Snowmobile Braking Data, Sign Recognition Analysis And Validation

Final Report

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1.0 INTRODUCTION

The U.S. Forest Service San Dimas Technology and Development Center (SDTDC) was interested in conducting a study to develop signage guidelines for motorized trails with the end result being a table showing advance placement distances for warning signs based on speed and other relevant factors. The purpose of the study was to determine appropriate sign size, height, reflective sign material and how far away the sign should be placed from a hazard or event to warn and instruct the rider to take an appropriate action under various climatic and environmental conditions. This was done by determining stopping distances for OHVs under various physical conditions of the trail including different soils and conditions along with recognition and reaction time.

One of the major purposes of this trail signage effort was to collect braking distance information for a long and short track snowmobile without any traction aids on packed snowmobile trails and ice. The literature search revealed that some braking data existed for snowmobiles. Hermance[1] published some braking data for snowmobiles with and without traction studs. Some of his work led to IASA sign placement guidelines[2], but most published braking distance testing has been done with cars and light trucks or heavy trucks. The goal of the studies in the literature was to develop a consistent methodology for conducting the braking tests for cars and light trucks, for the purpose of comparing braking distances of different types of vehicles on a consistent surface while minimizing other variables.

The braking tests for the sign study have an entirely different reason and goal than the braking tests described in the literature researched for this project. The end goal is to determine the range of braking distances for various trail surfaces for the variety of snowmobiles that are available. This not only involves a range of long and short track snowmobiles on the market, but also involves the variety of riding experience from novice to experienced, and a variety of trail surfaces including packed/groomed snowmobile trails and very slippery ice. Variables such as the experience level of the rider, the rate of brake application and the trail surface condition cannot be minimized, as was done in the literature for the on-road vehicles. The snowmobile braking data was collected to be used with the sign recognition and reaction distance data to develop guidelines for the placement of warning signs along U.S. Forest Service trails.

Also important, as mentioned above, are the sign recognition and reaction distance. This report discusses a sign recognition test that was conducted to determine how recognizable the various types and sizes of signs are by measuring time, distance and speed.

The braking distance and sign recognition data is used to develop a table for sign size and placement on the trail, based on average trail speed. Data from this table was then validated in a final validation test.

2.0 SNOWMOBILE BRAKING

Snowmobile braking is discussed first in the following sections.

2.1 Snowmobile Braking Testing

2.1.1 Test Vehicles

The selection of the test vehicles for the braking distance study was based on time available, cost and expected reasonable differences in snowmobiles and rider habits. For this study it was determined that two types of snowmobiles would be used for the braking tests. One of the most common types of snowmobiles on the market is the long track deep snow / workhorse generally used in the mountains and for carrying heavy loads or pulling a sled. The second most common type was the sport type of snowmobile with a short track that generally accelerates much faster and is lighter than the long track snowmobile. The following vehicles were used for the braking study:

1) Yamaha Vector Short Track
2) Yamaha Vector Long Track with 1 ½ inch paddle track.

2.1.2 Test Terrains

The types of trails available throughout the United States vary considerably. It would be impossible to test for all types of trail terrains and conditions unless an extraordinary amount of time and funding was available. Therefore, the number of different types of terrains was limited to the following as representative of most trails and range of braking coefficients:

1) Ice such as that found on a frozen lake or icy trail with no snow. Ice has a very low coefficient of friction, usually less than 0.1.
2) Packed snow, typical of mid-western U.S. snowmobile trails, with loose snow on the surface. A snowmobile trail will have a hard packed base with one to three inches of loose snow on top, depending on traffic and weather conditions.

All trails are not flat so therefore it was decided to test for situations where the riders may have more difficulty in stopping. Three downhill grade ranges were tested for braking distances. The grade ranges were the following:

1) 0 to 8% grade – generally a flat surface.
2) 8 to 15% grade – a mid-level downhill grade.
3) 15 to 25% grade – a steep downhill grade.

2.1.3 Test Riders

Both novice and experienced riders were used for all braking tests in an effort to cover the range of potential riders. Novice riders are those that have rarely driven a snowmobile, if at all. The novice can generally ride and handle the snowmobile to some degree but may not be comfortable in certain situations. An experienced rider is one that has driven several different snowmobile's in a variety of situations and at a range of speeds such that he or she feels comfortable at near the top speed possible for a given trail condition. The experienced rider also knows how to control the vehicle in these situations, based on experience, and therefore brakes using that experience. A prudent driver may be either novice or experienced but drives on the public trails at their personal limits of handling capability, similar to a defensive driver on the road.

Test speeds were selected to be 35, 45 and between 55 and 65 mph, if attainable, and the drivers attempted six or more braking stops for each terrain, vehicle and speed.

2.1.4 Data Acquisition

Each vehicle was instrumented to monitor: longitudinal and lateral acceleration, using Crossbow TG series Triad accelerometers; throttle position, using the throttle position sensor on the vehicle; brake activation, by measuring brake pressure; and speed, using a Javad Precision GPS speed sensor. Special brake lines were ordered for each vehicle to accommodate the pressure transducers. These were installed and the brakes bled prior to testing and then replaced with the originals after testing was completed. Each vehicle had a box (cooler) that contained the NI CompactDAQ data acquisition hardware and laptop for data acquisition. The data acquisition program was written in LABVIEW and the data was later processed using MATLAB. Final data analysis and curve fitting was done using Microsoft EXCEL for this report.

2.2 Braking Data Analysis

The following sections contain the analysis of the braking data. The long track was compared to the short track. The novice rider was compared to the experienced rider. The data points were plotted and then curve fit for comparison to show general average trends using a parabolic curve fit. The spread of the data points show the range of braking distances that can be expected between vehicles and rider skill levels.

The data was analyzed using the curve fit equations to determine the average coefficient of friction. This was done using the following equation found in the literature [3]:

$$D = \frac{\left(V_o^2\right)}{2g(\mu \pm grade)}$$

Where:
D = Braking Distance (ft)
V_o= Original velocity at which brakes were applied (ft/sec)
g = acceleration due to gravity (32.2 ft/sec^2)
μ = Coefficient of friction
Grade = grade of surface in percent/100 (subtract grade for downhill slopes)

2.2.1 Snowmobile Braking on Flat Ice

Braking data was collected for both the long track and short track snowmobiles with each being driven by both the novice and experienced rider. The braking data on flat ice is shown in Figure 1. The data was curve fit for each vehicle and level of rider experience. Figure 1 shows a separate curve for each of the four combinations; experienced rider on the Long Track, novice rider on Long Track, experienced rider on Short Track, and novice rider on the Short Track. Note that the novice rider had shorter or equal stopping distances as compared to the experienced rider for each vehicle. The data looks fairly consistent which indicates that the ice conditions were similar and the riders applied the brakes in a consistent manner.

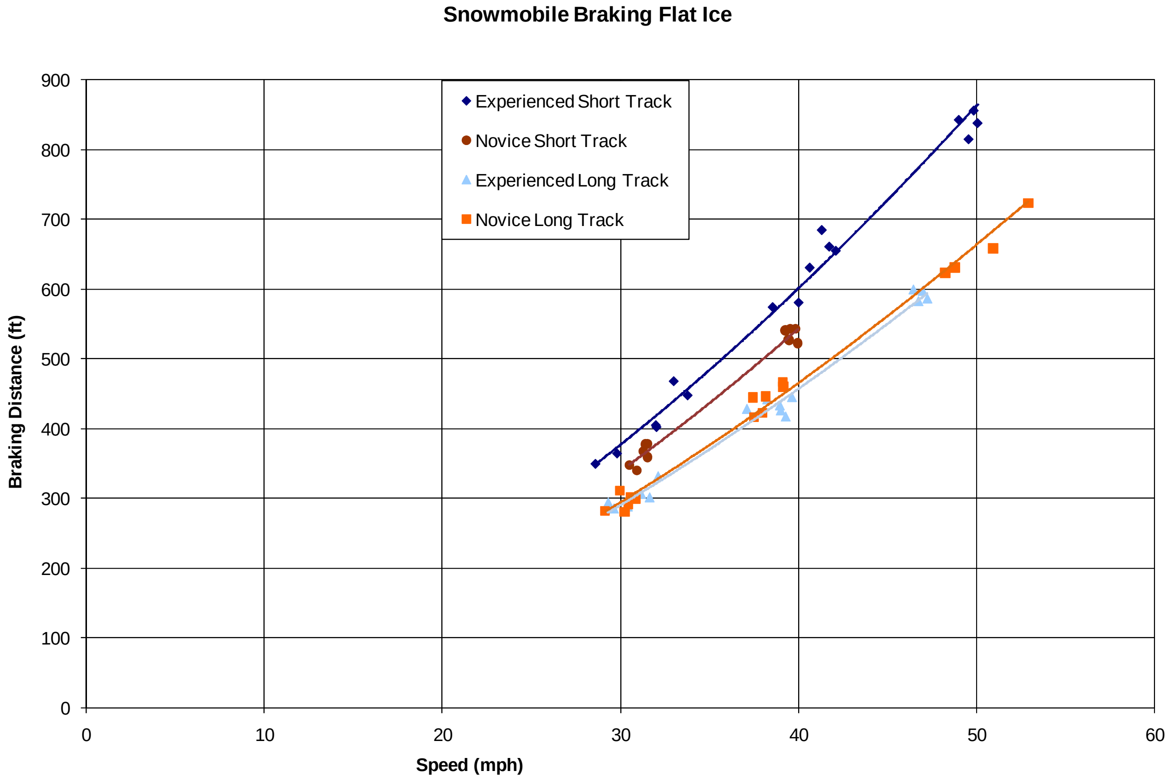

Figure 1 Plot showing braking data for both rider types and vehicles on flat ice.

Figure 2 is a plot of the Long Track data for both riders versus the Short Track data for both riders, with no separation of driver experience. Note that the Long Track curve indicates shorter braking distances than the Short Track.

Figure 3 is a plot of the entire short and long track data combined for ice, on flat terrain, with one parabolic curve fit through all of the data. This would be a representation of average braking data for snowmobiles, in general, on flat ice.

Note that, in general, braking distances on flat, polished ice can range from over 285 feet at 30 mph to over 800 feet for speeds of 50 mph. Braking on ice grades was not conducted.

