JOINT TRANSPORTATION RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION AND PURDUE UNIVERSITY

Cost-Effectiveness of Constructing Minimal Shelter to Store INDOT Equipment (Weather Protection)

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16. Abstract

Currently vehicles used by INDOT are more likely to be subject to maintenance and repair than to replacement. The extent of wear and tear on the vehicles is likely to be impacted by the lack of covered storage in all districts. There are many different levels of covered storage—from tent-like structures to completely covered garages to temperature-controlled environments—each of which has different associated costs. But the associated reduction in equipment wear, speed of startup of equipment, and perhaps better mileage may all reflect savings to INDOT. This project evaluates INDOT's expected return on investment to create covered areas for equipment (vehicles, other assets), while also assessing the cost difference between vehicles left in covered versus uncovered areas.

This project can be used to benchmark certain lot sizes of equipment in order to decide whether or not implementing an indoor storage facility is efficient given the harsh conditions that the equipment may be facing during certain periods of the year. The information can be used to see the impact of weathering on snowplow trucks, the maintenance costs that can be reduced, and the payback period of building a shelter facility.

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EXECUTIVE SUMMARY

COST-EFFECTIVENESS OF CONSTRUCTING MINIMAL SHELTER TO STORE INDOT EQUIPMENT (WEATHER PROTECTION)

Introduction

This project is an analysis of the weathering impact on Indiana Department of Transportation (INDOT) snowplow trucks and the rationality of storing them indoors versus leaving them outdoors. This project was conducted to determine (1) what costs could be saved by moving from outdoor to indoor storage and (2) the efficiency of INDOT-owned snowplow trucks, which are used throughout the state of Indiana for various purposes year-round. This project focused on the winter season since most weathering costs are incurred then. After analyzing the weathering impacts on snowplow trucks, the maintenance difference between indoor- and outdoor-stored vehicles, and other findings, the project group completed a net present value analysis and a JaamSim simulation model to allow INDOT to more easily determine whether indoor shelters should be implemented.

Findings

Most INDOT vehicles are left outdoors for their lifespan. Because of the weathering effects on these vehicles, extra costs are incurred in maintenance, safety, and labor hours. The project group began the research process by determining the weathering effects and delays incurred by snowplows stored outdoors. The findings were that weathering effects not only impact maintenance, safety, and labor costs but also decrease vehicle lifespan due to corrosion and fissures.

Next, the project group focused on appropriate facility design to keep the equipment safe and regulated while still reducing maintenance costs and increasing productivity. The project group compiled information on four main structure types: prefabricated, panelized, conventional method, and temporary. The structure type chosen would depend on the number of trucks to be stored, and whether they would be stored year-round.

Aside from labor hours and gasoline, regular maintenance costs are the highest costs incurred during the lifespan of a snowplow truck. During the winter months, plow trucks experience intense temperature changes and are regularly in contact with salt, which causes corrosion in metal pieces and parts. Our research indicated that indoor storage can reduce maintenance costs by more than 20% and also reduce the impacts of corrosion. With snowplows costing upward of $125,000 apiece, this is significant.

The JaamSim simulation model gauges the impact of shelter on truck performance. The model studies the maintenance and service cycle of trucks in one facility (50 trucks) to understand the impact of the shelter on performance and efficiency. The model found that the average number of sheltered trucks ready to be put into service was ~41 compared to an average of ~36 for trucks stored outdoors. This indicates that better service with high readiness for emergency can be provided, or the number of actively used vehicles can be reduced.

Implementation

This project can be used to benchmark equipment lot sizes and help INDOT determine whether implementing an indoor storage facility would be efficient. The findings show the impact of weathering on snowplow trucks, maintenance cost reductions associated with sheltered vehicles, and the payback period from building a shelter facility.

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Currently vehicles used by INDOT are more likely to be subject to maintenance and repair than to replacement. The extent of wear and tear on the vehicles is likely to be impacted by the lack of covered storage in all districts. There are many different levels of covered storage, from tent-like structures to completely covered garages to temperature-controlled environments, each of which has different associated costs. But the associated reduction in equipment wear, speed of start-up of equipment and perhaps better mileage may all reflect savings to INDOT.

2. OBJECTIVE

Evaluate INDOT's expected return on investment to create covered areas for equipment (vehicles, other assets), while also assessing the cost difference between vehicles left in covered versus uncovered areas.

3. TASKS

3.1 Identify Alternate Ways to Create Covers for Equipment and Associated Costs

3.1.1 Prefabricated Structures

Structural insulated panels (Figure 3.1). A wall that has foam in the center sandwiched between two oriented standard boards is made at the company and delivered and installed according to the design provided by the customer.

Precast concrete (Figure 3.2). Precast, insulated wall panels are made from concrete by the company, according to the design (door, window opening included) and installed at the site.

