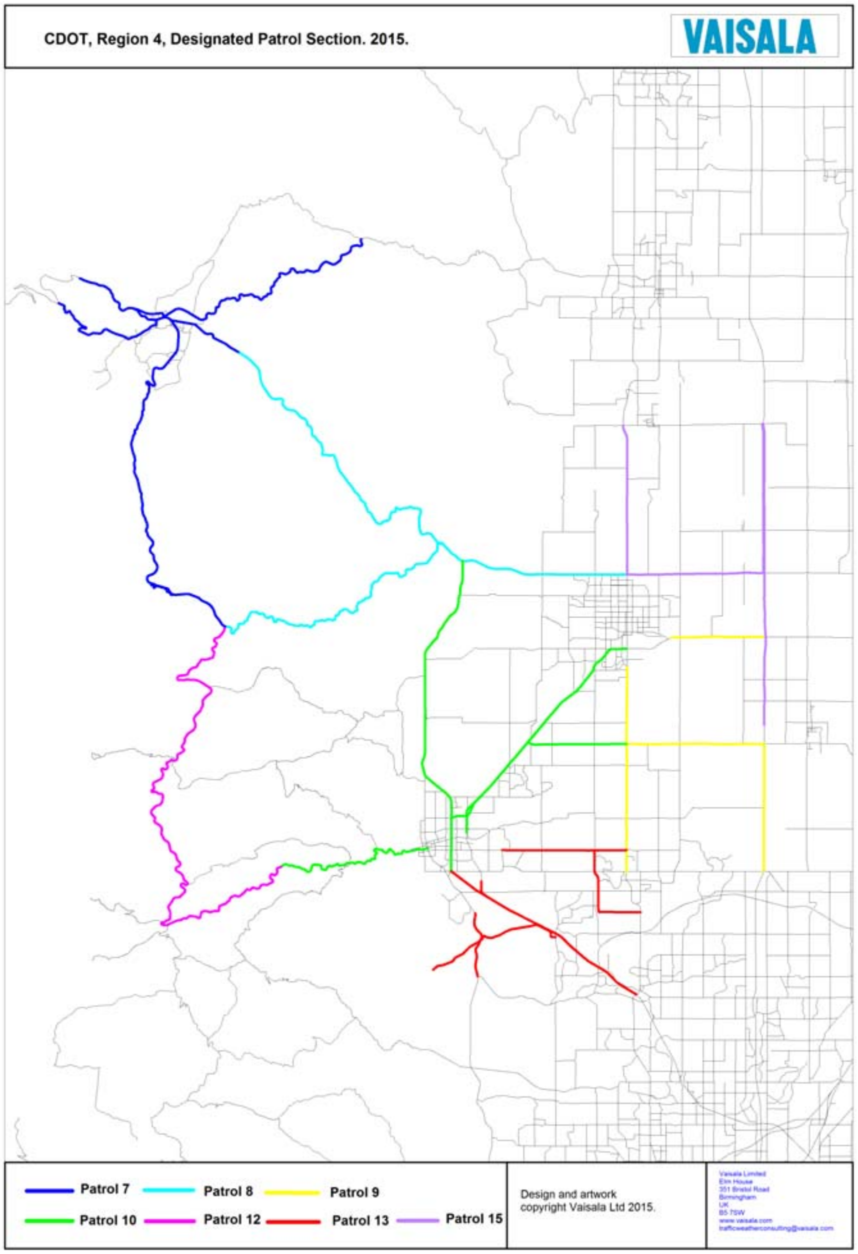
This chapter briefly outlines the current situation in Colorado. The scenarios and resources described have in many ways been inherited from historical customs and practices across the region.

1 - Network

Following initial discussions between CDOT and Vaisala, a specific network has been assessed within this report, and as a result, any roadways that fall outside of this network will not be included in this study. The assessed network falls within the Maintenance Supervisory Area of Boulder, and will be referred to as the Designated Patrol Section; however, the greater picture of Region 4 and Colorado in its entirety has been considered in context.

Colorado’s current treatment network is comprised of approximately 9,103.1 center line miles (9,699.6 miles including ramps). The Region 4 network has 3,463.5 center line miles (3,937.2 miles including ramps). The Designated Patrol Section which this report will study has 249.0 center line miles (263.1 miles including ramps). These distances were derived from reviewing GIS data provided by CDOT. Colorado falls partly within the United States Snowbelt and the Designated Patrol Section falls entirely within. It is also well within an area recommended for snow tire use in winter.

Map 1: Plan of Designated Patrol Section by Patrol



2 - Routes and Depots

This network is currently serviced via several discrete routes called ‘Patrols’ which operate from many depots located in strategic proximity to defined operational areas. There is no specified routing to these patrols but each truck within a ‘patrol’ is considered to be driving a ‘route’ for the purposes of context within this report. The Designated Patrol Area is serviced by 6 depots.

3 - Treatment Time

Within the Complete Level of Service Manual, Section 7, treatment time can vary greatly depending upon the defined Level of Service (LOS) for the roadway. This varies from maintaining bare pavement at all times to 72 hours depending on the category, while other roads may not be cleared until the thaw. Additional details on LOS and categories are discussed in further in this report.

4 - Route Efficiency

Various international authorities gauge the routes by efficiency, defined as treated distance as a percentage of total route length. It is a function of network type and route complexity. The situation in CDOT Region 4 does not naturally lend itself to this type of gauge. The time taken to complete the operation as well as the condition of the road (whether clear or not) is given more importance than an efficiency measure. This ties in with the CDOT LOS Manual as described below. However, it should be noted that using efficiency to evaluate a route can indicate how balanced a set of routes are within any given area.

5 - Fleet

There are 29 trucks in the Designated Patrol Section. The type, size, and configuration of the vehicles used for these routes may vary between 3½ ton dump trucks to larger 6 x 6 wheel drive tandem axle trucks. CDOT also employs the TowPlow system on larger highways and/or Interstates. These TowPlows are capable of clearing and/or treating 2 lanes. CDOT is one of several states to embrace this new technology including, but not exclusively MoDOT, MDOT, PennDOT and NDDOT.

6 - Spread Rate

The spread rate is given in pounds per lane mile, ranging from 120 to 250 depending on the weather conditions. This is a figure per lane; therefore, a 2 lane road will require twice as much material as a single lane road per mile treated.

7 - Spread Width

For ice clearance, the spread width is dependent on the number of lanes. This information has been derived from the supplied CDOT GIS data. This can be from 1 lane to up to 6 lanes on Interstates. The GIS data suggests that CDOT utilizes an average of 12 feet to describe a lane width. So although the center line miles of the designated network may be 263.1, including ramps, the actual lane miles are 693.7 miles. On roadways with more than 3 lanes, several passes are required to clear the entire width of the highway, and potentially with more than one truck traveling in echelon formation.

8 - Snow Plowing

For snow clearance, most trucks can only plow one lane at a time. As stated previously, larger trucks can have a side or towed plow enabling 2 lanes to be cleared. If conditions allow, this can be most effective when combined with treatment material. As an example, on Interstates, two trucks could work an Interstate rather than three, enabling the third truck to be deployed elsewhere. It is often the case that a truck will plow and treat at the same time to either create or maintain the de-bonding layer.

9 - Treatment Materials

Use of Magnesium Chloride and Derivatives

For pavement temperatures warmer than 16°F, Magnesium Chloride (Mag Chlor) is the preferred product relative to its cost. Mag Chlor is still essentially a salt. Many states use Sodium Chloride as an alternative or in addition to Magnesium Chloride; however, studies to whether Mag Chlor has less corrosive properties than Sodium Chloride have resulted in mixed conclusions.

For temperatures colder than 16°F, cold temperature modified Mag Chlor, (i.e. Apex, Ice Ban Ultra, Caliber M-1000) is the preferred liquid product due to its effectiveness. This is a more expensive product but has a greater water freezing point depression effect than unmodified Mag Chlor.

Sand is used as a tractive abrasive, often with a wetting agent. Care must be made to ensure the correct size of sand particles are used. If too small particles are used, there is a possibility that it will be ineffective and may cause pollution; if too large particles are used, it becomes an abrasive to vehicles. Sand has inherent clean-up problems, as it can build up on curves or bends in the road and cause a skid hazard. Salts are water soluble and will wash away, although this does lead to its own pollution problems if over used.

There are three types of situations for the use of Liquid Products, Solid De-icers, and Sanding Material described in the CDOT Standard Operating Guide (SOG). These are:

Anti-Icing: A snow and ice control strategy in which a de-icing product, either in a liquid, solid, or pre-wetted solid form, is spread directly onto the pavement at the beginning of a winter precipitation event, but before any snow or ice bonds to the pavement.