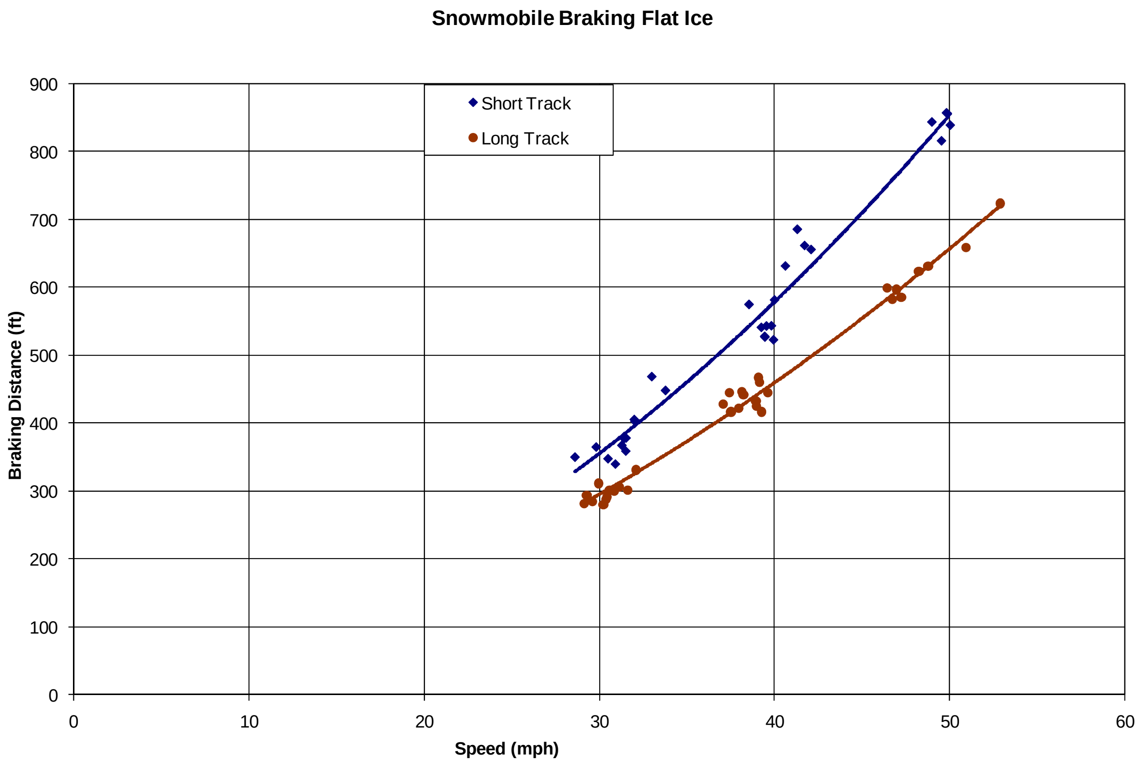

Figure 2 Plot comparing braking distances of the short and long track on ice.

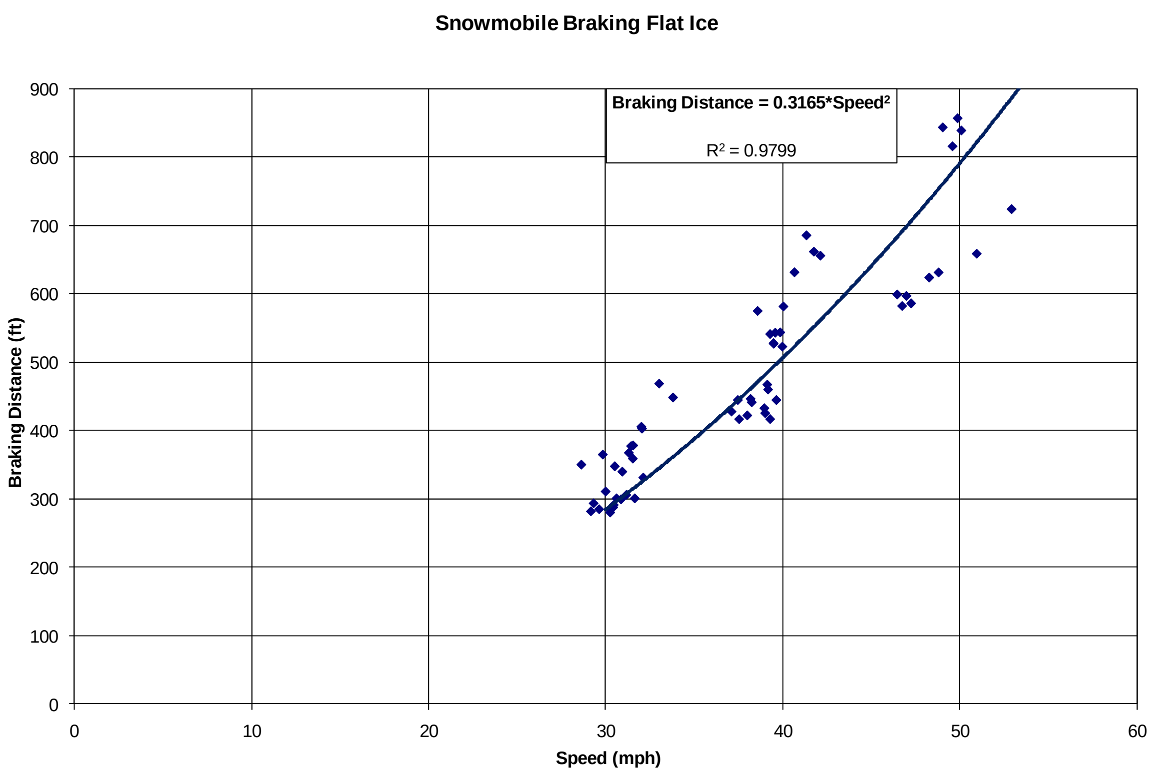

Figure 3 Plot of all short and long track braking data on flat ice with one curve fit.

2.2.2 Snowmobile Braking on Flat Packed Snow

Braking tests were also conducted on a flat packed snow snowmobile trail. Figure 4 is a photograph taken during the packed snow braking test.

Braking data was collected for the both the long track and short track snowmobiles with each snowmobile being ridden by a novice and experienced rider. The braking data on flat packed snow is shown in Figure 5. The data was curve fit for each vehicle and level of rider experience. Figure 5 shows a separate curve for each of the four combinations; experienced rider on the Long Track, novice rider on Long Track, experienced rider on Short Track and novice rider on the Short Track. The braking data for each rider and snowmobile is very consistent.

Figure 6 is a plot of the Long Track and the Short Track data for both rider types on flat packed snow. Note that the Long Track curve indicates slightly shorter braking distances than the Short Track.

Figure 4 Photograph of the snowmobile trail used for flat packed snow braking tests.

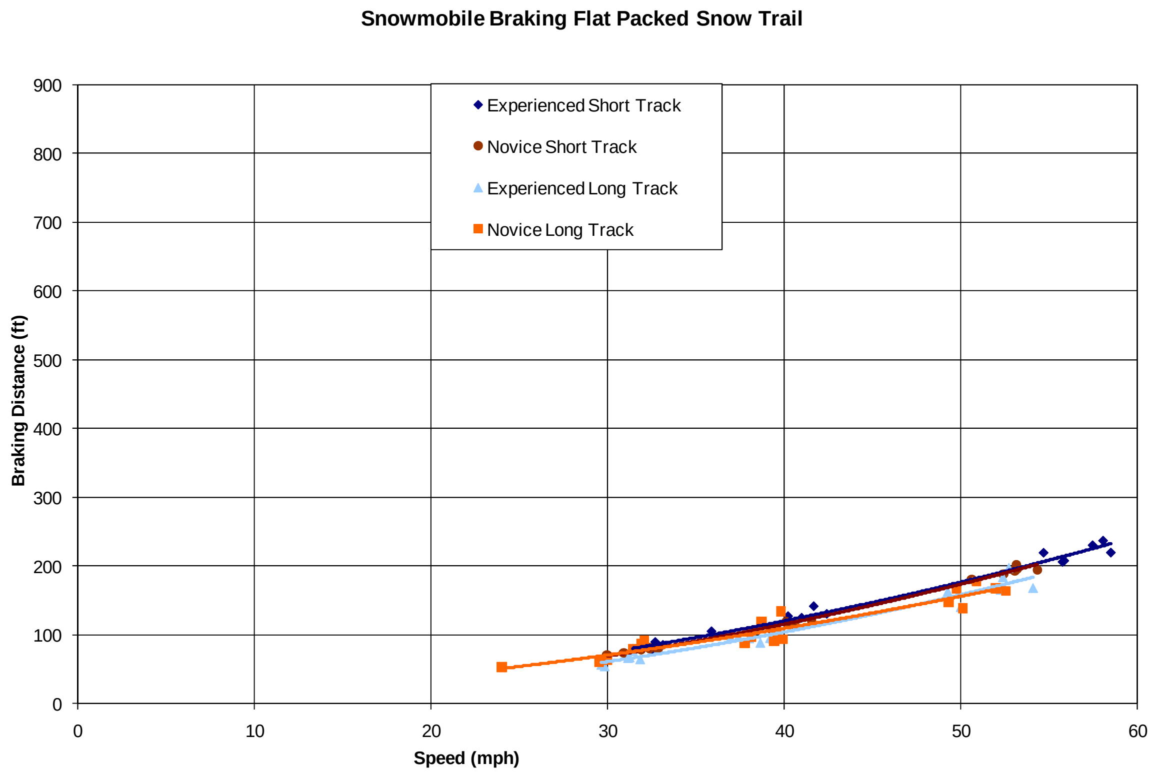

Figure 5 Plot showing braking data for both rider types and vehicles on flat packed snow.