Modular structures (Figure 3.3). Modular structures consist of one or more modules that are built in a factory and then transported separately to the building site for installation (Williams, n.d.). These modules are fully outfitted with interior fittings—electrical, plumbing, door, closet, floor, lighting. Unfinished modular structures generally cost $40 to $80 per square foot. Finished modular structures cost $80 to $140 on an average. This excludes permits and taxes.

Panelized structures (Figure 3.4). Panelized structures are built in panels—a wall, for instance. Each panel is transported to the building site where the structure is erected (Williams, n.d.). These panels are not fitted with anything and so finishing takes time, if required. The average cost of installing a concrete wall is $5,850, though it ranges between $2,750 and $9,750. This includes material, labor, and finish but excludes permits and taxes.

Shipping container structures (Figure 3.5). Made of industrial steel, shipping containers (usually 20 feet) can be stacked or joined together as per requirement to erect a low-cost storage facility. Prefabricated shipping container structures cost as low as $15,000 and can cost up to $250,000 for larger facilities or customizations.

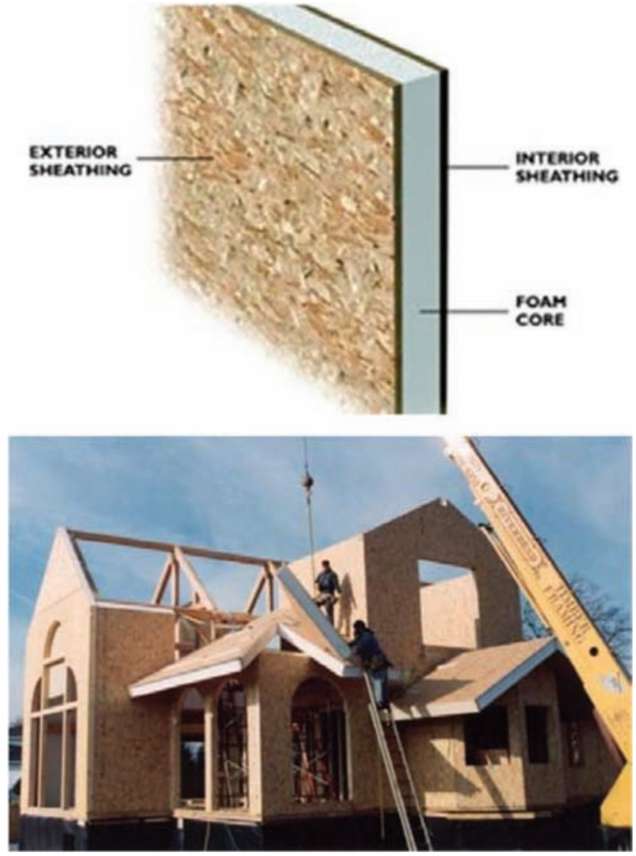

Figure 3.1 Structural insulated panels. (Source: https://www.cascadetimberframes.com/sip-panels/)

Figure 3.2 Precast concrete. (Source: https://www.designingbuildings.co.uk/wiki/Precast_concrete_cladding)

3.1.2 Conventional Method Structures

Adobe brick structures (Figure 3.6). These structures are made of environment friendly adobe bricks of two types: Puddle Adobe bricks (made of earth and water) which are made using molds and left to dry; and Pressed Adobe bricks (made of earth, water and

Figure 3.3 Modular structure. (Source: https://www.nrb-inc.com/)

Figure 3.4 Panelized structure. (Source: http://www.dukepacific.com/projects/commercial-warehouse-panelized-roof)

stabilizing agent like cement) which are made using hydraulic press and machine automation. The puddle adobe brick cost ranges from \$1.40 ($4 \times 4 \times 16$) to \$3.00 ($16 \times 4 \times 16$). The pressed adobe brick cost ranges from \$1.80 ($8 \times 4 \times 14$) to \$2.60 ($10 \times 4 \times 16$). This cost excludes taxes and delivery.

Reinforced concrete (RC) structures (Figure 3.7). These structures are made of reinforced cement concrete (RCC) which is a composite material that has relatively

Figure 3.5 Shipping container structures.

Figure 3.6 Adobe brick structure. (Source: https://www.builddirect.com/blog/earth-building-adobe-brick-and-compressed-earth-blocks/)

Figure 3.7 Reinforced concrete structure. (Source: https://www.designingbuildings.co.uk/wiki/Concrete_frame)

low tensile strength and ductile concrete. This is counteracted by inclusion of reinforcement (generally steel reinforcing bars embedded passively in the concrete) that has high tensile strength or ductility. The average cost of RC structures is between \$60 and \$100.

FlexLock block structures (Figure 3.8). These structures are made using flex blocks which are stacked together on top of a concrete base and locked using tendon anchor joints. The hollow blocks are filled with

Figure 3.8 FlexLock block structure. (Source: https://www.seminarsonly.com/Civil_Engineering/mortarless-system.php)

concrete mixture to provide stability and strength. The average cost of a block ranges from $1.20 to $7.00.