Pre-Wetting: The intention of pre-wetting sanding material is to enhance the ability of the sand to stick to the road, reducing bounce or removal of product by wind or traffic. Application rate for spraying liquids on de-icer/sand piles, or to hot-shot a load, is approximately 4 to 8 gallons per ton.

De-Icing: A snow and ice control strategy in which a de-icing product, either in a liquid, solid, or pre-wetted solid form, is spread directly onto the top of an accumulation of snow, ice, or frost that is already bonded to the pavement surface.

10 - Level of Service

The LOS manual has a standard layout of each Maintenance Program Area (MPA).

CDOT includes nine MPAs in its maintenance program:

1. Planning and Training

2. Roadway Surfacing

3. Roadside Structures

4. Roadside Appearance

5. Traffic Services

6. Structure Maintenance

7. Snow and Ice Control

8. Material, Equipment and Buildings

9. Tunnel Activities

Each of these MPAs follow the same LOS categories, labeled A thru F respectively. Descriptions of each category are included below:

Category A

Plowing and de-icing products or abrasives applications proactively maintain very high levels of mobility throughout storms (refer to Table 1 below). Snow drifts and localized ice patches are treated quickly to avoid closures and hazards. Proactive avalanche control minimizes traffic interruptions and avoids unanticipated road closures.

LOS 'A' represents the highest level of service, which ranges from proactive efforts to maintain wet (bare) pavement throughout a storm on higher-standard or highly travelled highways to snow-pack or icy but passable conditions on lower-standard or low-volume roads.

Category B

Plowing and abrasives or de-icing solutions maintain high levels of mobility as much as possible (refer to Table 1 below). Snow drifts and localized ice patches may be treated during storm with abrasives or de-icing solutions. Proactive avalanche control minimizes traffic interruptions and avoids unanticipated road closures.

LOS 'B' represents a high level of service, which ranges from targets of wet (bare) pavement as much as possible on higher-standard or highly travelled highways to snow-pack or icy conditions on lower-standard or low-volume roads.

Category C

Plowing and abrasives or de-icing solutions applications maintain good levels of mobility on high-standard roads (refer to Table 1 below). Snow drifts and localized ice patches are treated as soon as possible at end of storm. Avalanche control focuses on high-priority locations and situations.

LOS ‘C’ represents a moderate level of service. On higher-standard or highly travelled highways, LOS ‘C’ ranges from wet (bare) pavement as much as possible to patches of snow or slush. On lower-standard or low-volume roads LOS ‘C’ ranges from patches of snow or ice to predominately snow-pack or icy conditions.

Category D

Plowing and abrasives or de-icing solution applications are performed on a limited basis and some traffic delays are anticipated on all roads (refer to Table 1 below). Snow drifts and localized ice patches are treated after mainline roads are cleared. Limited avalanche control is performed. Chain station operation may be scaled back.

LOS ‘D’ represents a marginal level of service, which ranges from patches of ‘oatmeal’ snow, packed snow or ice on higher-standard or highly travelled highways to predominately snow-packed or icy conditions on lower-standard or low-volume roads.

Category F

Plowing and abrasives or de-icing solution applications are performed on a very limited basis, impairing mobility on all roads (refer to Table 1 below). Snow drifts and localized ice patches may not be treated for some time. No preventive avalanche control is performed. Chain station operations are scaled back or suspended.

LOS ‘F’ represents a poor level of service. Patches of snow or ice exist even on the highest-standard roads, and these conditions may degenerate to predominately snow-packed or icy conditions throughout with accompanying slowdowns or delays.

In order to determine the correct LOS, the following steps are taken:

Step 1 identifies a range of condition levels that define various levels of snow and ice control and their likely impacts on traffic movement.

Step 2 assigns condition levels to the various categories of highways. These assignments define the different levels of service on each highway category.

Each of the condition levels are described below.

Condition 1: Maintain wet (bare), tractive surface through proactive anti-icing prior to the storm and de-icing and application of abrasives during and after the storm. Objective is to keep a wet road surface as much as possible during the storm period. Traffic moves smoothly at a speed consistent with wet pavement and as weather conditions allow. (Note: anti-icing and de-icing are used predominantly in non-windy areas.)

Condition 2: Maintain wet (bare) surface as much as possible throughout the storm. Anti-icing is applied prior to the storm, and abrasives (with or without de-icers) may be applied during the storm, possibly at lesser frequency than for Condition 1. The road may be de-iced after the storm, or only abrasives may be used. Traffic moves relatively smoothly, though at reduced speed.

Condition 3: Patches of ‘oatmeal’ snow, slush, or packed snow may exist. Anti-icing, de-icing, and application of abrasives may be done on a limited basis. Traffic may experience isolated slowdowns or delays, but movement is otherwise unimpeded, although at reduced speed.

Condition 4**:** Icy or packed snow conditions prevail. Abrasives may be applied to improve traction. Traffic moves slowly and is delayed.

Condition 5: Road is snow-covered and may be blocked in locations. Traffic flow will be impeded at these locations and motorists may encounter substantial delays. On highways designated for seasonal closure (currently Mt. Evans, Independence passes), the snow cover is left untouched until the spring.

As previously mentioned, in addition to these condition levels, LOS is also assessed by Highway Category. Table 1 below shows the different LOS based on these characteristics.

Table 1.

Highway Category	A	B	C	D	F
Interstate, > 75,000 AADT	Cond. 1	Cond. 1	Cond. 2	Cond. 3	Cond. 3
NHS, >75,000	Cond. 1	Cond. 1	Cond. 2	Cond. 3	Cond. 3
Interstate, 15K < AADT < 75K	Cond. 1	Cond. 1	Cond. 3	Cond. 3	Cond. 4
NHS, 15K < AADT < 75K	Cond. 1	Cond. 1	Cond. 3	Cond. 3	Cond. 4
Other, >50,000 AADT	Cond. 2	Cond. 3	Cond. 3	Cond. 3	Cond. 4
Interstate, < 15,000 AADT	Cond. 1	Cond. 2	Cond. 3	Cond. 4	Cond. 5
NHS, < 15,000 AADT	Cond. 1	Cond. 2	Cond. 3	Cond. 4	Cond. 5
Other, 5K < AADT < 50K	Cond. 4	Cond. 4	Cond. 4	Cond. 4	Cond. 5
Other, <5,000 AADT	Cond. 4	Cond. 4	Cond. 4	Cond. 5	Cond. 5
Mountain Passes	Cond. 3	Cond. 3	Cond. 4	Cond. 5	Cond. 5
Seasonal Highways	Cond. 5	Cond. 5	Cond. 5	Cond. 5	Cond. 5

Source: LOS Manual

As can be seen from the table above, due consideration has been given to the roads with greater traffic count and demand.

11 - Road Weather Station Data

The configuration of the road weather data collected is such that CDOT is utilizing data from 98 weather stations (viewable on the CDOT website) and a monitoring system on which to base its winter treatment operations. The data is also used by the weather forecaster to help produce detailed winter road forecasts.

12 - Unscheduled Callouts

It is understood that there are occasions when trucks are called out to areas or roads where officials, State Highway Patrol, etc. have requested clearance. A patrolperson may phone in to CDOT stating that a section has not been covered. A truck will then be dispatched to the location.

13 - Mobile Weather Monitoring

CDOT employs two systems to gather mobile weather observations. One is the Vaisala Condition Patrol DSP310; the other is the RoadWatch SS system by M. S. Foster & Associates. These devices are mounted on the plow trucks to monitor the pavement surface temperature in real time. It is understood the sensors are used by the drivers to measure the highway temperature to ascertain if a section of pavement requires treatment or not.

CHAPTER 5

TREATMENT ROUTE OPTIMIZATION

CDOT is interested in exploring the potential route numbers needed to treat the predefined Designated Patrol Section.

The following section discusses whether a Route Optimization exercise might be feasible across the Designated Patrol Section, and if so what results may be expected.

1 - Route Optimization: Overview

Route Optimization is a customized, impartial and comprehensive service focusing on highway winter maintenance. It specializes in the development of treatment routes to meet a range of targets, including service level improvements, resource reallocation and changes to overriding constraints. Route Optimization can also be used to undertake ‘what-if’ scenario modeling, for example proposing optimum treatment regimenns and vehicle capacities before the procurement of new resources, and it is within this context that CDOT has asked Vaisala to produce this feasibility study.

2 - Assessment of CDOT’s Current Treatment Regimen

The following section of this report will assess CDOT’s current treatment regimen, and examine whether there is any scope for service level improvement through a Route Optimization exercise. This report shall mainly concentrate on the Designated Patrol Section as this is a good mix of geographical, highway categories and traffic count types. Other treatments, previously mentioned, shall also be considered.

3 - Plowing vs Spreading

The treatment and clearing of a snow and/or ice-packed road back to a wet pavement can involve plowing alone or plowing and spreading of material at the same time. When a truck is undertaking plowing-only operations then vehicle speeds and traffic are the most important factors to be taken into consideration.