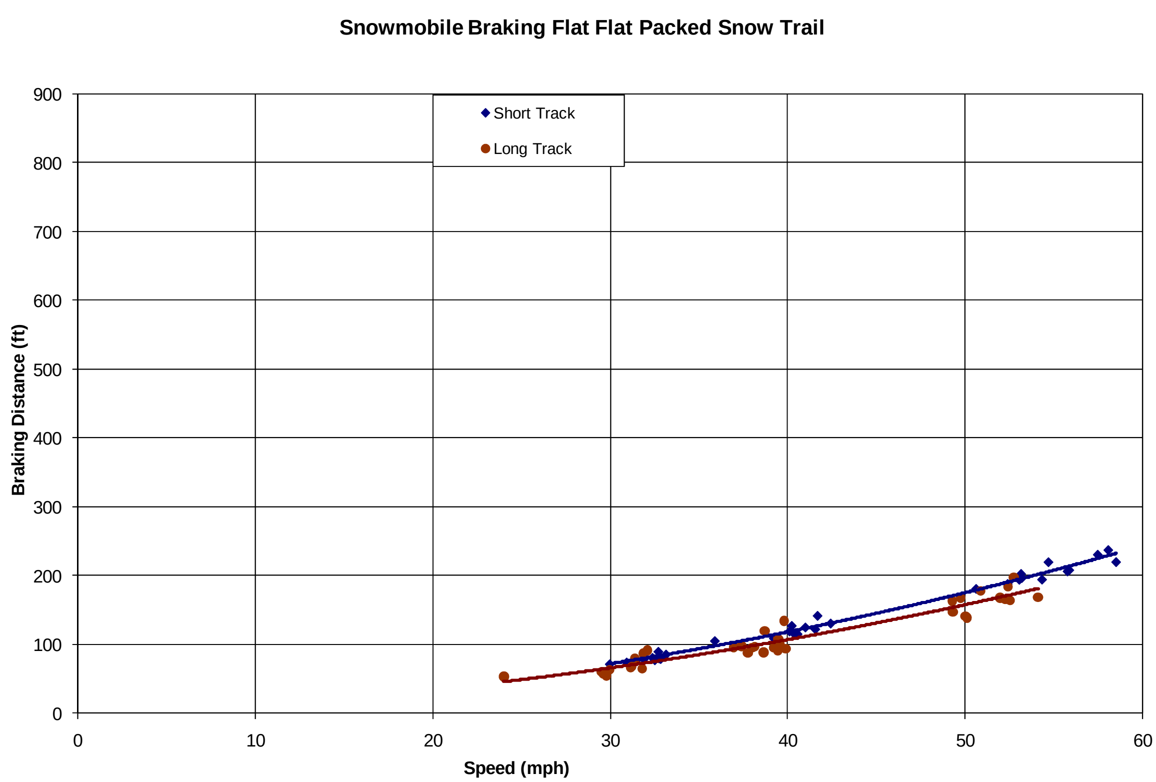

Figure 6 Plot comparing braking distances of the short and long track on packed snow.

Figure 7 is a plot of a parabolic curve fit for all braking data for the short and long track snowmobiles on a flat packed snow snowmobile trail.

Note that, in general, braking distances on a flat packed snowmobile trail are much shorter than on ice ranging from about 60 feet at 30 mph to around 205 feet at 55 mph.

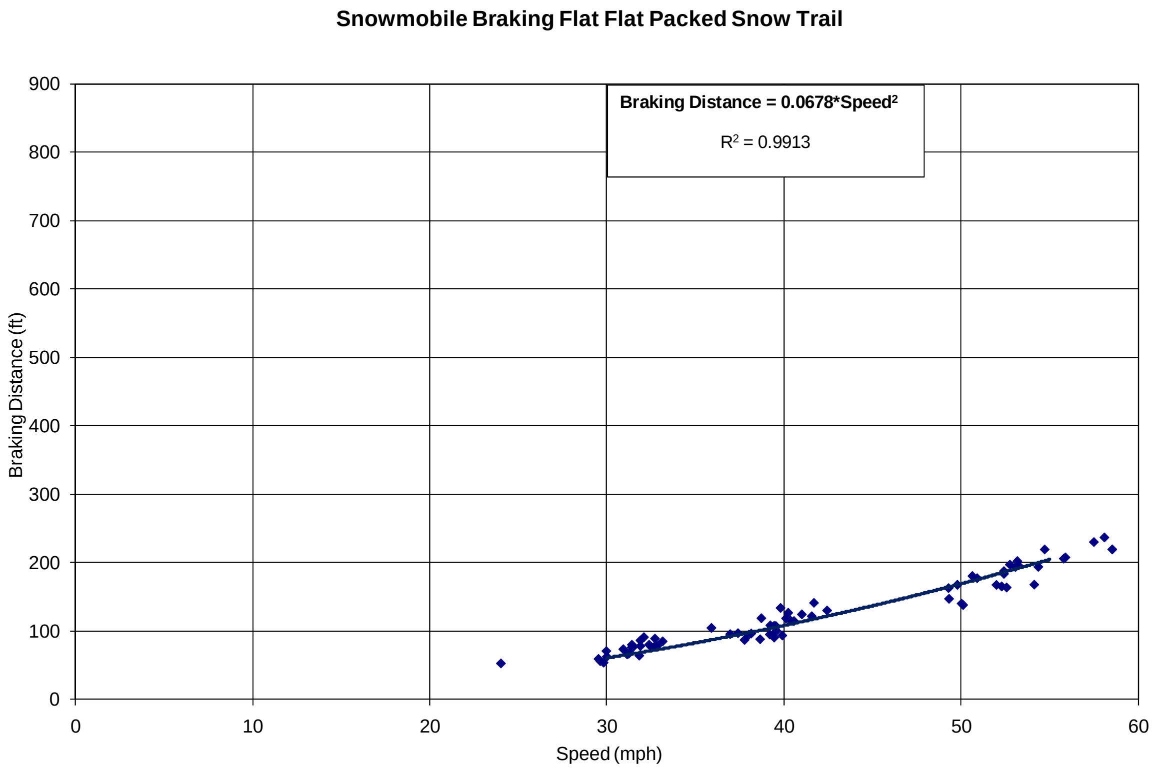

Figure 7 Plot of all short and long track braking data on flat packed snow with one curve fit.

2.2.3 Snowmobile Braking on 9% Packed Snow Grade

Braking on a downhill packed snow grade may require a longer stopping distance due to having to overcome the gravitational forces but it also depends on the coefficient of friction. Figure 8 is a photograph from the packed snow grade testing. Figures 9 and 10 are the plots for the short and long tracks braking on a 9% grade on packed snow. Figure 9 separates out both vehicles and both riders while Figure 10 separates only the short track from the long track.

Figure 9 shows that the braking distances were greater, due to stopping on the grade. Note that the novice and experienced riders had slightly different braking distances as the novice had shorter stopping distances than the experienced rider. It was noted that the experienced rider tended to keep the snowmobile under control while the novice allowed the snowmobile to turn to the side on several of the braking runs.

Figure 10 shows that the long track had consistently shorter stopping distances than the short track on the 9% grade at all speeds.

Figure 11 shows the data for all short and long track snowmobile braking data on the 9% packed snow grade. As expected, the braking distance is greater than on flat packed snow as the distance ranged from about 85 feet at 30 mph to about 285 feet at 55 mph.

Figure 8 Photograph of braking on a packed snow grade.

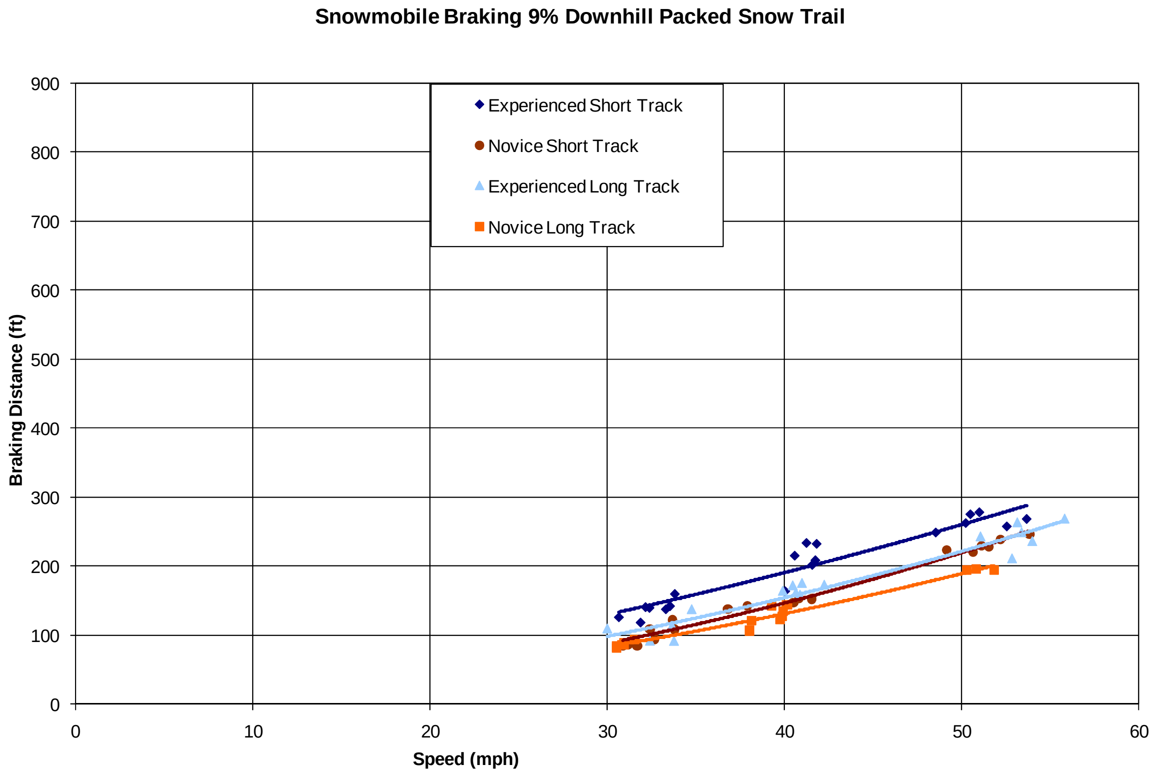

Figure 9 Plot showing the short and long track braking data for both rider types on 9% grade.