Insulated concrete form (ICF) structure (Figure 3.9). These structures are a system of formwork made of rigid thermal insulation that stays in place as a permanent exterior or interior substrate for walls, floors, and roofs. The forms are interlocking modular units that are dry-stacked and filled with concrete (Archer, n.d.). The average cost of ICF structures range from $60 to $105 per square foot. But, since they're more energy efficient, the cost is cut down by $0.75 per square foot.

Concrete Canvas (Figure 3.10). Concrete Canvas is a flexible, concrete impregnated fabric that hardens on hydration to form a semi-permanent thin, durable, waterproof and fire-resistant concrete layered structure (Concrete Canvas, n.d.). The average cost of Concrete Canvas ranges from $23 to $60 per square meter.

3.1.3 Temporary Structures

Tents (Figure 3.11). Temporary storage structures like heavy duty canopy are tent-like structures made up of UV polyethylene or UV polyester. The cost of these structures range from $400 to $800 per tent. Prices vary according to the size and material of the structure.

Tension fabric structures (Figure 3.12). These structures are forged from galvanized carbon steel frame trusses with engineered high-density polyethylene fabric

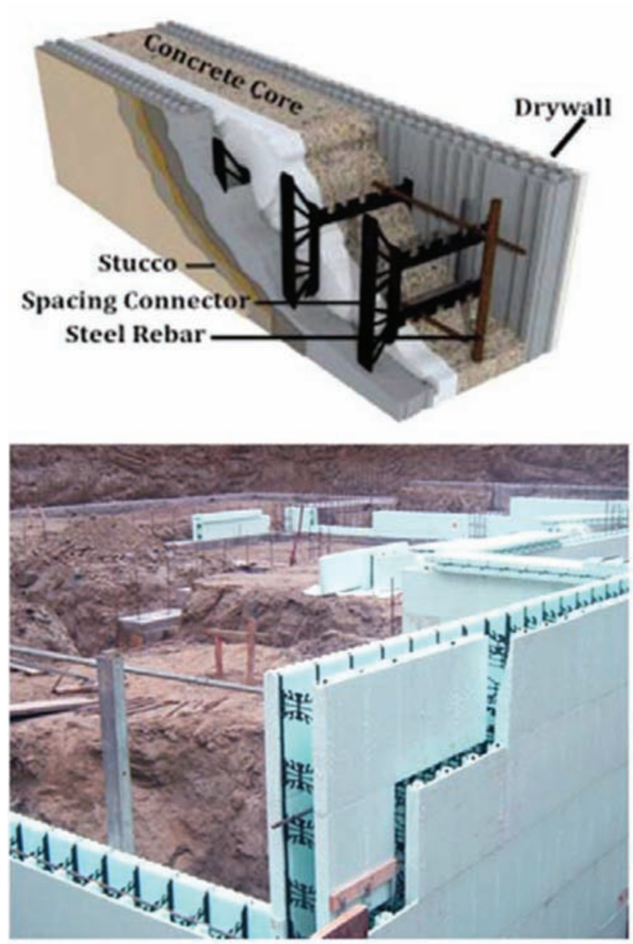

Figure 3.9 Insulated concrete form structure. (Source: https://decentralizedinc.com/the-anatomy-of-an-icf-wall/)

Figure 3.10 Concrete Canvas structure. (Source: http://nunainnovations.com/Concrete_Canvas_Shelter.html)

Figure 3.11 Tent structures. (Source: https://www.losberger.com/us/en_US/datasheet/storage-tents/)

Figure 3.12 Tension fabric structure. (Source: http://www.ufsinc.com/products/aluminum-frame-structures/tension-fabric-structures-tfs-series/)

membranes. The average cost ranges from $6 to $20 per square foot. Price may vary.

For the cost analysis of the structures, we found the various costs associated with building the different types of structures, and then calculated what that would cost for a certain number of snowplow trucks, negating the cost of labor. The only structure that was included in the analysis that requires minimal construction costs was the FlexLock block.

3.2 Create a List of the Current Inventory of Equipment, Age, Maintenance Level, Performance and Condition, and Associated Incurred Costs

Refer to the Excel document titled "List of Equipments_INDOT" (Tab: List), available for download at https://doi.org/10.5703/1288284316917, for the current status and age-based distribution of trucks (list of all INDOT Plow Trucks, Types of Plow Trucks, and Types of Plow Trucks per year). This list was provided by the Indiana Department of Transportation. It only includes the age and cost of snowplow trucks that INDOT owns and operates.

Average life-cycle cost for a dump truck (Figures 3.13 and 3.14). The main three metrics that we considered when analyzing the maintenance plan and whether or not shelters are an efficient way of lowering costs and increasing productivity were the cost of maintenance labor, cost of scheduled maintenance, and average cost of repair. We took those metrics and calculated the total cost of maintenance per vehicle per eight-year life cycle.