If the truck is plowing and spreading concurrently then there is only a finite amount of material available within any truck. Once that is expended, the truck must return and reload. This takes time to return, reload and get back to where the truck was in the first place. There are some factors that have a bearing on this, including the size of the truck and the required spread rate.

4 - Maximum Treatment Range of Current Fleet

In order to evaluate the maximum treatable distance (MTD) of a vehicle, a set of basic mathematical considerations must be applied to the treatment criteria.

For ice clearance only, the MTD will be governed by the amount of material on board, whereas for snow or snow and ice clearance, the size of the plow and the amount of material both need to be considered when calculating the MTD. The MTD in tons can pertain to sand, sand and chloride, or salt.

The supplied truck data has three types:

- 4x4 with a 3.0 ton capacity
- Dump truck with a 3.5 ton capacity
- Tandem truck with a 7.5 ton capacity

Each truck will spread its material at a rate known as ‘spread rate,’ expressed as ‘pounds per lane mile’.

Table 2: Distance treated by one ton of material at differing rates and numbers of lanes.

Lbs/lane mile	Miles per ton, 1 lane	2 lanes	3 lanes
120	16.67	8.33	5.56
150	13.33	6.67	4.44
175	11.43	5.71	3.81
200	10.00	5.00	3.33
225	8.89	4.44	2.96
250	8.00	4.00	2.67

Fleet Capacity Figures.

Fleet figures supplied from CDOT suggest 29 trucks.

Based on the supplied truck list there are 29 trucks indicated with a spread accordingly. ***Please Note***: it is assumed the list may have been a sample of available trucks and perhaps not definitive.

Table 3.

29 Trucks	4x4	3.5 ton Dump	Tandem	Total Fleet Tons	Total Lbs capacity of fleet
Tons Capacity of truck	3	3.5	7.5		
# trucks	2	12	14		
Tons	6	42	105	153	306000

Tables 4, 5, and 6 show the comparable treatable distances for fleets of different capacities.

Table 4: 4x4 Treatable Distances

4x4			
Lbs/lane mile	Maximum Treatable Distance 1 lane	Maximum Treatable Distance 2 lanes	Maximum Treatable Distance 3 lanes
120	50.00	25.00	16.67
150	40.00	20.00	13.33
175	34.29	17.14	11.43
200	30.00	15.00	10.00
225	26.67	13.33	8.89
250	24.00	12.00	8.00

Table 5: Dump Truck Treatable Distances

3.5 ton Dump			
Lbs/lane mile	Maximum Treatable Distance 1 lane	Maximum Treatable Distance 2 lanes	Maximum Treatable Distance 3 lanes
120	58.33	29.17	19.44
150	46.67	23.33	15.56
175	40.00	20.00	13.33
200	35.00	17.50	11.67
225	31.11	15.56	10.37
250	28.00	14.00	9.33

Table 6: 3.5 Tandem Truck Treatable Distances

Tandem			
Lbs/lane mile	Maximum Treatable Distance 1 lane	Maximum Treatable Distance 2 lanes	Maximum Treatable Distance 3 lanes
120	125.00	62.50	41.67
150	100.00	50.00	33.33
175	85.71	42.86	28.57
200	75.00	37.50	25.00
225	66.67	33.33	22.22
250	60.00	30.00	20.00

Network Lane miles and distance by multiples of lane. *Please Note*: all ramps have been assumed to be 1 x lane for simplicity.

Table 7.

Patrols area lanes	total centerline miles	Lane multiplier	total lane miles
Ramps	14.1	x 1 lane =	14.1
1 lane	0.2	x 1 lane =	0.2
2 lane	169.9	x 2 lanes =	339.8
3 lane	5.6	x 3 lanes =	16.9
4 lane	58.0	x 4 lanes =	231.9
5 lane	0.9	x 5 lanes =	4.3
6 lane	14.4	x 6 lanes =	86.5
Totals	249.0		679.6
Total inc ramps	263.1		693.7

5 - Treatment Times

The average vehicle speeds for treatment used in this report have been given by CDOT as 30 mph top speed during the daytime and 35 mph for nighttime. There must be a balance between wide and straight main roads and narrow country roads. It must be noted that these are average speeds accounting for stops and starts, acceleration and deceleration. The top speed of the truck will be higher than the average. Some routes will require a weighting towards the rural speed while others will be more weighted towards the urban speed. Vaisala has calculated the figures into an average for urban and rural settings and these are represented in Table 8 below.

Average Plow Speeds.

Please Note: For comparison WyDOT quotes a 35mph plow speed and MDOT a 25mph plow speed. We have erred on the side of caution of what is achievable for our calculations.

Table 8.

Urban	**Treat/Plow**	**Free Run**
MPH	15	20
Rural	**Treat/Plow**	**Free Run**
MPH	25	30

The table below displays the maximum route lengths and times that can be treated for the vehicle sizes under different spread rates. These are based upon the average speeds shown in Table 8. An average route efficiency of 60% (treated distance of a route as a percentage of the total route length) and an assumed network split of 50% Rural and 50% Urban have been utilized for this analysis. This figure has been determined as an average for the whole Designated Patrol Section. Individual routes and even certain areas within those routes, such as city or mountain, will have their very own unique set of figures. It should be noted that an average efficiency of 60% is considered to be conservative.

Table 9: Maximum route lengths under varying scenarios

Treat/Plow, Dead and Total shown in Miles.

120lbs, 1 Lane				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**50.0**	**33.0**	**83.0**	**4:02**
3.5 Dump	**58.3**	**39.0**	**97.3**	**4:44**
Tandem	**125.0**	**82.0**	**207.0**	**10:04**
120lbs, 2 Lanes				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**25.0**	**17.0**	**42.0**	**2:02**
3.5 Dump	**29.7**	**20.0**	**49.7**	**2:25**
Tandem	**62.5**	**42.0**	**104.5**	**5:04**
120lbs, 3 Lanes				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**16.7**	**11.2**	**27.8**	**1:21**
3.5 Dump	**19.4**	**13.0**	**32.5**	**1:34**
Tandem	**41.7**	**27.9**	**69.6**	**3:23**
150lbs, 1 Lanes				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**40.0**	**26.8**	**66.8**	**3:15**
3.5 Dump	**46.7**	**31.3**	**78.0**	**3:47**
Tandem	**100.0**	**67.0**	**167.0**	**8:07**
150lbs, 2 Lanes				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**20.0**	**13.4**	**33.4**	**1:37**
3.5 Dump	**23.3**	**15.6**	**38.9**	**1:53**
Tandem	**50.0**	**33.5**	**83.5**	**4:03**
150lbs, 3 Lanes				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**13.3**	**8.9**	**22.2**	**1:04**
3.5 Dump	**15.6**	**10.4**	**26.0**	**1:15**
Tandem	**33.3**	**22.3**	**55.7**	**2:42**
175lbs, 1 Lane				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**34.3**	**23.0**	**57.3**	**2:47**
3.5 Dump	**40.0**	**26.8**	**66.8**	**3:14**
Tandem	**85.7**	**57.4**	**143.1**	**6:57**
175lbs, 2 Lanes				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**17.1**	**11.5**	**28.6**	**1:23**
3.5 Dump	**20.0**	**13.4**	**33.4**	**1:37**
Tandem	**42.9**	**28.7**	**71.6**	**3:28**
175lbs, 3 Lanes				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**11.4**	**7.7**	**19.1**	**0:55**
3.5 Dump	**13.3**	**8.9**	**22.3**	**1:04**
Tandem	**28.6**	**19.1**	**47.7**	**2:19**

200lbs, 1 Lane				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**30.0**	**20.1**	**50.1**	**2:26**
3.5 Dump	**35.0**	**23.5**	**58.5**	**2:50**
Tandem	**75.0**	**50.3**	**125.3**	**6:05**
200lbs, 2 Lanes				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**15.0**	**10.1**	**25.1**	**1:13**
3.5 Dump	**17.5**	**11.7**	**29.2**	**1:25**
Tandem	**37.5**	**25.1**	**62.6**	**3:02**
200lbs, 3 Lanes				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**10.0**	**6.7**	**16.7**	**0:48**
3.5 Dump	**11.7**	**7.8**	**19.5**	**0:56**
Tandem	**25.0**	**16.8**	**41.8**	**2:01**
225lbs, 1 Lane				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**26.7**	**17.9**	**44.5**	**2:09**
3.5 Dump	**31.1**	**20.8**	**52.0**	**2:31**
Tandem	**66.8**	**44.7**	**111.5**	**5:09**
225lbs, 2 Lanes				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**13.3**	**8.9**	**22.3**	**1:04**
3.5 Dump	**15.6**	**10.4**	**26.0**	**1:15**
Tandem	**33.3**	**22.3**	**55.7**	**2:42**
225lbs, 3 Lanes				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**8.9**	**6.0**	**14.8**	**0:43**
3.5 Dump	**10.4**	**6.9**	**17.3**	**0:50**
Tandem	**22.2**	**14.9**	**37.1**	**1:48**
250lbs, 1 Lane				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**24.0**	**16.1**	**40.1**	**1:57**
3.5 Dump	**28.0**	**18.8**	**46.8**	**2:16**
Tandem	**60.0**	**40.2**	**100.2**	**4:52**
250lbs, 2 Lanes				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**12.0**	**8.0**	**20.0**	**0:58**
3.5 Dump	**14.0**	**9.4**	**23.4**	**1:08**
Tandem	**30.0**	**20.1**	**50.1**	**2:26**
250lbs, 3 Lanes				
Route	**Treat/Plow**	**Dead**	**Total**	**Time h:m**
4x4	**8.0**	**5.4**	**13.4**	**0:38**
3.5 Dump	**9.3**	**6.3**	**15.6**	**0:45**
Tandem	**20.0**	**13.4**	**33.4**	**1:37**

It should be noted that the distances above are absolute until all the material is expended. Working out an average of all the above tables when plowing only a distance of approximately 22 miles can be covered in one hour.