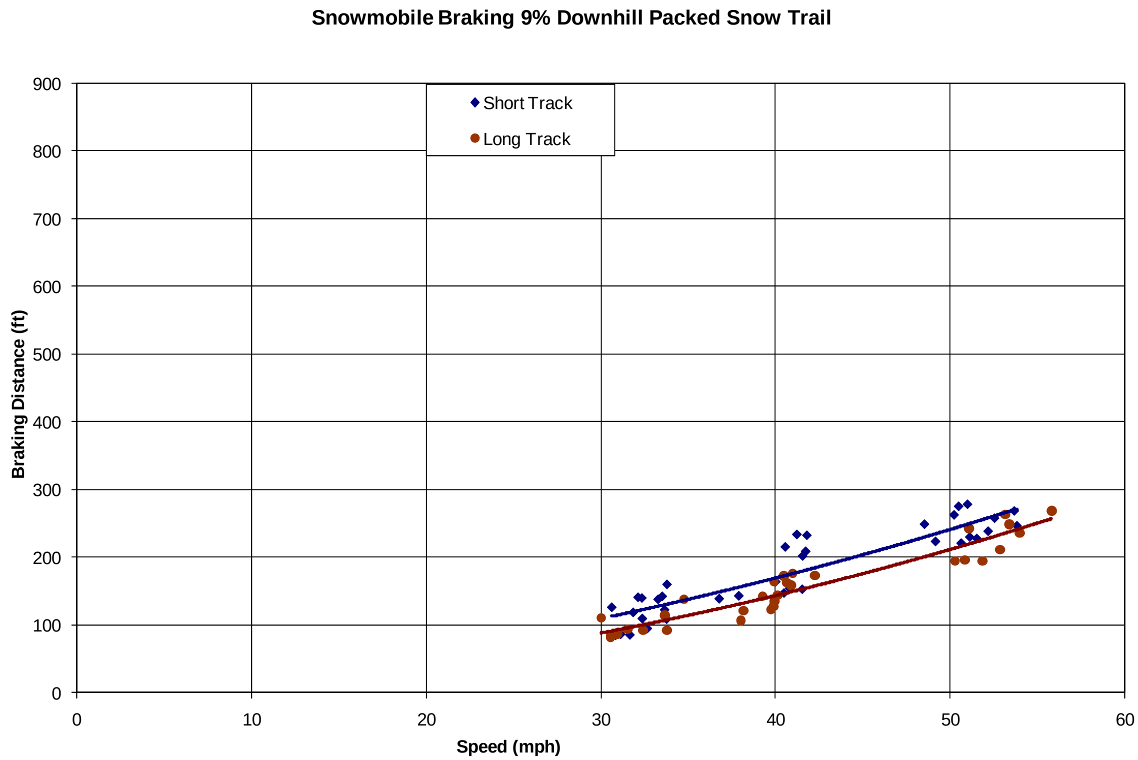

Figure 10 Plot of short and long track braking data independent of rider type on 9% grade.

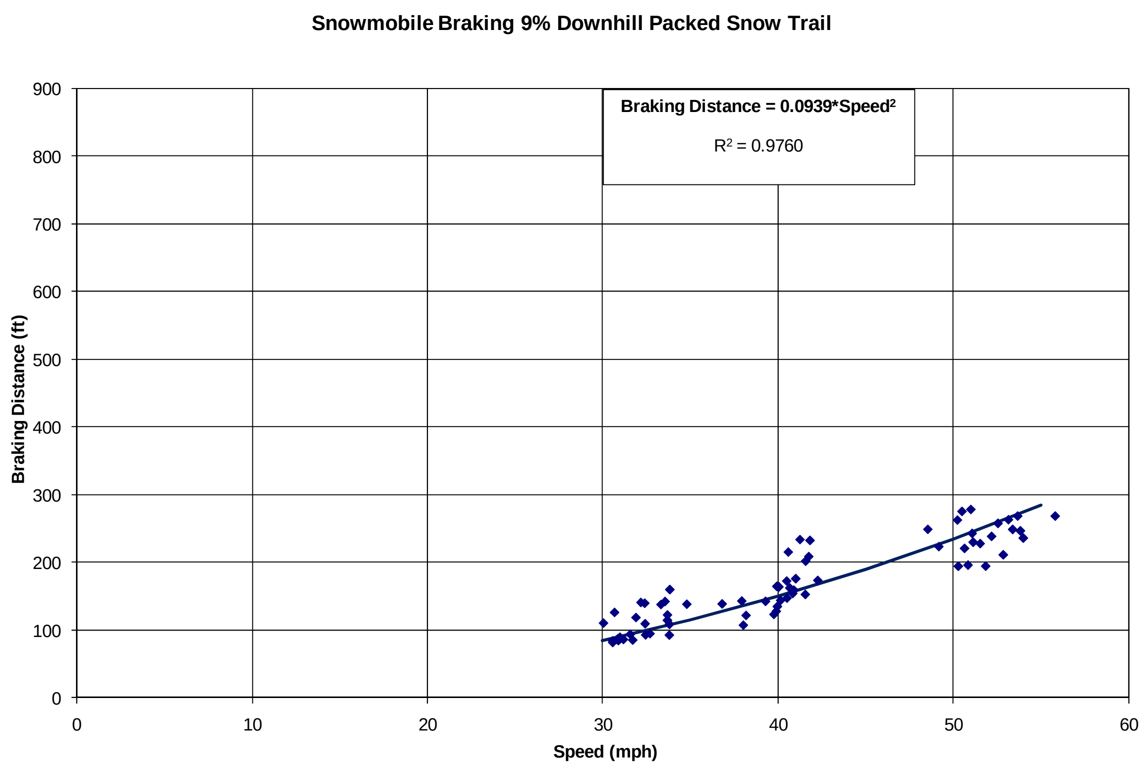

Figure 11 Plot of the general curve fit for all short and long track data on 9% grade.

2.2.4 Snowmobile Braking on 15% Packed Snow Grade

The steepest grade test was conducted on a 15% grade. The short track was less stable than the long track and the novice rider did not feel comfortable testing the short track at the highest speed.

Figure 12 is a plot showing the short and long track braking data for both rider types. Note that the data is more scattered on the steeper grade as compared to the less steep grade and flat packed snow. The novice rider had the shortest stopping distance on both snowmobiles. Again it was noted that the novice rider would allow the snowmobile to spin sideways and just lock the brakes where as the experienced driver stopped with control and in a straight line.

Figure 13 is a plot showing the short and long track braking distances and curves independent of rider type. The curves show a greater difference between the long track and the short track braking for the 15% grade as compared to the flat packed snow trail and the 9% packed snow grade.

Figure 14 is a plot of all short and long track data and one curve fit for both snowmobiles and riders on the 15% packed snow grade. Note also that stopping distances increased to about 100 feet at 30 mph and to about 340 feet at 55 mph on the 15% grade.

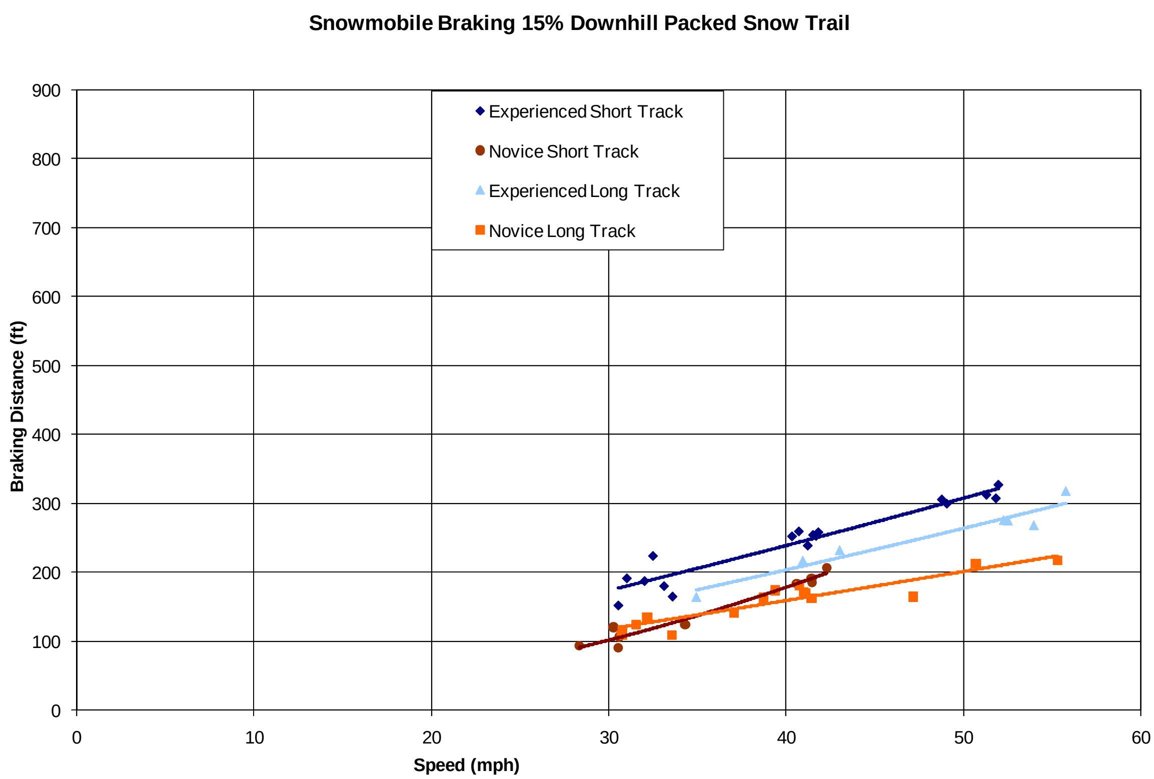

Figure 12 Plot of the short and long track braking data for both rider types on 15% grade.