3.3 Identify Personnel Using This Equipment and Interview Them to Understand the Issues With the Equipment During Different Seasons

Current level of usage of equipment by district. For this specific deliverable, the main aspect that we needed to focus on was how the Indiana Department of Transportation compared to its neighboring states, those with close to the same weather conditions. While researching the numbers and projections of INDOT, we compiled an Excel document titled "IN District_metrices& comparison" (Tab: District metrices), available for download at https://doi.org/10.5703/1288284316917, that outlines the different metrics that affect usage, such as the number road miles in each county, the population in each district, and the number of snow routes in each district. By comparing the metrics and creating ratios for each district based on need of snowplows (the equipment category that we focused on for this deliverable), we were able to define the level of usage for each district, and were also able to effectively visualize the size of shelter units that would be needed if we were just analyzing the equipment based on snowplows. Because INDOT may have other equipment that will need to be stored, we can use the ratios that we created that separates all of Indiana into their respective districts by usage to analyze the size of shelter units that will be needed based on the total size occupied by all the equipment that INDOT owns, operates and maintains.

Once the ratio for individual districts was created, we could visually conceptualize the total usage of equipment for the Indiana Department of Transportation. The next step was to compile as close to the same metrics for Indiana's neighboring states as possible, such as Michigan, Ohio, and Illinois. When analyzing the usage for the neighboring states, we could see a clear distinction between the amount of equipment and the number of snow routes/road miles.

We ran a benchmark analysis comparing each district in Indiana by calculating the total road miles, population, and snow routes. By finding the specific number for each one of those metrics for each of Indiana's six districts, we formulated a ratio that can be used for consumption requirements and to analyze whether there was a surplus or shortage of equipment in each district.

	Per 8 year life cycle
Owning Cost	
Purchase Price	$ 121,958.00
Resale (30%)	$ 36,587.40
Net Owning Cost	$ 85,370.60
Operating Cost	
Fuel cost (considering Total Miles not exceeding 100,000)	
Considering average 6.2 MPG @ $3/gallon	$ 48,387.10
Other (Diesel Exhaust Field)	$ 2,419.35
Tires	
4-5 sets consumed in 8 year life cycle @ $2400 (6 tires per set)	$ 10,800.00
Driver Wages & Benefits	
$35/hr	$ 560,000.00
Scheduled Maintenance	$ 11,289.60
Repair Cost	$ 23,833.60
Operation Costs	$ 656,729.65
Total Owning and Operating Costs	$ 803,706.70

Maintainance Cost per Truck per 8 YEAR LIFE CYCLE	
$35/hr (2.5 hours of PM per week)	$ 36,400.00
Scheduled Maintainence	$ 11,289.60
Repair Cost	$ 23,833.60
Total maintenance cost per truck per 8 YEAR LIFE CYCLE	$ 71,523.20

Maintainance Cost per Truck per Year	
$35/hr (2.5 hours of PM per week)	$ 4,550.00
Scheduled Maintainence	$ 1,411.20
Repair Cost	$ 2,979.20
Total maintenance cost per truck per YEAR	$ 8,940.40

Figure 3.13 Owning and operating cost of a dump truck.

Refer to the Excel file titled “IN District_metrices& comparison,” available for download at https://doi.org/10.5703/1288284316917, for ratios and calculations of snow routes, road miles, population size, area by district (Tab: District metrices) and annual snowfall by region (Tab: Snowfall).

3.4 Management Strategies for Equipment Need and Usage Across Districts and Impact: Can Districts Be Benchmarked Against Each Other to Understand Best Practice

3.4.1 Management Strategies

Pre-emptive detection and elimination. If you want less maintenance, you must start with appropriate design choices that reduce the amount of maintenance. The methods used to highlight opportunities to reduce maintenance are based on failure mode and effects analysis (FMEA). A simple way to understand the approach is to consider it as a series of answers to “what-if” questions used on each part of the equipment (Sondalini, n.d.).

For example: For State of Ohio—Dump trucks have stainless steel beds and have an onboard material spreader. The material of construction of new dump truck reduces the maintenance cost by a factor of two.

Preventative maintenance. Preventative maintenance (PM) strategy was one of the very first and it is still very effective. It comes in two forms: (1) inspection and observation and (2) intervention and replacement. The first preventative maintenance form is the usual response used for equipment and parts that show signs of

COST REDUCTION IN LABOR COMPENSATION		
Average salary of a driver	$ 35,000.00	per year
	$ 16.83	per hr
Compensation due to overtime work (x1.5)	$ 25.24	per hr
Number of snow days	24	days
Time saved per callout	30	minutes
Total time saved due to Reduced preparation time	12	hours
Money saved in the form of driver compensation due to reduced vehicle preparation time	$ 302.88	per truck per year
Money saved in the form of driver compensation by 1100 trucks due to reduced vehicle preparation time	$333,173.08	per year

COST REDUCTION IN FUEL USAGE		
Number of snow days	24	days
Time saved per callout	30	minutes
Total time saved due to Reduced preparation time	12	hours
Fuel saved by remaining idle due to reduced preparation time	1	gallon/hr
Fuel saved by remaining idle for 12 hours	12	gallons
Price of fuel (Diesel) in Indiana	$ 3.28	per gallon
Money saved by keeping a truck idle	$ 39.36	per vehicle per year
Money saved on fuel by 1100 trucks due to reduced preparation time	$ 43,296.00	per year

Figure 3.14 Cost reduction in labor and fuel.

age and wear. It involves inspecting and noting the condition of equipment and its parts and servicing it on a regular basis, such as changing old lubricant. A preventative maintenance strategy stops failures proactively. One can expect a well-run and always done-on-time PM strategy to stop failures by up to 90% (Sondalini, n.d.).