6 - Optimum Vehicle Size

In general it would appear that based upon proposed treatment constraints, the fleet of vehicles currently in place realistically represent the optimum fleet designation for CDOT based on the current LOS. As there are both large and small trucks available, wider main highways and smaller roads can be covered successfully. As older trucks are replaced tandems should be acquired as they represent a more efficient use of resources.

- If the larger Tandem trucks were increased in number, in certain instances they could be effectively deployed on wider, faster stretches of highway which could maximize their extra capacity and ensure more road could be treated in one route, especially at high spread rates. However, on the whole, it would not be recommended that vehicles of this size be considered in urban centers or some of the smaller rural roads. They would have to drive more cautiously and may not be able to gain access to certain areas. The Interstate highway could be plowed in echelon formation more frequently. CDOT would have more trucks to use in heavy storms utilizing a rolling plow system.

- Smaller vehicles (e.g. 4x4 or dump) may offer some flexibility if it were possible to reload during the course of treatment. If routes are designed effectively to maximize treatment before and after reloading, then it could theoretically prove possible to utilize a dump truck to deliver a performance near to that of a tandem truck. However, in practice it is probable that reload routes will not be able to utilize their full capacity either before or after returning to depot, and this depot return journey will incur additional dead mileage, leading to increased cycle times. The best use of smaller vehicles would be in urban areas where access may be an issue and in rural areas where the roads are narrower. CDOT has not indicated any access issues. It is unlikely that the increased use of smaller vehicles would bring any increased benefits to CDOT's treatment regimen.

7 - Possible Route Changes Under Current Treatment Regimen

From the tables on the following two pages it can be seen that mathematically the fleet capacity far exceeds the required material capacity to treat the entire Designated Patrol Section very comfortably at any spread rate. This leads us to conclude that there could be scope for a reduction in the route numbers.

In Section 11 - Capacity-Based Route Reductions, we shall investigate several possibilities, both exact mathematical scenarios and recommendations taking into account the unique structure of CDOT's network using the most pertinent figures from these tables.

Table 10: 29-Truck Fleet

At a Spread Rate of 120 lbs			
Capacity tons	MTD: Miles per Vehicle	Number of Vehicles	Miles Treatable by Type
3	50.00	3	150.0
3.5	58.33	12	700.0
7.5	125.00	14	850.0
Total		29	1700.0

At a Spread Rate of 150 lbs			
Capacity tons	MTD: Miles per Vehicle	Number of Vehicles	Miles Treatable by Type
3	40.00	3	120.0
3.5	46.67	12	560.0
7.5	100.00	14	680.0
Total		29	1360.0

At a Spread Rate of 175 lbs			
Capacity tons	MTD: Miles per Vehicle	Number of Vehicles	Miles Treatable by Type
3	34.29	3	102.9
3.5	40.00	12	480.0
7.5	85.71	14	582.9
Total		29	1165.7

At a Spread Rate of 200 lbs			
Capacity tons	MTD: Miles per Vehicle	Number of Vehicles	Miles Treatable by Type
3	30.00	3	90.0
3.5	35.00	12	420.0
7.5	75.00	14	510.0
Total		29	1020.0

At a Spread Rate of 225 lbs			
Capacity tons	MTD: Miles per Vehicle	Number of Vehicles	Miles Treatable by Type
3	26.67	3	80.0
3.5	31.11	12	373.3
7.5	66.67	14	453.3
Total		29	906.7

At a Spread Rate of 250 lbs			
Capacity tons	MTD: Miles per Vehicle	Number of Vehicles	Miles Treatable by Type
3	24.00	3	72.0
3.5	28.00	12	336.0
7.5	60.00	14	408.0
Total		29	816.0

8 - Possible Implications of Changes to Current Performance Criteria

In an ideal situation, depots would be evenly spread across the network to be treated, ensuring the routes radiate out from each depot as the central point. As far as route numbers are concerned, in most cases, better sited depot locations can be a key factor in achieving route reductions. In real terms, the cost implication of keeping open a depot is by far the overriding factor over route reductions.

The CDOT Designated Patrol Section has a unique and varied winter network with some urban centers, but mainly open highways and rural spreading across a wide area. To cover this, there is a good spread of depots across this network.

While it may be possible to meet these figures in some instances, as stated previously, one of the guiding principles of Route Optimization is to design routes which respect treatment continuity. As such, the design of the route will ensure that treatment actions will often be curtailed to end at breaks in a network continuity (road intersections, traffic lights, yield signs, etc.) rather than being designed so that the vehicle will run out of material part of the way along a stretch of road.

As such, it is more likely that the average treatment range may be reduced somewhat. For the purposes of this exercise a small reduction of 5% in the total distance a fleet or a single truck can treat shall be levied on an average route treatment distance.

9 - Anti-Icing vs De-Icing

Anti-icing is laying down material, Mag Chloride, Brine, Sodium Chloride, etc. before a storm hits to help prevent the formation of ice or to stop snow from bonding to the pavement. De-icing is laying down material, Mag Chloride, Brine, Sodium Chloride, etc. after a storm hits to help melt ice or snow once it has settled on the pavement. This could include mechanical means of breaking the bond, i.e. plowing.

Anti-icing has several advantages over de-icing:

- The trucks do not need to plow at the same time as spreading, thus decreasing the potential for damage to hidden roadside structures, post boxes, etc. or to the plow itself.

- The amount of material used to achieve and maintain a wet pavement through anti-icing is far less than through de-icing. This has several positive effects including material cost savings, reduced vehicle corrosion, and reduction of any environmental impact.

- The pavement is not allowed to form ice or let snow form a bonding layer, thus adding to driver safety from the outset.

- All the roads are ‘prepared’ for the storm and trucks can potentially be used in a targeted manner in locations that may require a higher level of service as the storm develops.

This doesn’t mean to say that there are no potential disadvantages of anti-icing over de-icing. Some disadvantages of anti-icing are:

- Adverse public perception arising from trucks being seen to ‘waste’ material on roads that are not yet effected by ice or snow. This could even lead to mistrust of CDOT by the public. The minimum result of this practice is confusion to an uninformed public.

- If the storm does not appear as predicted or at all then the time and material can be considered wasted.

The advantages to anti-icing far outweigh the disadvantages if the decision makers get it right. To that end, it is essential that they have the latest and most accurate weather information at their disposal, whether this is predicted weather forecasts or even real-time observed data of an approaching storm. This data can be from within the state itself or from neighboring state departments. The advantage of using forecast and observed data is the decision maker can time the call to treat accurately.

As the trucks do not need to plow as well as spread while anti-icing they can treat several lanes at one time, and therefore the road network can be served more quickly than with concurrent plowing and spreading. As mentioned elsewhere in this report, larger trucks are more useful than small trucks in this case due to the larger capacity and the reduction in refill needs. This must be tempered with public perception as cars in other lanes may be splashed by the spread. A program of driver education in the media and/or on the website could help drivers better understand the savings that are being made.

A study from the Pacific Northwest Snowfighters shows that CDOT, averaging over a 5 year period, used 118,000 tons of material at $88 a ton, or $10,384,000 worth of Ice Slicer/Salt.

A sample of other Snow Belt States over the same 5 year period is as follows:

- Idaho, straight rock salt, 43,000 tons at $64 a ton or $2,752,000.

- Utah, straight rock salt, 205,000 tons at $31 a ton or $6,355,000.

- Wyoming, straight rock salt, 20,000 tons at $64 a ton or $1,280,000.

- Montana, straight rock salt, 35,000 tons at $85 a ton or $2,975,000 plus solar salt with inhibitors, 24,000 tons at $110 a ton or $2,640,000. Total of $5,615,000.