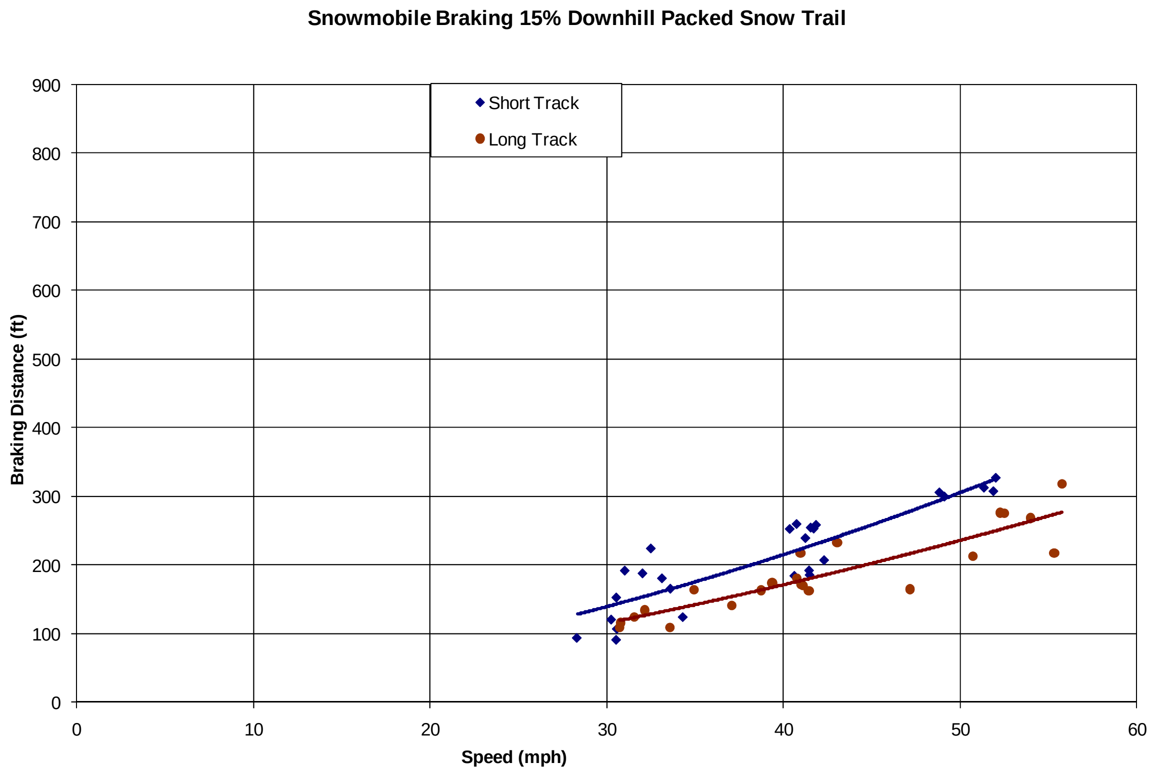

Figure 13 Plot of short and long track braking data independent of rider type on 15% grade.

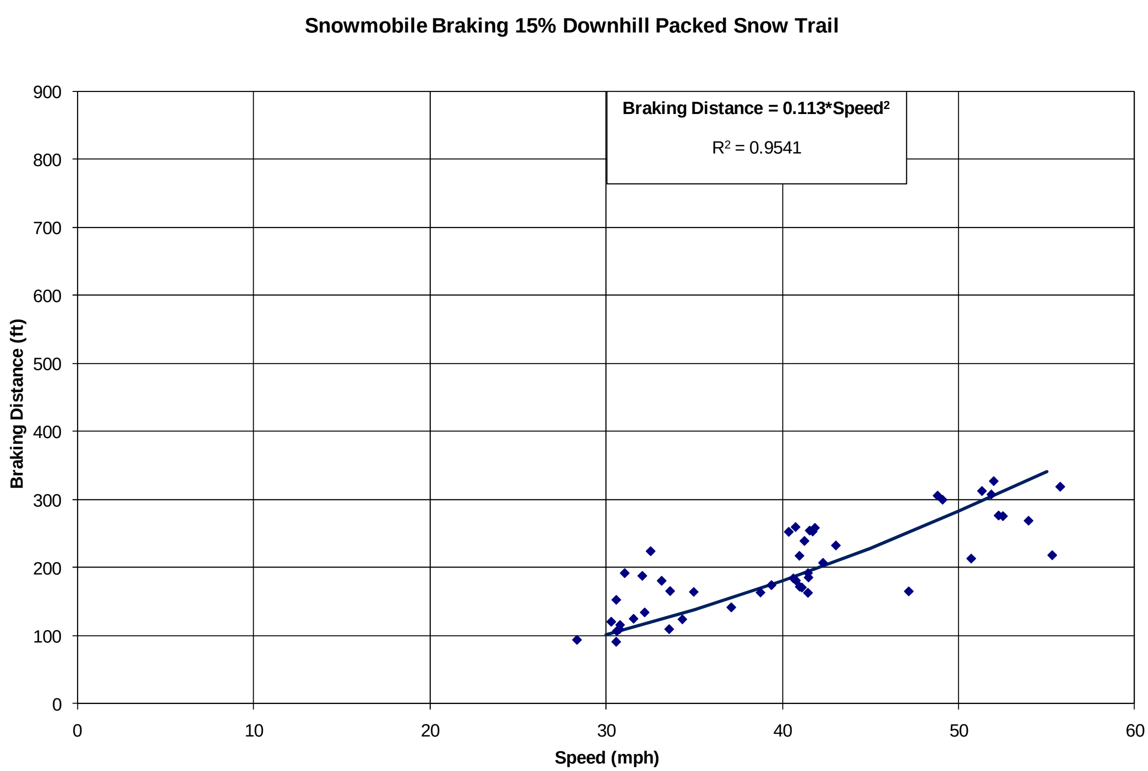

Figure 14 Plot of general curve fit for short and long track braking data on 15% grade.

2.3 Snowmobile Braking Summary

There are several different curves shown in the analysis. The data shows that on flat polished ice the braking distances are considerably long. On flat packed snow the braking distances are reasonable but as the downhill grade on packed snow increases, the braking distance increases. As noted above, the long track has shorter stopping distances on most surfaces. Figure 15 is a plot of all of the surface curves generated by the curve fit equations which were developed from all the snowmobile braking data acquired in this study.

Table 1 shows the curve fit average braking distances for speeds ranging from 30 to 55 mph for the four different surfaces tested. The user needs to be cautioned that the coefficient of friction of the surface may vary due to a number of factors and can make a significant difference in the braking distance for a particular type of surface.

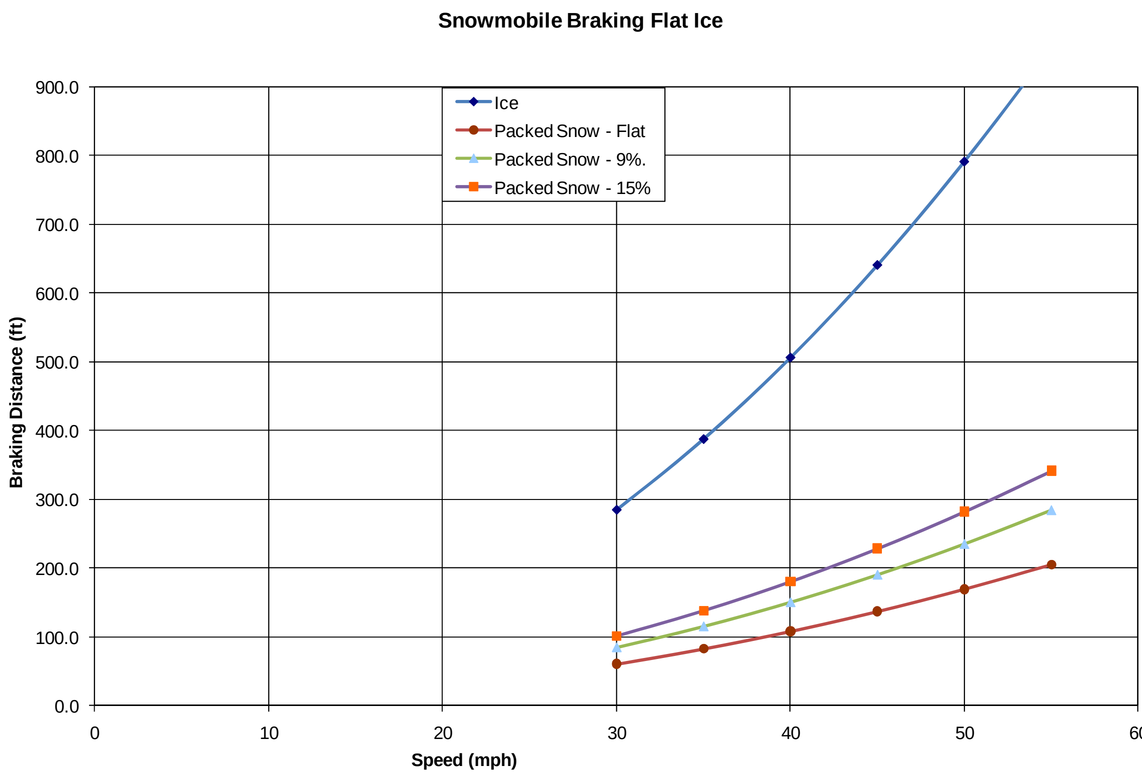

Figure 15 Plot of all snowmobile curve fits for all surfaces and grades tested.

Table 1 Snowmobile Braking Distances From Curve Fit Equations

Speed in mph	Snowmobile Braking Distances for Ice and Packed Snow			
	Ice	Packed Snow	Packed Snow	Packed Snow
	0-8%	0-8%	8-15%	15-25%
30	284.9	61.0	84.5	101.7
35	387.7	83.1	115.0	138.4
40	506.4	108.5	150.2	180.8
45	640.9	137.3	190.1	228.8
50	791.3	169.5	234.8	282.5
55	957.4	205.1	284.0	341.8

3.0 SNOWMOBILE SIGN RECOGNITION

Another part of this study is to determine the sign recognition/reaction distance for different types and sizes of signs for motorized trails. Before reacting to a sign a driver needs to be able to comprehend what the sign is telling them to do. Signs come in a variety of sizes. Some of the most common sign sizes are 12 by 12 inches, 18 by 18 inches and 24 by 24 inches. The trails need to be signed so riders can safely recognize and react to the message on the sign. Signs need to be visible in all types of conditions such as day time, night time, in rain, fog, or when it is snowing and there is not much contrast, etc.

Signs were purchased in the three sizes noted above. They included STOP, Stop Ahead words, Stop Ahead symbol, Chevrons, Arrow, One Way with Arrow and Speed Limit. Some signs were purchased without any specific reflective coating, some with standard reflective coating and a couple in the super reflective coating.

Prior to the data collection various sign layouts were attempted but the final layout that was used for the study was slightly different than earlier layouts. The following photographs are taken from one of the earlier layouts that were not used for the data collection. These photographs are used for typical examples of how a snowmobile rider might see and comprehend signs. For these photographs the camera was adjusted to try to mimic what the rider's eye could see at each position. Figure 16 is a typical photo showing where a rider might see that there is a sign (at approximately 400 feet from the sign) and Figure 17 is a photo showing where a rider might be able to read or comprehend what the sign means (approximately 175 feet from the sign). This is a stop ahead worded sign. The yellow background of the sign is typically used for warnings.

Figure 18 is a photograph of a 12 x 18-inch speed limit sign at approximately 475 feet. Speed limit signs have a white background with black letters. White signs may be more difficult to read in low contrast situations, such as on a white snowmobile trail with gray/white clouds, snow falling and black trees in the background. Figure 19 is a photograph of the 12 x 18-inch speed limit sign at approximately 160 feet from the sign, where most riders can see or comprehend that it is a speed limit sign.