For example: Truck inspection—Make sure equipment is ready to go, pre-wet system is ready to go and have plenty of liquids, and chains are set properly for the front body plow to allow an even distribution of weight on the plow. There is usually plenty of time to check the truck before the storms. Check the blade to make sure that there is enough left (Elhouar, Dragoo, Khodair, & Lee, 2015).

Shutdown overhaul maintenance. The second PM form is to automatically replace the parts known to experience age and use related degradation on a set frequency shorter than the mean time between failures. Doing this should prevent an unexpected failure and give life expectancy. Such work is typically done as an overhaul where the whole of the equipment is removed from operation during a shutdown and taken to the workshop to be stripped down to its component parts and rebuilt as new (Sondalini, n.d.). This is usually done prior to winter operations in most states (Sondalini, n.d.).

Predictive maintenance and sensor mentoring. It involves monitoring for evidence of changed conditions within the equipment. The amount of change and the rate of change are tracked and used to predict the time of failure (Sondalini, n.d.). The data from the sensors built in the equipment help to predict in advance and thus increasing the service level.

Improved technologies. New inventions and innovative designs usually occur in response to existing problems. It is a wise and valid maintenance strategy to be constantly looking for new technologies that reduce equipment operating problems.

For example: The State of Ohio uses its own developed truck that serves mainly for snow removal but can fulfill other responsibilities throughout the year. During summer, the trailer can be used to haul slag, salt, dirt, and pavement grindings. With this wide range of functionalities, the state procures fewer trucks, thus reducing its overall cost of capital for trucks. Each of the multi-purpose trucks cost around $125,000.

Proactive education and training. This is one of the most important aspects in maintenance a proper trained driver would be able to react in cases of failure. People can only change their behavior and thoughts when they find better ways to behave and think. Once a person knows what is right to do, they will most likely do it. One of the best maintenance strategies is to teach the engineering design requirements of the equipment to the operators and maintainers who will run and care for it. This is a sound strategic step because it means key knowledge is transferred to the users of the machinery (Sondalini, n.d.).

Maintenance planning and scheduling. This is a key strategic maintenance planning move! It is based on the principle that prior planning and preparation will improve the actual performance (Sondalini, n.d.).

Maintenance planning and scheduling can be expected to reduce your maintenance crew manning by at least 25% over the next two years.

Proper maintenance and storage facility. The State of Ohio is actively building new facilities that include equipment storage/maintenance along with salt and cold storage shelter for ice removal. These shelter facilities reduce the overall downtime. As we know it's very important to clean the equipment post its operations and such facilities help in such activities keeping the equipment maintained thus increasing its life period. Especially after snow operation the equipment cleaning would get rid of salt, snow and other chemicals which lead to corrosion. Some states have heated bays in their facilities that automatically drains of snow when it enters the shed.

3.5 Project's Impact of Enclosures on Equipment Maintenance Cost, Performance (e.g., Time to Start, Ability to Be Preloaded)

For this deliverable we mainly focused on the effects of weather and temperature on equipment and how the proper management of these two variables can prolong equipment life and productivity. Knowing that the preferred method of maintenance for INDOT is to repair existing equipment as opposed to replacing it with new equipment, we researched the harshest factors of weather which can shorten the lifespan of equipment used by INDOT. Our findings have shown that the biggest factors on equipment performance (start-up times and productivity) and lifespan are severe temperatures and, as is pertinent for the equipment used during the winter season, the corrosive abilities of chlorides (salt) on metal equipment. Salt is mainly able to corrode the components of vehicles by sticking to its components when driven over.

The lifespan of this winter equipment can be greatly reduced by constant contact with inclement winter weather and contact with salt. The use of a shelter for storage during equipment downtimes would help with the weather's effects on said equipment, including start-times. However, the use of shelters would not be effective in reducing contact with salt, which possesses the harsher effects of the two. Protection against salt and its corrosive abilities may be better achieved by placing protective coatings on all winter equipment.

3.5.1 Shelter Advantages

We have identified some benefits that would help consider the building of a shelter facility for trucks and equipment storage.

- Public safety
- Employee safety
- Cost savings
- Efficient and cost-effective operations
- Protection of equipment
- Impacts to the environment
- Impacts to the abutters

Public safety. The vehicles that are used to respond to the calls to clear the snow, snow storms, and other emergencies are temperature sensitive and if left outdoors, during the cold weather months, they may be subject to starting problems that can delay the response time. This can result in unsafe conditions for the public especially during emergencies. In addition to starting problems, employees may be required to waste valuable time warming up and cleaning off a vehicle prior to responding to a call every time (Alberti, n.d.).