It must be noted that Colorado has its own unique climate and road configuration. Additionally, the figures above do not relate to distances of roads covered. A general comparison does show that CDOT spends significantly more money just on material than other neighboring states in the region. CDOT also is the second highest user of salt in the region, behind Utah, which has the lowest cost per ton. This must in some way be related to the fact that CDOT mainly de-ices instead of anti-icing the roads. There would be real savings in tons used if a robust science-based anti-icing policy utilizing RWIS data was implemented. If CDOT were to implement a statewide anti-icing program backed up by good RWIS and MDSS science there could be potential to reduce just the salt costs by up to 20 or 30%. It should be noted that any savings are dependent on reducing not only the use of salt through a change of treatment policy but also a reduction in procurement cost from the current $88 per ton. The dollars saved would not only be able to be used elsewhere within CDOT to improve services, but the positive publicity would be of great benefit and would go towards offsetting any negative public perception towards anti-icing.

Several DOTs in North America utilize an anti-icing program to good effect.

Some but not all examples are Massachusetts (MassDOT), Montana (MDOT), Washington State (WsDOT), Minnesota (MnDOT), Idaho TD and Iowa DOT. Additional details on a few of these are provided below.

WsDOT employs both liquid chemicals, pre-wet and solid salt anti-icing and de-icing to achieve their level of service on winter roads. The rate of application, in line with most DOTs, rises as the temperature decreases and also according to the condition; black ice, heavy snow, etc.. The rates are from a light application of 30 lbs/lane mile of solid chemical at 35 deg F for a predicted frost to 400 lbs/ lane mile for a pre-wet solid chemical at 15 deg F for a freezing rain storm.

Idaho TD is divided into six districts with each district selecting their product(s) of choice. The products used by Idaho TD are liquid MgCl and salt brine, the solids are straight sodium chloride, blended anti-skid at ratios 1:1, 2:1, 3:1 and straight anti-skid. Rates of application are benchmarked to temperature zones, thus a warmer event requires less product than a colder event. They use large 9 cubic yard 10 wheelers and 5 cubic yard 6 wheelers. As stated elsewhere in this report, the larger trucks can treat a greater distance before refilling. Idaho TD encourages operators to pre-wet their product, as all of their trucks have pre-wetting systems and some choose to pre-wet the stock pile or the load. Most trucks pre-wet at time of application. The salt brine target rate is 12-20 gallons per ton, MgCl is 7-10 gallons per ton. Although Idaho TD discourages the application of dry solids, it does occur. The anti-icing rates are salt brine at 30-50 gallons per lane mile and MgCl at 15-30 gallons per lane mile, depending on the forecasted precipitation amount. Idaho TD solid chlorides are spread at a similar rate to CDOT at 75-300 lbs. per lane mile. With regards to anti-icing, they target no more than one day in advance of a storm and many districts anti-ice using the “just in time” principal a couple of hours before an event.

MDT uses a ‘just in time’ approach to anti-icing. The Department monitors the weather data and makes a decision to anti-ice based upon many factors including air temperature, pavement temperature, humidity levels, dew point temperatures, exposure to solar radiation, type and rate of precipitation, weather forecast, weather radar data, and satellite data. MDT monitors road conditions using infrared sensors, thermal mapping, and Road Weather Information Systems (RWIS).

10 - Depot Location vs. Route Numbers

It is understood that the existing depot locations and numbers are not to be altered. Assessing them using the GIS information provided by CDOT and the expertise of the Vaisala consultancy team, it appears that the current locations are good and optimally placed. Closing a depot can produce huge savings in labor, land retention, tax rates, etc.. It is generally cheaper to maintain one large depot centrally placed within the network than to have many several smaller depots spread around any given area due to efficiencies in scale.

11 - Strategically Placed Refill Stations

There will be instances where heavy material treatment is necessary due to conditions, for example 250 lbs./lane/mile or more, across long stretches of road will inevitably require trucks to reload. Driving back to the original depot will take time and effort that is better used treating the roads. If stand-alone, strategically placed refill stations were available, this would provide much better continuity of service across the network. In reality not every section will need such refill stations, but a survey of individual roads and discussions with drivers would have to be undertaken to identify the best location and size of these dumps. During the route design stage of the project, Vaisala will also comment on potential locations and the impact on cycle times that these may have. The driver could refill at these stations although it would be important to accurately record material usage. This would allow replenishment of the dump when required.

Patrol boundaries are normally the product of many factors which have built up over a period of time. Many new factors such as changing traffic flow, density and new road construction since the implementation of these boundaries have an effect on the current validity of these boundaries. The study and rationalization of patrol boundaries could help with truck distribution and refilling. Without rationalizing the patrol boundaries there are several options for refill locations.

- Patrols 7, 8, and 12 join at the road junction of the 7 and the 72. This is an obvious place to put a fill point.

- Patrols 10 and 13 meet in the city of Boulder and theoretically a site there would be beneficial; however the cost of real estate purchase, unless already owned by CDOT, would potentially be prohibitive. A location near but not necessarily at Hayden Lake would give good access to the 36, 119 and 157.

- Patrol 15 would find it useful to refill at or near the junction of 287 & 56 near Berthoud. Note: this site would only be of benefit to Patrol 15.

- Patrols 9 and 13 would benefit from a site near or where they meet at North 107th St and Arapahoe Road, Junction of the 7 & 287.

All of these recommendations are for consideration only. There will be a great many factors in any siting decision, for instance: Is there land already owned by the State in these locations? Would the purchase of real estate be prohibitive against potential savings and LOS targets? What would be the timeframe of implementation and how long would the site be expected to be viable?

It could be helpful if routes could refill at neighboring sites.

- Patrol 10 could refill at Lyons when treating the 7 north to join with the 66.

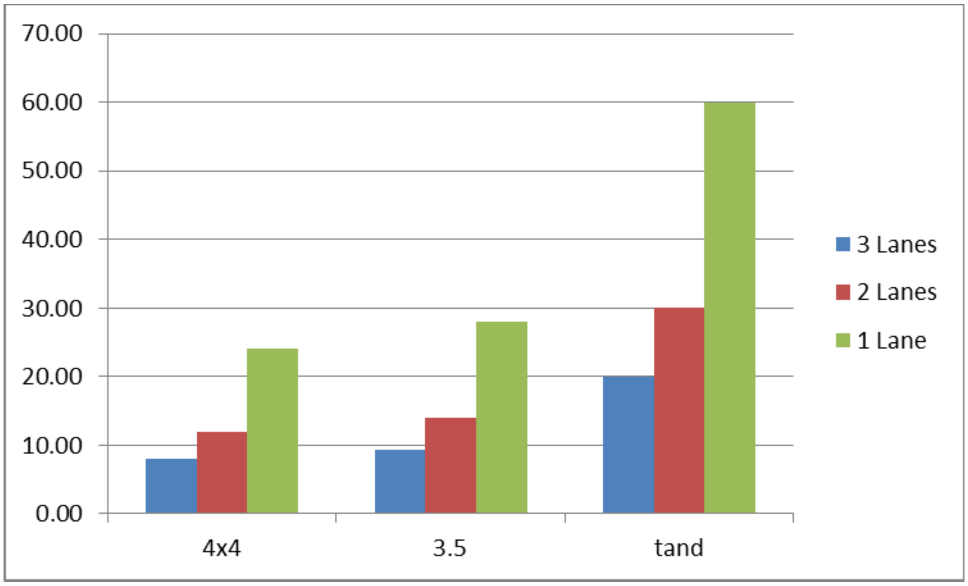
- Patrol 9 could refill at Longmont.

- Patrol 8 could refill at Longmont although there would be a 7.6 mile travel to and from the 66. The same could be said for Patrol 15 as it joins Patrol 8 at the junction of the 66 and the 287.

The boundaries between Patrols 7 & 8 are unusual in that they do not seem to correlate to distinct junctions. A road user on the 36 north out of Lyons or south out of Estes Park may find that treatment and clearing are not consistent over the whole stretch of the 36. It is the same situation with Patrols 10 & 12 on the 7. Nederland only treats circa 59 miles with 4 people but it is again some of the most upland and potentially most challenging routes.

Currently patrols load their trucks 3 to 4 times in a 12 hour shift. This is weather and treatment dependant and can sometimes be greater. Obviously a larger tandem truck will refill less than a 4x4 or a dump truck. The Tandem can cover over twice as many miles as a 3.5 dump before refilling; therefor it would be preferable to use larger trucks on longer stretches of pavement. This must of course be tempered with the requirement for larger trucks to be used on roads with higher levels of service. An example of a ‘250 Lbs/lane mile’ coverage in miles over 1, 2 and 3 lanes is shown below.

Table 11



The table below demonstrates the distribution of miles and labor by Patrol.