Figure 16 Photograph of worded stop ahead sign where rider can see that there is a sign.

Figure 17 Photograph of worded stop ahead sign where rider can comprehend the sign.

Figure 18 Photograph showing where rider might know there is a sign there.

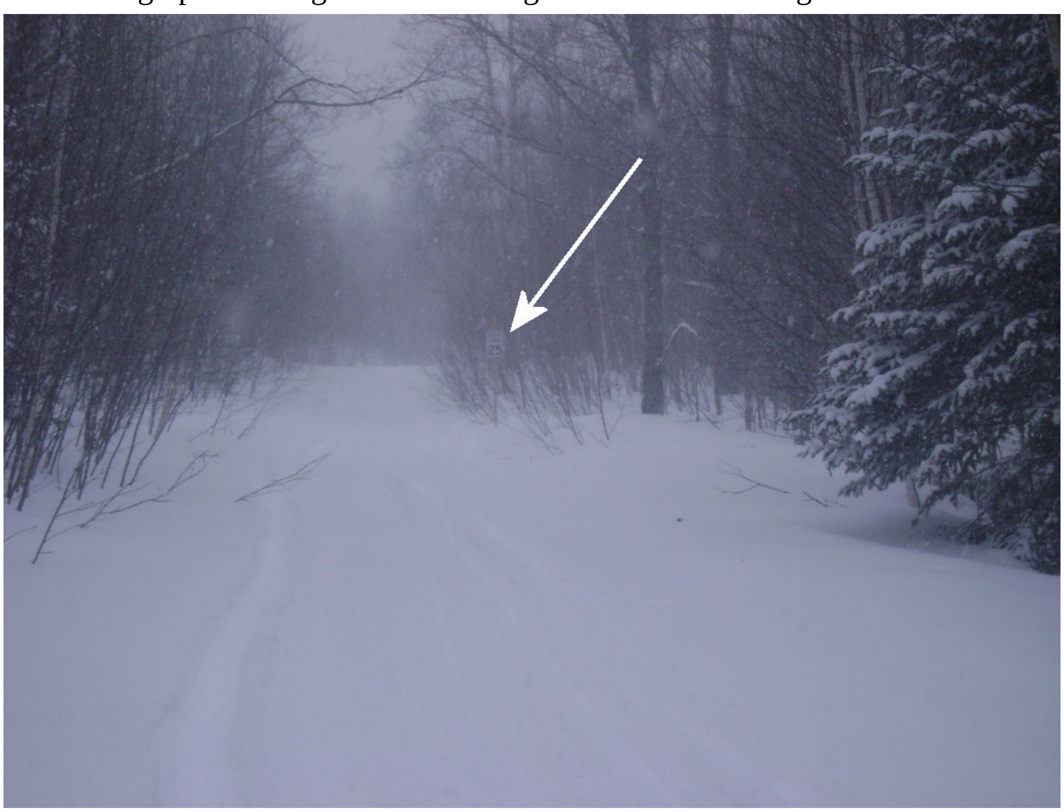

Figure 19 Photograph showing where a rider might comprehend the speed limit sign.

Some signs are more easily recognizable. For example, on white snowmobile trails red signs show up very well and appear to be more recognizable at longer distances. For example, Figure 20 is a photograph of a 12-inch stop sign from a distance of 400 feet and most riders can recognize this as a stop sign.

Figure 20 Photograph showing stop sign on the trail at a distance of 400 feet.

Symbol type signs, especially red stop ahead signs, are recognizable from longer distances as shown in Figure 21, which is an 18-inch symbol stop ahead sign at a distance of approximately 425 feet.

3.1 Snowmobile Sign Recognition Course

For the snowmobile recognition study a trail was laid out to portray a standard U.S. Forest Service type of snowmobile trail. A U.S. Forest Service type trail tends to be more narrow than a lot of the common snowmobile trails in the Midwest. The trail was about a half mile long and contained a number of undulations and some elevation changes but the elevation changes were not large. The trail layout is shown in Figure 22. Note that the photo was taken from Google Earth so it did not have snow on it but there was snow during the test.

The first sign was a reflective stop-ahead symbol. The second sign was a non-reflective intersection symbol. The third sign was a non-reflective stop ahead symbol. The fourth was a non-reflective stop sign. The fifth was a non-reflective one way sign with an arrow. The sixth sign was a reflective speed limit 25 sign. The seventh sign was a super reflective chevron and the eighth sign was a non-reflective lettered stop ahead sign.

Figure 21 Photograph of a symbol stop ahead sign from a distance of 425 feet.

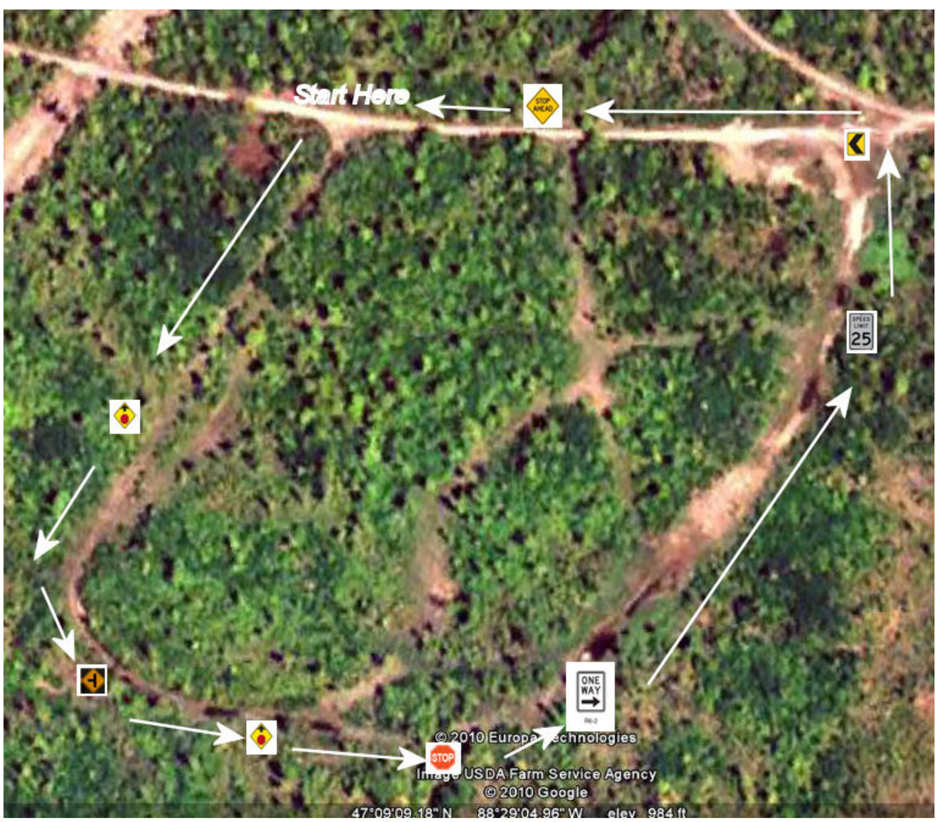

Figure 22 Snowmobile sign recognition sign placement trail layout.

3.2 Snowmobile Data Acquisition

Both the short and long track Yamaha snowmobiles were set up with the same data acquisition for the sign recognition testing as they were for the braking testing. A switch was added to the left handle bar. The riders were instructed to press the switch when they first saw that there was a sign and press it a second time when they could read or understand what the sign was saying. The speed limit sign was the only anomaly as the riders were told to push the button first when they could see the sign, press it a second time when they could read the larger speed limit numbers and press it a third time when they could read the writing on the sign.

3.3 Snowmobile Sign Recognition Testing

The signs were placed following the basic International Association of Snowmobile Administrators (IASA) guidelines of distance from the trail (three to five feet) and height above the ground surface (two to seven feet) for snowmobile trails as this had appeared to be a good methodology to use [2].

Each rider drove two laps of the loop with the 12-inch signs, then the signs were switched to 18-inch signs and two more laps were driven. Finally, the signs were switched to 24-inch signs and each rider drove two laps again. The speed limit and one way signs were two sizes, 12 by 18 inches and 18 by 24 inches, respectively. For the final 4 laps the speed limit and one way signs were the same size.

A total of 12 different riders ranging in age from 20 to over 60 years old ran the snowmobile sign recognition loop. Each rider completed six laps, two laps for each sign size for a total of 72 files of data. In the data for each file the main data items considered were:

- Distance to sign from when rider first saw the sign
- Distance to sign from when rider could understand sign
- Time at which rider first saw the sign
- Time at which rider could understand sign
- Average speed during sign recognition process

The final data presented in this section is the distance to the sign from where the rider could understand the sign and the average speed the drivers were going when they were reading the signs.

3.4 Snowmobile Sign Recognition Data

The tabulation of all sign recognition data is shown in Figure 23 as an error bar type of chart. The sign type is shown at the bottom and each sign had three sizes, 12, 18 and 24-inch. The Y axis shows the distance to the sign. The horizontal bars show the average distance the riders were from the sign when they could understand what the sign wanted them to do. The vertical bars are the calculated standard deviation from the center horizontal bar. The numbers directly above each set of three bars is the furthest measured distance a rider could see that there was a sign along the trail.

The number directly above each sign near the bottom of the plot was the average speed for that particular section of trail as measured during the sign recognition data acquisition period.