Employee safety. During the normal course of the day or during unscheduled emergencies, an employee will be required to access motorized vehicle and non-motorized equipment attachments to meet the needs of the community. Storing larger vehicles outdoors during inclement weather may require an employee to climb around the exterior of the vehicle to clean off and prepare the vehicle for use. This exposes the employee to unnecessary risks associated with slipping or falling from the vehicle. In addition, employees must also access and connect smaller non-motorized equipment attachments such as plows, mower attachments, towed compressors, etc., which may also pose risks when conducted in foul weather or in areas with inadequate lighting (Alberti, n.d.).

Cost savings. Cost saving is a crucial benefit of building a shelter. Though the benefits might not be immediate, but in the long run shelters help save costs in many ways. Due to the vehicles stored in a minimally heated and safe space, there are less unscheduled maintenance activities. This allows more vehicles to be available for service. Reduced maintenance activities and safekeeping vehicles from harsh conditions that induce harm to the vehicle like corrosion, lead to increased life expectancy of the vehicles. This decelerates vehicle replacement schedules or even vehicular parts replacement schedule. Due to the readiness of the vehicles to go out (no time required to warm and clean the vehicle), the labor productivity is increased leading to higher efficiency and reduced costs. Apart from these primary cost savings, there are additional, attribute costs that can be saved with the shelter facility in place. These are: costs associated with potential injuries to employees and/or the public due to unsafe conditions; costs associated with impact to the environment; costs associated with impacts to abutters; costs associated with vandalism.

Efficient and cost-effective operations. Storing vehicles and equipment in a minimally heated and well-lit storage garage will result in efficient operations by providing an environment that is conducive to both vehicles and the employees. The minimally heated environment will enhance the performance of the vehicles, eliminating potential delays associated with cold engines and frozen equipment. This will also allow employees to quickly access their vehicles thus eliminating the loss of productive labor associated with preparing vehicles and equipment for operation. This reduces response time thereby providing quick and quality service to the public.

Protection of equipment. One of the most important reasons to store the vehicles indoors is to protect a community's investment in equipment. In many cases, communities have millions of dollars invested in the equipment used to service the city/town and its infrastructure. A vehicle and equipment storage garage is the most inexpensive space to construct, but it is responsible for protecting the single largest investment in equipment. Locating vehicles indoors will reduce maintenance costs, protect the vehicles from corrosive conditions, extend the useful life of the vehicles, and protect the vehicles from exposure to potential vandalism.

Impacts to the environment. Storage of vehicles and equipment outdoors increases potential impacts to the environment associated with oil or grease entering the storm-water system. Engine fluids from leaks or hydraulic line breaks have the potential to be washed into the storm-water system if the vehicle is stored outdoors. However, any leaks that occur within a vehicle storage garage will be captured in a closed floor drain system, which will prevent the fluids from reaching the storm-water system, which in turn will assist in protecting the environment (Alberti, n.d.).

Impact to the abutters. Often the storage facilities are located in residential neighborhoods. The outdoor storage of vehicles will most likely increase the noise output and exhaust emissions from the site. The exterior storage of vehicles will require extended periods of idling as vehicles are prepared to respond to the needs of the community. Due to unanticipated emergency calls or storm events at any time of the day or night, these extended idle periods could take place at 2:00 or 3:00 in the morning, increasing the inconveniences already imposed on the neighbors (Alberti, n.d.).

3.6 Payback Period of Equipment (Figures 3.15 and 3.16)

The payback period that was analyzed was based on the metrics that were provided to the team, as well as some assumptions that were made. The metrics that were provided to the team include the following:

- 114 shelters being built
- $250,000 cost to build per shelter
- Land is already owned by INDOT
- Labor cost for building shelters is negligible

The assumptions that the team made include the following:

- 30 minute time difference of plow truck start-up time between indoor versus outdoor storage
- 1 gallon of diesel used per hour of idle time
- 10 hours of work per snow day (overtime cost incurred)
- All 1100 trucks are utilized on a given snow day
- $250,000 is the total cost of building a shelter. No other costs are added (labor, utilities, etc.)

From the calculation of the labor and usage cost incurred due to the 30 minutes of extra idle time for the trucks and the decrease in maintenance cost of plow trucks in indoor facilities, the group concluded that it would take approximately 14 years to payback this project. This includes the cost of building but does not include the cost of maintaining the shelter as that is a metric that was not given to us, and would be too speculative to assume.

The NPV (net present value) analysis concluded that for a 50-year life cycle, the project's NPV is approximately $23.4 million, meaning that the Indiana Department of Transportation would lose $5.6 million on their investment during the 50 years of operation.