Table 12

Yard	Patrol	miles	lane miles	People	Miles per person
Estes Park	7	106.19	227.94	6	37.99
Lyons	8	31.82	87.63	4	21.91
Dacono	9	31.86	111.71	6	18.62
Longmont	10	44.25	124.62	7	17.80
Nederland	12	28.78	58.92	4	14.73
Superior	13	39.94	99.82	6	16.64
Mead	15	40.15	87.22	6	14.54
Total		282.85	797.86	39	

Estes Park has by far the greatest mileage and also the greatest distance treated by person. Together with Patrol 12 it is also the most upland Patrol. Patrols 8 & 10 having some upland also. Prima facie it would seem that Patrol 7 is covering a disproportionate amount of network to the other patrols per person. The difficult areas of upland network would suggest more resources would be required. However, some roads are closed for the season and this would offset these figures somewhat.

12 - Capacity-Based Route Reductions

As illustrated previously, it appears possible within an individual route for CDOT's current fleet to deploy its treatment material, with a huge variation in time, from 38 minutes to over 10 hours depending upon truck size and spreading criteria. For example, at a rate of 250 pounds per lane mile, plowing and spreading just one lane, the trucks will have a typical maximum time before re-loading as outlined below:

Table 13.

250lbs, 1 Lane	
Route	Time h:m
4x4	1:57
3.5 Dump	2:16
Tandem	4:52

Regardless of truck size, in a simple plow/not spreading scenario the route times will be subject to travel speeds. These speeds are absolutely dependent on road category, traffic density, and snow and ice conditions. The Designated Patrol Section has a total centerline distance of 263.1 miles, including ramps. The total lane mile distance is 693.7 miles including ramps.

One Ton of Treatment Material.

The lane miles that can be treated by one ton of treatment material at differing spread rates.

Table 14.

Miles treated per ton of material	
Lbs/la mi	Miles Treated
120	16.67
150	13.33
175	11.43
200	10.00
225	8.89
250	8.00

The total capacity and total lane miles the fleet can treat under any given spread rate needs to be understood in order to be able to analyze if there would be any benefit in a reduction of trucks. The tables on the next two pages show the Maximum Treatable Distance (MTD) of the fleet at varying spread rates.

As previously stated, CDOT's current treatment and vehicle sizes, not numbers, probably represent the optimum requirement for their current scenario. However, that doesn't preclude investigations into whether further savings might be available should these parameters be reviewed.

Assuming that it is possible to design a new set of treatment routes which meet the average treated distance, time and efficiency figures outlined previously, then:

693.7 miles of network including ramps.

At the heaviest material usage of 250 lbs. per lane mile a 29 truck fleet can treat **816 miles** of lanes.

- 816 minus 5% safety margin = 775.2 miles of potential capacity.
- 775.2 minus 693.7 = 81.5 miles of potentially unused capacity.
- 81.5 miles/8 miles treated per ton = 10.2 tons unused.
- 10.2 tons = the capacity of 1.4 Tandem trucks @7.5t, realistically 1 from the total of fleet of 29 = **28 trucks**.

The above calculations are based purely on the capacity of the fleet and spreading, not necessarily plowing, and have been calculated using pessimistic figures. It could be possible to use even fewer trucks. There are several factors that may cause a variation in these figures. For example, if the average truck speed is slower for some sections of the network then the route will take longer and may be subject to time constraints, not capacity. The optimum plowing speed may well be slower than the optimum spreading-only speed. The above estimated Capacity Based Route Reductions take note of reductions in the largest Tandem trucks. It is noted that these would in fact be the last trucks to go in favor of replacing the smaller, less useful trucks with Tandems.

13 - Costs - Trucks, Labor, and Material

Every truck, every driver, every ton, every hour has a cost. In this current economic climate it is essential that DOTs are seen to do more with less.

This requires rationalization of resources, both physical and human as well as time.

A set of breakdowns are reproduced on the following page. It can be seen that, unsurprisingly, the Midrange are the cheapest to run by the hour and the Tandems are the most expensive. However, the Tandems offer the best value for the money by having the larger capacity, resulting in reloading less often than other vehicles.

Ta**ble 15: Breakdown of plant and labor costs by the hour. All costs, material, labor and plant, supplied by CDOT during information gathering phase.**

Hours	Midrange 4x4 $	Labor $	Total costs by hours $
1.00	21.80	31.00	52.80
2.00	43.60	62.00	105.60
4.00	87.20	124.00	211.20
Hours	**Tandem Dump $**	**Labor $**	**Total costs by hours $**
1.00	20.10	31.00	51.10
2.00	40.20	62.00	102.20
4.00	80.40	124.00	204.40
Hours	**Tandem 6x6 $**	**Labor $**	**Total costs by hours $**
1.00	17.39	31.00	48.39
2.00	34.78	62.00	96.78
4.00	69.56	124.00	193.56

Table 16: Breakdown of materials by spread rate and ton (DPS – designated patrol section). ***Please Note*****: the dollar costs of each of the materials, Ice Slicer, etc, have been averaged.**

Lbs/Lane /Mile	Total Lbs used to treat DPS network	Total Lbs / 2000 to give Tons	Total Gallons of Liquid @ 8 Gals/Ton	Total cost of Ice Slicer $	Total cost of Liquid $	Total cost of Sand Slicer $
120	62972.1	31.49	251.89	3173.64	189.55	579.21
150	78715.1	39.36	314.86	3967.05	236.93	724.01
175	91834.3	45.92	367.34	4628.22	276.42	844.68
200	104953.5	52.48	419.81	5289.39	315.91	965.35
225	118072.7	59.04	472.29	5950.57	355.40	1086.02
250	131191.9	65.60	524.77	6611.74	394.89	1206.68

Reducing the routes through an optimization process will not reduce the material costs incurred, as the same roads will be treated regardless. However, the plant and labor costs will be reduced in line with the number of routes or trucks reduced. If the same network is treated or plowed by a lesser number of trucks, this will equate to a direct cost savings. If the routes are optimized to take into account meteorological and hierarchical constraints, the network will be treated more efficiently, and therefore in a safer manner, and the unseen savings will also increase.

Assuming that it would be possible to design a new set of treatment routes which meet the average treated distance, time, and efficiency figures outlined above, and also using those potential route reductions projected, the potential saving across the Designated Patrol Section accounting for various scenarios would be:

Taking the greatest spread rate of 250lbs over 3 lanes giving us a reduction of 4 routes.

Table 17.

250lbs, 3 Lanes				
Route	Treat/Plow	Dead	Total	Time h:m
Tandem	20.0	13.4	33.4	1:37

A 4 Route Reduction.

An average Dollars **per hour** cost of a Tandem is **$199.**
Time – 1:37 h:m

$199 x 1.37 (h:m) = $322.38 per route x 4 = **$1,289.52** saving per network treatment.

Although it is never possible to predict how many storms CDOT will encounter in a season, this can be obviously be a significant savings over a winter.

These are mathematical savings based on the scenario above using an average of the costs supplied. In a real optimization exercise these route reductions may vary either higher or lower depending on real, on the ground situations.

CHAPTER 6

CONCLUSIONS

1 - Level of Service

There is a logical desire to maintain a commonality between MPAs in their approach to LOS, but a simplification of the criteria and a customized and logical definition could lead to better winter service overall. CDOT's current approach to snow and ice management appears unnecessarily complex, and a simplification of the criteria could bring cost savings to CDOT while increasing road users' safety.

It's worth noting that an increase in road safety brings its own savings with the reduction of traffic collisions. These are an unseen savings and can only be measured retrospectively by comparing collisions, deaths and injuries against previous years. The United Nations General Assembly has declared 2011-2020 the Decade of Action for Road Safety. Motor vehicle crashes in the United States are the leading killer of children, teens, and young adults (ages 5 to 34) and among the top ten causes of death for all ages. Over 30,000 people are killed in crashes each year in the United States. In 2005, in addition to the impact on victims' families and friends, crash deaths resulted in $41 billion in medical and work loss costs, with Colorado accounting for $623 Million (annual cost, not limited to winter-weather incidents). Snowfall obviously makes for dangerous road conditions. But fatalities actually drop across the nation during days with high amounts of snow, both because more people stay at home and because they tend to drive slower under inclement weather. (Source - University of Michigan). Researchers at Berkeley evaluated 1.4 million fatal crashes attributed to weather conditions from 1975 to 2000. They found that fatal crashes were 14% more likely to happen on the first snowy day of the season compared with subsequent ones.

The LOS could be rationalized and made less complicated without compromising safety. Some examples are included below.

Example of a section of Wyoming (WyDOT) approach to LOS

They have only 4 categories, one of which is 'Closed' category.