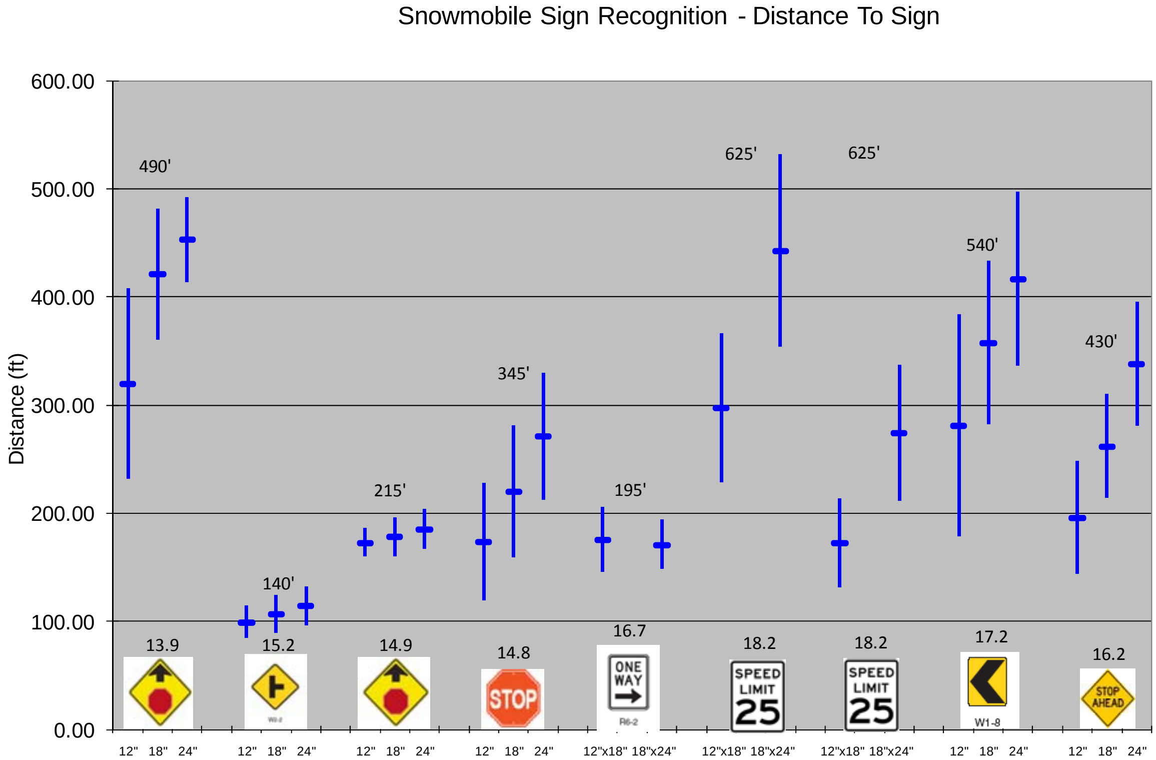

Figure 23 Plot of snowmobile sign recognition data for each sign size and type.

As mentioned above, the trail used for this study was similar to a U.S. Forest Service trail that was narrower than most snowmobile trails in the Mid-west. Some of the corners were tight and with the moguls or bumps in the trail the speeds for this study averaged less than 20 mph in the sign reading zones. Experienced riders averaged nearly 30 mph on some sections but the novice riders didn't feel comfortable traveling fast in most sections of the trail. This resulted in low overall average speeds, 14 to 18 mph, in the sign sight range.

Some riders consistently saw and read the signs at a great distance (good distance vision) and some were much closer to the signs before they could read or understand the signs. The following are some basic statements of the results shown in Figure 23:

1. The best results are the ones where the sight recognition distances increase at a positive slope as the sign size increases, like the stop sign, speed limit, chevron and worded stop ahead. In this sign recognition study some of the signs were like that but others had almost the same sight recognition distance for the larger sign as the smaller sign.
2. The first stop ahead symbol sign sight recognition distance data shows that the recognition distance difference between the 12-inch and 18-inch signs was greater than the sight recognition distance difference between the 18-inch and 24-inch signs. This leads one to believe the overall total sight distance was short for obtaining 24-inch sign recognition distance but the sight recognition data for the 12-inch sign was over 300 feet, a relatively long sight distance.

3. The intersection, second stop ahead symbol and one-way signs sight recognition distances were nearly the same for the 12, 18 and 24-inch signs.
4. The one-way and speed limit signs were only available in the 12-inch by 18-inch and 18-inch by 24-inch sizes. For the 18-inch and 24-inch runs the 18-inch by 24-inch signs were used and therefore the data was averaged for those runs.
5. The data for the stop sign (fourth one from left) has a slope similar to the speed limit, chevron and worded stop-ahead sign but that sign could be seen while the driver was still seeing the stop-ahead symbol sign (third one over). The chevron after the speed limit sign was a similar situation to the stop sign.
6. A 12-inch worded stop-ahead sign could be read and understood about 200 feet from the sign and the black on white speed limit sign required the driver to be 175 feet on average before they could read the words.
7. The stop sign was in an unusual spot in the woods because it could be seen while seeing the stop-ahead symbol sign, which was ahead of it. In other words, for the third and fourth signs the rider could be pushing the button four times in a row as fast as he or she could. The rider may have wanted to push the button sooner for the stop sign. Knowing that the red stop sign is easily seen leads one to question the validity of this specific sign's recognition distance of about 175 feet in the 12-inch size.
8. The first symbol stop-ahead sign could be understood over 300 feet away (for the 12-inch size) while the 12-inch worded stop-ahead could only be understood about 200 feet away, therefore the symbol stop-ahead is a better sign to use on a trail.
9. A sight recognition distance of 175 feet is a good distance to use to cover all types of 12-inch signs.
10. Riders in the study covered all levels of experience from the novice (even rarely ever rode a snowmobile) to highly experienced (people that have raced in snowcross events).

3.5 Sign Recognition Study Considerations

The results from the snowmobile sign recognition study seem appropriate but there are a few factors the reader needs to understand. One is that the speeds were relatively slow for a snowmobile trail. Overall average speeds ranged from 14 to 18 mph. Novice riders averaged 7 to 15 mph while experienced riders averaged 16 to 29 mph in the sign sight area.

Since the riders ran through the trail twice for each sign size they knew where the signs were and may have biased the study. Riders were told to look for signs and hit the button when first seeing the sign and then when they comprehended the sign. Nobody hit the button where the sign could not be seen. The data was generally consistent from run to run. Smaller signs were run first so they were not biased in the results from running larger signs first because the smaller signs were the main question.

A sight recognition distance of 175 feet or greater is recommended based on the data collected in the snowmobile sign recognition study. It's interesting to note that 175 feet is the standard sign recognition distance from signs with five inch standard D type lettered signs from the manual on uniform traffic control devices (MUTCD) based on studies done for the National Highway Traffic Safety Administration (NHTSA) and the American

Association of State Highway Traffic Officials (AASHTO) [4]. The 175 foot sign recognition distance is sited in several places on the internet.

The MUTCD uses the 175 foot recognition distance in conjunction with perception, identification, emotion, volition (PIEV) time. One internet source that refers to MUTCD for sign placement guidelines uses a 2.5 second PIEV time and a coefficient of friction of between 0.3 and 0.4 sighting a 1990 AASHTO policy [4]. For example, if the sign is to be used to warn of an upcoming stop condition it allows a 2.5 second PIEV time, assume a coefficient of friction between 0.3 and 0.4 (which could be a wet pavement or in some cases a snow covered pavement) and then use a form of the equation presented at the beginning of this report. Finally, it subtracts off the 175 foot sign recognition distance.

MUTCD presents a table of values derived from a combined braking and sight distance equation but reference a deceleration rate in place of a coefficient of friction and a slightly different format of the combined braking and sight distance equation. This is also reported in an addendum to a Massachusetts Highway Design Manual to be in conformance with AASHTO [5]. In the Massachusetts Highway Design Manual they state that, “Studies documented in the literature show that most riders decelerate at a rate greater than 14.8 ft/sec^2 when confronted with the need to stop for an unexpected object in the road way. Approximately 90 percent of all riders decelerate at rates greater than 11.2 $feet/sec^2$. Such decelerations are within the rider’s capability to stay within his or her lane and maintain steering control during a braking maneuver on wet surfaces. Therefore, 11.2 $feet/sec^2$ is recommended as the deceleration threshold for determining stopping sight distance.” Both references discussed here show columns for “Heavy Traffic” or “High Judgment Area”, stopping completely and then slowing down to 10, 20, 30 mph, etc. The table from the International Association of Snowmobile Administrators (IASA) seems to follow the same format except it does not have a column for “High Judgement Area”. The snowmobile braking distance data for this study was not analyzed for deceleration rates but the validation data deceleration rates are presented in the validation section of this report.

4.0 SNOWMOBILE VALIDATION

Based on the data collected from the snowmobile braking and the snowmobile sign recognition study and the information discussed above from MUTCD and IASA, a table can be developed for sign placement distance from the event. It is important that the warning signs be placed far enough in advance of the particular event, but not too far. The distance has to be long enough for a snowmobile to brake safely from the maximum speed for the particular section of trail. If the signs are placed too far in front of the event, the rider may forget that there is a place that they will have to slow down or stop for, or may think that the trail was signed improperly and actually speed up.

For the type of braking and sign recognition data collected in this study it is most appropriate to use a form of the equation that includes coefficient of friction (mu value) such as the equation presented in the braking section of this report (see page 4). Using the equation presented in the braking section, the curve fit average braking data was used to calculate the braking coefficient of friction of the various surfaces that were tested on for braking performance. The formula was rearranged to solve for the mu value. For grades, the percent grade was used.

The coefficient of friction for ice was 0.11. For flat packed snow the coefficient of friction was 0.49. For the 9% and 15% grades the coefficient of friction was 0.45. On a snowmobile trail there is loose snow and the snow acts with a bulldozing effect which essentially increases the braking coefficient of friction. The lowest value of 0.45 was used for all snow surfaces.

To add a safety factor, a coefficient of friction lower than the average calculated from the braking data was used to determine sign placement distances, as this follows the pattern used by others such as the deceleration rate discussed in the last section. A lower coefficient of friction will result in a longer braking distance, a longer total stopping distance and a longer distance between the warning sign and the event. A coefficient of friction value of 75% of the calculated coefficient of friction from the braking tests was chosen for the safety factor.

With this in mind a table was developed for sign placement guidelines for snowmobiles on different trail conditions and grades by combining the braking distance equation with a stopping sight distance equation [6]. The equation takes the form shown below:

$$D = 3.67V_o + 0.033\frac{\left(V_o^2\right)}{(\mu \pm grade)} - 175$$

where:

D = Total distance of warning sign placement relative to event in feet.
V_o = Vehicle speed for trail in mph.
μ = Coefficient of friction of trail – dimensionless.
Grade = Grade of trail in percent. Subtract grade for downhill stops.

A coefficient of friction for packed snow is recommended as 0.35 and 0.08 for glare ice. The 2.5 second PIEV time is incorporated in the first term of the equation and 175 feet is the sight recognition distance found in the sign recognition study for 12-inch signs. Using these values a table was developed for warning sign placement on snowmobile trails and is shown in Table 2 below. The calculated values were rounded up to the next five foot interval to add in another factor of safety.