The group believes that in ordinance with the NPV and payback period, along with the maintenance metrics that were calculated and the assumptions that were made, this project should commence, and shelters should be built at the earliest possible time. Security of fleet investment, lowered maintenance costs, safety of workers, and increase in rate of productivity are only a few aspects in this report that shed light on the idea of shelters and their effectiveness in this market space.

JaamSim model visualization (production rate for indoor vs. outdoor plow truck fleet; Figure 3.17). The JaamSim simulation model gauges the impact of the shelter on performance of trucks. The benefits are:

- More trucks available in the shelter at all times (~8% increase in on-hand trucks)
- Improved on-road performance for trucks (quicker fulfillment of requests)
- Lower frequency of trucks going to maintenance
- Reduced probability of requiring major service

Payback Analysis		
	Indoor (Shelter)	Outdoor (No Shelter)
Total Cost of Shelters across Indiana	$ 28,500,000.00	0
Total Maintenance Cost per truck per 8-year life cycle	$ 59,602.67	$ 71,523.20
Number of trucks owned by INDOT	1100	1100
Total Maintenance Cost for 1100 trucks per 8-year life cycle	$ 65,562,933.33	$ 78,675,520.00
Total Maintenance Cost for 1100 trucks per year life cycle	$ 8,195,366.67	$ 9,834,440.00
Maintenance Cost Difference (Outdoor-Indoor) per 8-year life cycle	$ 13,112,586.67	
Maintenance Cost Difference (Outdoor-Indoor) per year	$ 1,639,073.33	
Cost due to vehicle preparation time (salary compensation+fuel) per year		$ 376,469.08
Cost incurred per year due to absence of a shelter facility	$ 2,015,542.41	
payback period (years)	14.14	

Figure 3.15 Payback period of building shelter.

NVP ANALYSIS	
Number of years	50
Discount rate (%)	3
Initial investment (US $)	28,500,000.00
Return every year (US $)	2,015,542.41
NPV (US $)	23,359,430.56

Figure 3.16 Net present value analysis of shelter.

The model has the following components:

- Shelter
- Service loop
- Maintenance loop
- Maintenance station
- Light grey trucks—ready for service or just back from maintenance
- Dark grey trucks—ready for maintenance or just back from service

The model studies the maintenance and service cycle of trucks in one facility (50 trucks) to understand the impact of the shelter on performance and efficiency. The shelter contains both—trucks ready to go into service and trucks that are back from service ready to go into maintenance.

The cycle starts with the service loop, where a ready truck is pulled into service as per request, completes the job and comes back to the shelter. Time taken for service is governed by the age of the truck where newer trucks can complete the route quicker.

Once the truck is back from service, it would need some amount of maintenance like a wash down, oil change or major repairs. Trucks are sent to the maintenance facility for these services. Time spent at the maintenance facility depends on the type of service and probability of needing a more extensive service is also dependent on the age of the truck. After getting serviced, trucks come back to the shelter and join the other trucks ready to go to the field.

The covered shelter will change the following aspects:

- Improve on-road performance of trucks which helps them fulfill their service requests more efficiently