High volume (IA, IB) *service is provided on interstates and principal arterial and urban routes. If necessary, crews will work up to 24 hours a day on IA highways and up to 20 hours a day on IB highways with a goal of maintaining a bare roadway for driving safely at reasonable speeds.*

Medium volume (II) *service is provided on lesser used minor arterial routes. The goal is to keep the roadway passable for drivers who are taking reasonable winter driving precautions, although with less emphasis on keeping the roadway bare.*

Low volume (IIIA, IIIB) *service generally involves other less busy minor arterial and collector routes and is provided after high-volume and medium-volume routes have been cleared, with exceptions sometimes made for school buses or similar traffic. Low-volume service is provided only during daylight hours. Level IIIB state highways receive minimum levels of service as resources become available. During severe storms, scheduling depends on available personnel and equipment.*

Closed (IV) *service-level roads are the few that are allowed to close seasonally as snow accumulation dictates. For these roads, the cost of keeping them open through the winter overrides the benefits to the few travelers that might regularly use them.*

"During severe storms, scheduling depends on available personnel and equipment. Highways designated for high-volume service will be plowed first, with roads in other classifications handled as soon as possible thereafter. Changing weather and road conditions may require shifting resources from lower-priority roads to achieve the desired level of service on higher-volume highways. Each operator/vehicle combination has responsibility for plowing and sanding operations to keep roadways suitable for driving at reasonable speeds. With plow speeds averaging 35 mph, in a 10-hour shift each operator may drive 300 miles or more in the worst of winter conditions."

How Idaho measures winter maintenance

Performance measuring. ITD has two winter performance measures. The first is the Winter Performance Index that measures their effectiveness to deice the surface. This is attained by formulating the storm severity and the duration of time it takes to restore grip. The second is the Mobility *percentage. This measures how effective we are at preventing ice or snow floor during an event. This is done by looking at the percentage of time the grip is above .60 with precept on a below freezing surface.*

> *Spread Rate. ITD is divided into six districts that manage winter operations according to their geographical uniqueness and resource availability. This is becoming more standardized since the 2011 implementation of the WPM. ITD's most successful locations are anti-icing with salt brine prior to the event at 35-40 gallons per lane mile. This creates a bond breaker which is then followed by solid application during the event. Solid spread rate varies on severity of the event and surface temperatures. Solid chloride applications range from 75-200 pounds per lap and dilution of solution (DOS) is factored into the lap time.*
>
> *Categories of Highways. ITD have three levels of routes based on type of corridor; State wide (highest), District and Regional. Their goal is to measure the state wide and district levels and the regional is also measured.*

Example of a section of Montana (MDT) approach to LOS

The operating speed of a plow truck is directly related to efficiency and effectiveness. Operators will maintain a speed that does not endanger life or property, but provides a reasonably prompt service. Excessive plowing speeds can result in damage to the roadway, damage to the plow, poor performance, and a rough road. Excessive plowing speed in wet snow can damage mailboxes, other vehicles and cause injuries to pedestrians or cyclists and put snow onto sidewalks. Plowing speed shall not exceed 25 mph and should be slower under most conditions.

A paragraph or 2 detailing the effect of a higher level of service e.g. pressure on drivers, difficult decision making etc. Will need to include reference to drivers comments about what expected of them e.g. mailboxes, reacting to phone calls for not critical routes.

From the examples above it can be seen that CDOT employs a much more complex approach to winter maintenance with a great many levels and categories of highway as compared to other Snow Belt states. While this is to be commended, it can make the decision-making quite difficult and achieving consistency across the Region an enormous task. Getting the decision right is the primary factor in any call-out but the pressures from taking into account so many levels cannot be simple.

Accountability, making the right decision and robust documentation with any threat of litigation is, unfortunately, a real part of modern winter maintenance today.

Drivers would benefit from a simplified system. There are considerations regarding hours taken to complete any given route, where and how they should treat, how to cope with roadside structures such as mailboxes. Drivers must have confidence and a level of ownership over any undertaking they participate in. Consultations and discussions with drivers are essential if the system is to work efficiently. After all, they are the front-line personnel, they know where the problems occur and the department should listen to them if it does not already. There is naturally a cut-off point where the considerations of the State outweigh the wishes of the drivers.

2 - Pre-Treatment

Although CDOT does not currently employ a comprehensive pre-treatment regimen, a review into the benefits of anti-ice or pre-treatment may be of use. While some doubts remain about its effectiveness, there are proven benefits to utilizing dry salt or diluted salt in advance of an event. Pre-treatment of isolated areas on the network can prevent ice from forming before a plow can get to the location in normal operations. Pre-treatment should also result in less chemical being spread while plowing as the Mag Chlor (or other chemicals) would only need to maintain wet pavement and not to remove ice. If and when CDOT implements pre-treatment it will take a culture change and education for the operators and public. CDOT is in a much better situation with regards to RWIS and MDSS than before. The decision-making tools are now in place to allow CDOT to combine these with local knowledge and expertise and make pre-treatment a safe and cost effective treatment method.

3 - Optimization

If a route optimization exercise takes place, then it would be possible to decrease the size (numbers) of the current fleet, provide a satisfactory service, and comply with current legislations. Or alternatively, the number of trucks could be kept the same and an overall reduction in treatment time could be gained. Realistically, there is a middle ground where a small reduction in trucks and time could be achieved. Finding this balance may require further in-depth study and some route design work.

Further improvements in service delivery are potentially available across CDOT. If routes were to be reduced and rationalized through a Route Optimization exercise then the older trucks could be cast aside in favor of the newer and more suitable trucks. A Route Optimization exercise to increase efficiency within the treatment time limit is both achievable and should lead to a reduction of overall route numbers in most encountered weather circumstances.

Following further consultation with CDOT and firming up of procedures and information we can hopefully move forward and rationalize winter maintenance procedures across the area creating a better service for the Colorado road users, save costs, and make the highways and roads a safer place.

4 - Windrows

At the intersection of major roads, traffic lights, and so on, there may be problems with 'windrows' or snow berms. Wherever possible, routes should be designed to plow these intersections in an efficient manner to reduce impact on road users. Intersections should be analyzed as to traffic density, and assessed to see if these windrows can be pushed through the intersection and to the side of the roadway.

5 - Boundaries

It is evident that the level of winter service that CDOT currently supplies is adequate and is fit for purpose when placed within the context of its current resource constraints. Due care and attention has been paid to all legal and policy guidelines, and the service provided is consequently in line with these. Performance is on a level which would be expected with respect to current resources, budgets, local constraints and historical precedent. However, there is a need to improve service and reduce costs.

For Route Optimization to produce the most effective routes in the shortest treatment or plow time they must be free of political boundaries. A road-based approach that curtails treatment at logical intersections where another route, perhaps from an adjoining area, takes up the treatment must be taken. After all, if a truck has to treat to a given milepost it must travel a certain distance to find a safe turnaround point. The reciprocating truck will have to do the same travelling in the opposite direction leading to inefficiency and time wasted. Over some long stretches of road, a Tandem may expend most of its material but there may be potential to reload at the nearest depot, not its home depot, and return treating. Therefore, there must be cooperation between depots to allow trucks from other depots to reload.

6 - Fleet

CDOT's current fleet type appears to be of the optimum requirement based upon current constraints and time limits. However, the larger trucks having a greater capacity are far more useful and can spread material for a much greater time than the smaller trucks that have to return to reload more frequently, thus incurring longer cycle times and a less efficient use of the driver's time. Wasted time in winter treatment terms is, after all, wasted money. An increase in the number of Tandem trucks and a reduction in smaller trucks will lead to a far better system of deployment and more treatment on the road in less time. In some areas small trucks may well be of great benefit, but these will be very localized examples.

Some of the fleet used by CDOT is very old, with no trucks that could be considered new. It is essential to maintain a fleet in good condition, which means that trucks eventually do need to be deemed no longer fit for duty. Is it certain that the calibration of the fleet is correct? Is the fleet suffering from more breakdowns than is acceptable? Replacement of fleet is best done on an 'as need' basis, and not 'like for like.' For example, although it is necessary to maintain smaller trucks for certain areas there is no point replacing a small truck with yet another small truck, which can only treat a small section of road before having to return to the depot or refill station to reload, when a larger truck would far out-perform its predecessor. Again a survey should be undertaken as to the suitability of the current fleet and any replacements that may be required. Fleet replacement is by no means a small investment, and should not be undertaken lightly.

When old trucks are retired they should be replaced with a suitable truck. Not replacing a truck will leave a greater burden on the rest of the fleet unless route reductions are in line with an optimization exercise designed to provide reductions. To merely reduce the fleet is false economy; the LOS could suffer, potentially putting drivers in peril. With an overhaul of the winter maintenance procedure, cost savings could be made. These savings could be utilized to upgrade and update the fleet, thus providing a greater LOS to the road user. Following the route design stage of the project, Vaisala will be able to comment on the scenario of utilizing larger, newer vehicles in more detail. It is noted that CDOT do indeed replace older fleet with Tandems rather than lesser trucks.

7 - Mobile Weather Monitoring

As mentioned previously, CDOT employs two systems to gather mobile weather observations. One is the Vaisala Condition Patrol DSP310, the other is the RoadWatch SS system by M. S. Foster & Associates. It is essential to have commonality of measuring equipment since differing results will mean inconsistent treatments. Instances have been noted where trucks travelling side by side have had readings differing by up to 10°F, resulting in one vehicle treating and the other not. Using the same equipment will mean results will be calibrated across the fleet and usable by any truck.

Mobile monitoring is an excellent tool when used in coordination with fixed weather stations along the side of the road. The system is further strengthened when combined with a Decision Support System (DSS) to provide weather forecasting and prediction information.

8 - Unscheduled Callouts

Trucks are sometimes called away from their current operation by State authorities to address more of an isolated or individual need. It is understood that this has been an issue at CDOT and it represents a very poor use of resources. This should if at all possible be discontinued in areas of probable low traffic count. Convincing the State Patrol and other interested parties will require prior discussion and agreement, if at all possible. Trucks called away are not available to treat sections where higher demand, higher road use, and driver safety are more urgent. These trucks are able to serve the greater good and expend their precious resources more efficiently if used as part of designated routes rather than be on call for an individual or smaller community.

CDOT should try to reassure concerned officials and citizens that everything is being done to address their problem in a timely manner. Information and communication is key in addressing this issue, informing callers that a truck will become available once it is has performed its wider duty, or that if a truck is close by it may be detoured to help.

Once the height of the storm has passed, these areas can subsequently be addressed. Alternatively, if this process is continued and deemed an essential service, then a study into frequency and scale of requests should be made. It is recommended that a small, suitably sized, dedicated truck be available rather than a truck from any main fleet.

9 - Driver Warning System

It would be of immense benefit to the road user (and plow driver) if there was a visual warning system alerting the vehicle driver of snow removal work ahead. As an example, a sign alerting the driver to *'Slow down, Snow Plowing Trucks Ahead,'* or similarly worded alerts would help them to be prepared for slower moving trucks and the potential for delay. After all, information is one of the keys to successful traffic management. This wording could be programmed into existing overhead VMS signs, stand-alone or mobile signs targeted at areas most in need as weather and treatment dictates. Regardless of whether the selective lane clearance option is implemented or not, this would be a valuable measure to introduce.

CHAPTER 8

NEXT STEPS

1 - Route Optimization

The actual Route Optimization will commence following feedback/meetings with the steering group and relevant people within the Boulder Maintenance Area. One of the main principles of Vaisala Route Optimization is that the main stakeholders are involved with developing and finalizing routes. Localized experience is key to any successful optimization project and feedback and comments are welcomed. Any comments/suggestions on this report can be addressed to trafficweatherconsulting@vaisala.com, who can provide further information on any of the issues raised within this report. We understand that there are other research projects being undertaken at present which will investigate CDOT’s LOS and any decisions from this can be included in the Route Optimization exercise.

CDOT has also recently undertaken Thermal Mapping surveys across Region 4. Thermal mapping identifies the thermal relationship between sections of roads across a network. During the route design phase of the project, this available data can be utilized in the design process to ensure that colder sections are treated as soon as possible within a given route. However, consideration must be given to maintaining efficiencies throughout the design process and this will take priority.

2 - Network

One of the most important factors to be considered when it comes to Route Optimization is the actual network to be optimized. At the outset of this project, it was decided that the network covered by the Boulder crew was to be considered. However, it has recently been announced that US36 may be decommissioned as soon as summer 2015. This in effect means that operations on US36 will not come under the supervision of Boulder. This would have an impact on the validity of any new routes designed for winter 2014/15 going forward. Route Optimization may involve routes not just treating/plowing specific highways in isolation but maybe a combination of different highways on any given route. There are two ways of dealing with this issue in the short term:

- The route optimization exercise for this year will ignore the fact that US36 will be offline in the near future. This may mean that the newly designed routes will have to be amended when US36 is removed from the network.

- The new routes will consider US36 in isolation to the rest of the Boulder network so that the effects of the decommissioning of the US36 will be minimized.

In our opinion, the second option would be of more benefit to CDOT as there is minimal disruption in the near future. This scenario will affect route efficiencies slightly but should not impact final route numbers as outlined earlier. Vaisala would appreciate the study panel's opinions on this as soon as possible. If, during the route design phase, other issues come to light that may affect final route numbers then Vaisala will inform the study panel immediately.

3 - Software to Aid Decision-Makers

Another element of this project is to identify potential software and algorithms to help with daily operations in CDOT. The scope of which software to use is wide-ranging and therefore requires quite a bit of research. The specifications from the second meeting are that Vaisala should look at all aspects of routing (including potential dynamic capabilities). Once again, one of the key aspects of developing improved tools is the experience of the current decision-makers in CDOT. Discussions via e-mail with Boulder supervisors have begun but with no conclusions as of yet. At the conclusions of these discussions/brain-storming, there will be a clear picture of the limitations of the current system and this will fundamentally decide the approach towards developing algorithms/software to enable easier operational decision-making. Once feedback is received in the next month or so, Vaisala will report on the results and potential GIS solutions to deal with these issues in a separate report. These can then be reviewed and a decision about possible options finalized by the steering group. This will enable Vaisala to ensure that the software is ready for use this winter season.

4 - What to do first?

The priority of these recommendations are entirely for CDOT to decide but we have included a suggested priority of action below. Obviously some of the suggestions are cheaper and easier to achieve than others, which may have significant bearing on CDOT's prioritization.

- Level of Service
  This needs to be addressed and as expanded on above a more simple process would benefit both CDOT and roads users.

- Pre-Treatment
  Implementation would lead to great cost savings.

- Optimization
  The patrols and their routing could be rationalized.

- Fleet Replacement
  It is understood that CDOT are already replacing older trucks with new, better models.

- Mobile Weather Monitoring
  Use of truck mounted sensors together with the other supporting systems will give the drivers the right information at the right time.

- Unscheduled Callouts
  Although this is a difficult as CDOT are at the call of the authorities and the weather, any reduction would be beneficial.

- Driver Warning System
  A very clear way of communicating to the road user, making them feel informed and their safety cared for.

CHAPTER 9

TABLES, ABBREVIATIONS.

1 - Map

Map 1 - Plan of Designated Patrol Section by Patrol

2 - Tables

Table 1 – Level of Service based on highway category and road condition.

Table 2 - Distance treated by one ton of material at differing rates and number of lanes.

Table 3 – Table of the capacity of the fleet.

Table 4 - 4x4 Treatable distances at different spread rates and lanes.

Table 5 – Dump truck treatable distances at different spread rates and lanes

Table 6 - Tandem treatable distances at different spread rates and lanes

Table 7 - Network lane miles and distance by multiples of lane.

Table 8 - Average Plow Speeds

Table 9 - Maximum route lengths under varying scenarios

Table 10 – Miles Treatable by a 29 Truck Fleet.

Table 11 – Example of a '250 Lbs/lane mile' coverage in miles over 1, 2 and 3 lanes

Table 12 - The distribution of miles and labor by Patrol in the DPS.

Table 13 - Treatment times per truck treating one lane at 250 Lbs/Lane Mile

Table 14 - Lane miles that can be treated by one ton of treatment material at differing spread rates.

Table 15 - Breakdown of plant and labor costs by the hour

Table 16 - Breakdown of materials by spread rate and ton (DPS – designated patrol section).

Table 17 – Details of an average Tandem route at 250lbs over 3 lanes

3 - Abbreviations

MTD = Maximum Treatable Distance.

DPS = Designated Patrol Section.

4 – Information

Various documents both electronic and hard copy were supplied from CDOT to help with the writing of this report. These include –

Colorado Department of Transportation, Standard Operating Guide (SOG) For Winter Maintenance and Operations, Revised August 2010.

Highway Maintenance Levels of Service, December 22, 1999.

Scope Of Work – Snow Route Optimization. *Note, the scope has been scaled down from the whole or Region 4 to the Designated Patrol Section.*

CDOT GIS data in vector Shape format.

CDOT, Region 4, Boulder maintenance Area list of Patrols in the Designated Patrol Section by road name. Patrols 7, 8, 9, 10, 12, 13 and15 with numbers of people working each patrol, these totaled 39. *Note, Vaisala were advised by CDOT that any maps supplied were not as accurate as these Patrol lists. Any maps created for calculative purposes* *or inclusion into this report have been created by Vaisala from the GIS data supplied by CDOT. CDOT have replied confirming their accuracy.*

Boulder area Patrol Map. Note statement above regarding accuracy..

Photocopy of purchase order for treatment material.

Vehicle list of 29 trucks.

Post-it note with Truck and Labor costs per hour.