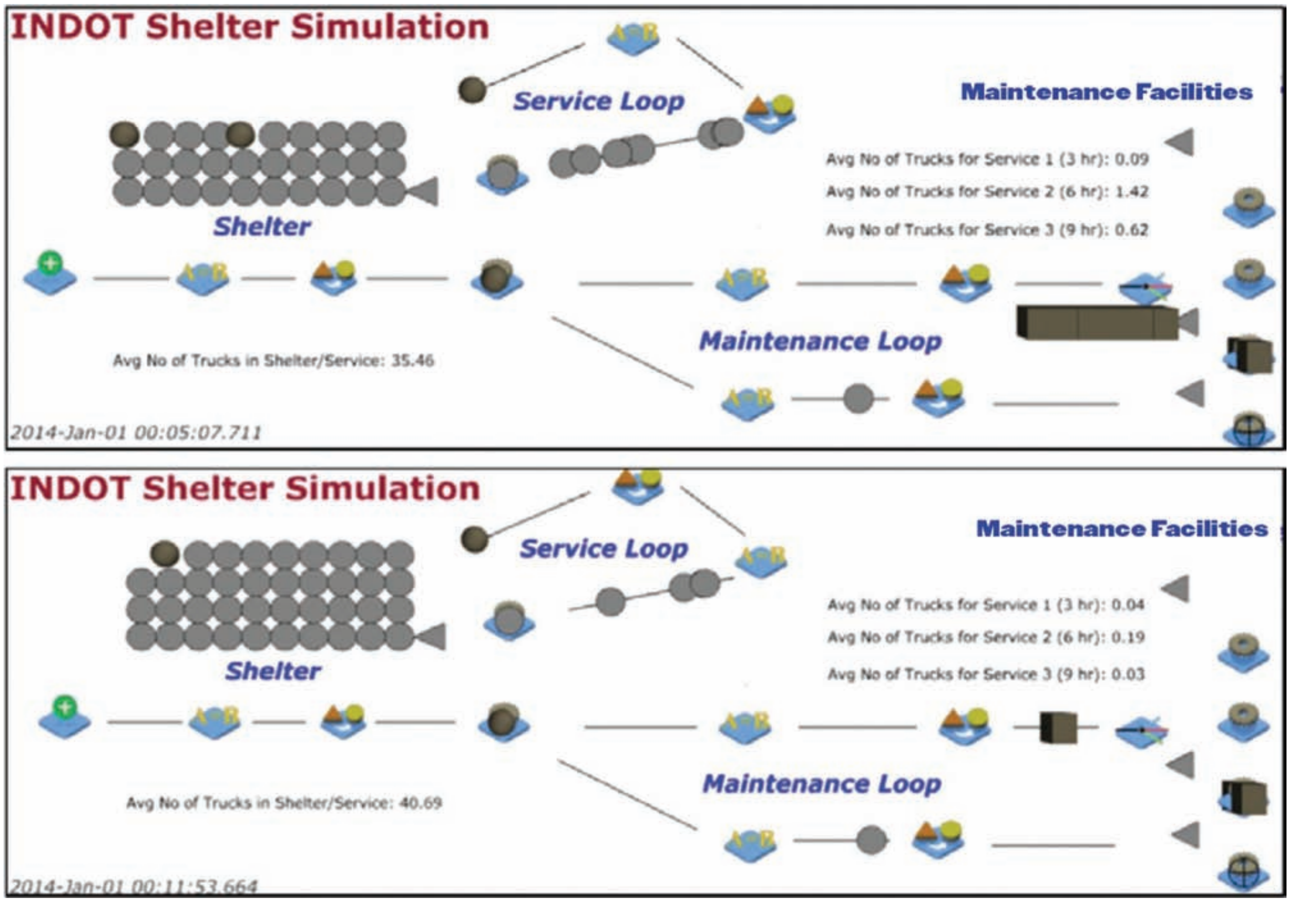

Figure 3.17 Maintenance simulation without shelter vs. with shelter.

- Reduced frequency of visits to maintenance facility. Trucks go into maintenance less often
- Reduced probability of needing a major service, therefore less time spent at the maintenance facility

Therefore, keeping demand and maintenance facility capacity same, we see that:

- We have more trucks on hand at every point of time ready for service
- The queue at maintenance facility was shorter

It is found that the average number of trucks in the shelter, at a time ready for service, is ~41 inside the shelter while compared to ~36 while outdoors.

This translates into two scenarios. First, the state has higher number of vehicles ready to roll out to perform the service at a given time. Thus, the work is distributed amongst more vehicles and can be completed at a faster rate thus, helping the public get back to normal commute quickly. Also, as the work is distributed among more vehicles, each vehicle undergoes less wear and tear compared to when it does more work. Therefore, this can increase the duration after which it requires service/ maintenance and thus increase the life cycle of the vehicle. This benefits the state financially and thereby paying off for the shelter.

Second, the state has larger number of vehicles available to do the work that can be done by a smaller number of vehicles. The state can let a certain number of vehicles standby just for emergency and over time reduce the number of vehicles it owns and thereby cutting the cost of owning and operating these vehicles. This again benefits the state financially and thereby paying off for the shelter.

The JaamSim simulation model can be used to realize these benefits that are posed by building a minimally heated shelter for the equipment and the vehicles.

4. SUMMARY

This project can be used to benchmark certain lot sizes of equipment in order to decide whether implementing an indoor storage facility is efficient or not, given the harsh conditions that the equipment may be facing during certain periods of the year. The information can be used to see the impact of weathering on snowplow trucks, the maintenance costs that can be reduced, and the payback period of building a shelter facility.

REFERENCES

Archer, T. (n.d.). What is ICF? [Seascape Homes web page]. Retrieved from https://www.seascapehomes.net/what-is-icf

Alberti, J. J. (n.d.). *DPW vehicle & equipment storage—Indoors vs. outdoors* (Technical memorandum). Foxborough, MA: Weston & Sampson. Retrieved from https://www.ayer.ma.us/sites/ayerma/files/uploads/dpw_vehicle_storage.pdf

Concrete Canvas. (n.d.). Retrieved from https://www.concretecanvas.com/concretecanvas

Elhouar, S., Dragoo, D., Khodair, Y., & Lee, Y.-S. (2015). *Performance evaluation of snow and ice plows* (Report No. FHWA-ICT-15-007). Rantoul, IL: Illinois Center for Transportation. Retrieved from https://www.ideals.illinois.edu/bitstream/handle/2142/88433/FHWA-ICT-15-007.pdf

Sondalini, M. (n.d.). *Correct equipment maintenance management strategy selection makes all the difference* [Lifetime Reliability Solutions website]. Retrieved from https://www.lifetime-reliability.com/cms/free-articles/maintenance-management/maintenance-strategy-101/

Williams, L. (n.d.). Building a prefab home—Types, cost, pros & cons. *Money Crashers*. Retrieved from https://www.moneycrashers.com/building-prefab-home-types-cost/

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

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