Table 2 Snowmobile Trail Warning Sign Placement Distance From Event

Speed in mph	**Snowmobile Trail Warning Sign Placement Distances From Event**			
	Ice - Flat	**Packed Snow - Flat**	**Packed Snow - 9%**	**Packed Snow - 15%**
30	310	30	50	85
35	460	70	110	160
40	635	125	175	240
45	825	185	250	325
50	1040	245	330	425
55	1275	315	415	530

The particular terrain needs to be considered when placing warning signs. Hills and curves may obstruct sign viewing and therefore it may be best to put the warning sign prior to the hill or curve in the trail.

4.1 Snowmobile Validation Test Layout

A trail sign validation study was conducted to ensure that the warning sign placement distances generated by the data and recommended in the tables are safe and appropriate. A trail was laid out to have narrow sections like a U.S. Forest Service trail and wider, faster sections like some of the standard trails found in the mid-west. Both 12-inch and 18-inch signs were used in the validation study. The trail was a winding loop with the 12-inch signs in one direction of travel and the 18-inch signs in the opposite direction. The trail layout is shown in Figure 24.

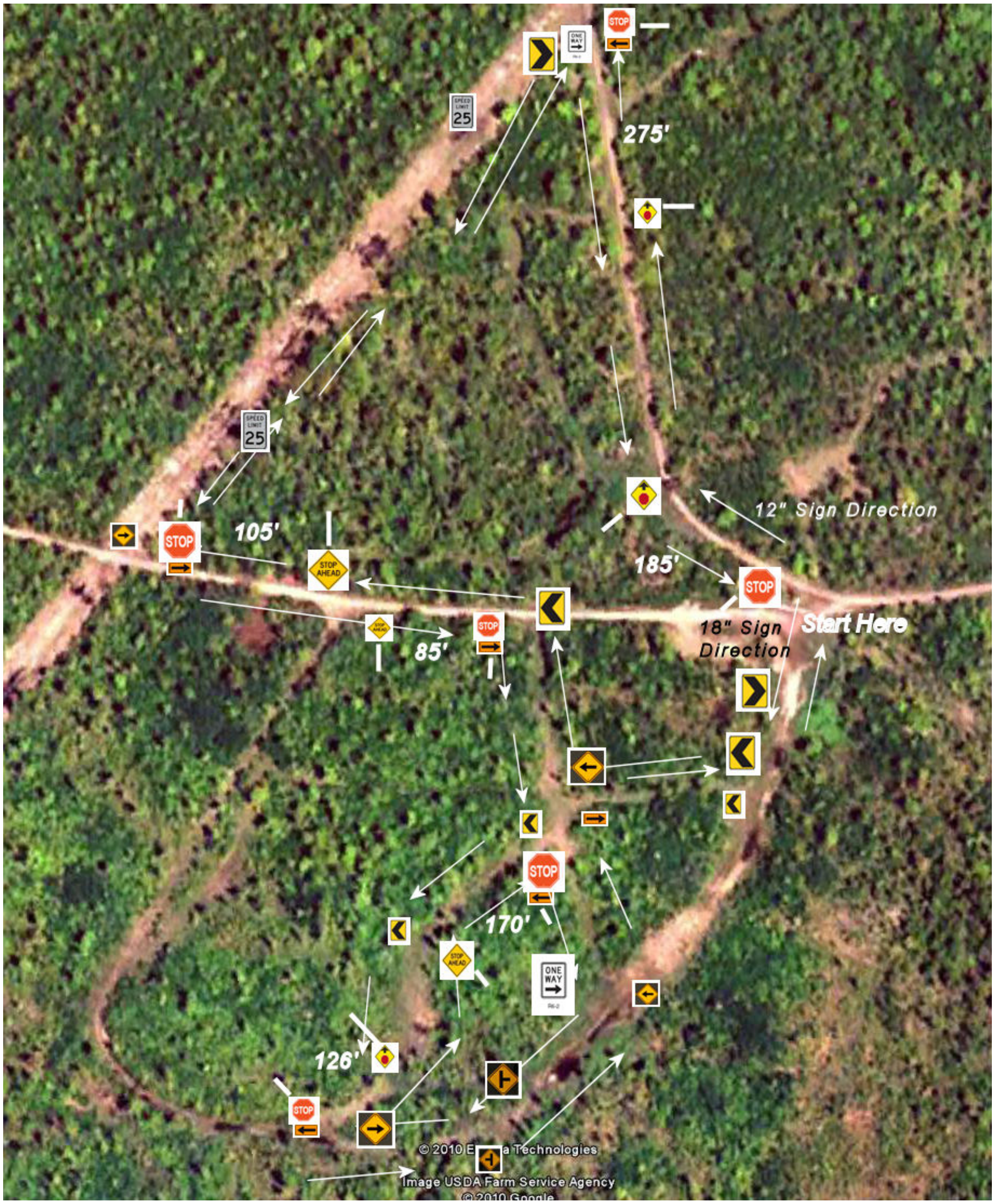

Figure 24 Snowmobile sign validation trail layout.

All of the signs purchased for this project were used in this study. Some of the stop signs were modified (as shown in Figure 27) to have an arrow pointing to direction of travel so that the riders knew where to go on some of the turns as it may not have been obvious.

The snowmobiles used for this study were the same two that were used for the braking tests. The riders were instructed to follow and do what the signs asked. They were also told to drive at their "comfortable" speed and to come to a complete stop at each stop sign using the brakes (it was thought that some might just release the throttle to slow down).

There were three stop signs in each direction/each sign size. In the 12-inch direction, a symbol stop ahead sign was used first and the second warning sign prior to the stop sign was a worded stop ahead sign. The final warning sign was a symbol stop ahead sign. In the 18-inch direction a worded stop ahead sign was used ahead of the first two stop signs. A symbol stop ahead sign was used for the last stop sign on the 18-inch trail. The trail layout for the 12-inch signs is shown photographically in Figures 25-48 to show the reader what the trails looked like during the validation test.

Figure 25 View for rider starting out on 12-inch sign trail (note back of 18-inch sign).

Figure 26 View of first stop ahead - stop sign combination - placement is 275 feet (warning sign to stop sign) on a high speed section of trail.

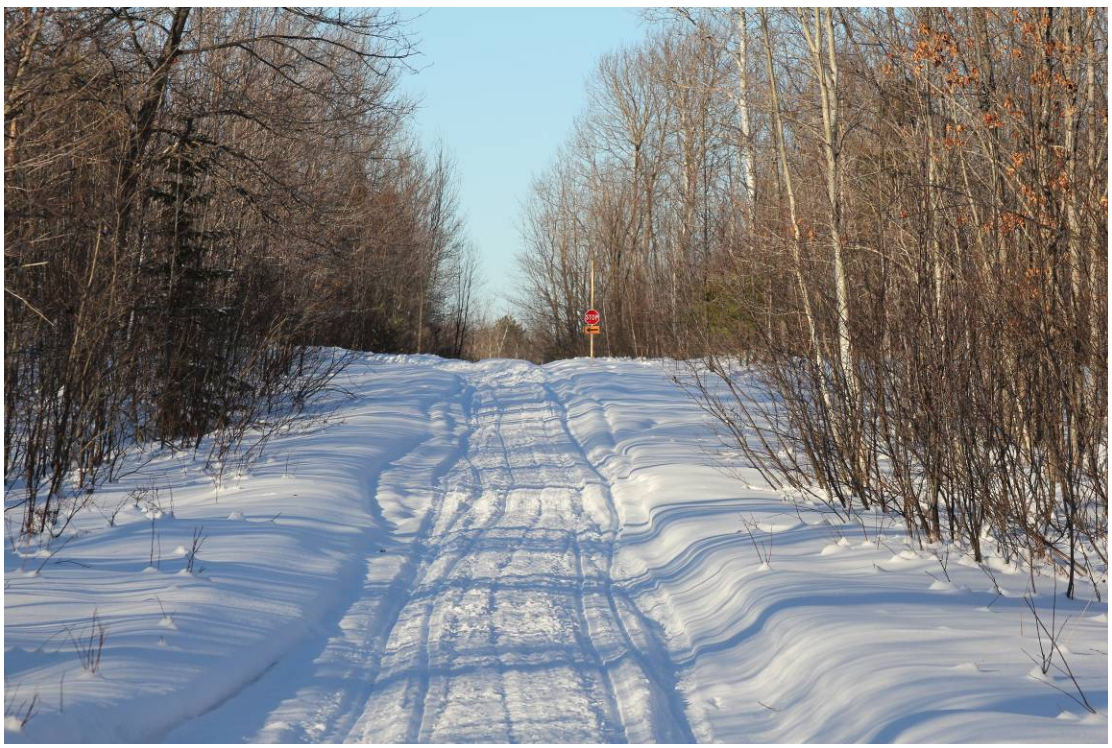

Figure 27 View of stop sign from symbol stop ahead sign at 275 feet.

Figure 28 View of 12 by 18-inch speed limit sign on slow trail section.

Figure 29 View of slow section of trail after speed limit sign.

Figure 30 View of 12-inch arrow sign on end of slow section of trail.

Figure 31 View after making left off of slow section to high speed section. Note back of 18-inch sign and 12-inch warning sign (see arrow) at approximately 400 feet.

Figure 32 View of worded stop ahead on high speed section of trail. Placement of warning sign was 85 feet from stop sign (see section 4.2.1 for an explanation of this distance).

Figure 33 View just after stop-right arrow turn on slow section of trail 125 feet from the sign.

Figure 34 View after making right near 12-inch chevron - this is a slow section of trail.

Figure 35 View of 12-inch left chevron on slow section after driving a short distance.

Figure 36 View from left chevron to a 12-inch symbol stop ahead sign - moderate speed trail-approximately 145 feet from this viewpoint.

Figure 37 View of 12-inch symbol stop ahead sign placed 126 feet from stop sign, before a curve.

Figure 38 View of 12-inch stop sign with left arrow from the symbol stop ahead sign.

Figure 39 View after making left turn at stop sign - moderate speed trail.

Figure 40 View on moderate speed trail of upcoming 12-inch intersection sign.

Figure 41 A close-up view of 12-inch intersection sign - note glare on sign.

Figure 42 View of 12-inch arrow sign on slower speed trail at 135 feet from the sign.

Figure 43 View of trail after making left turn at arrow.

Figure 44 View of right turn arrow partially blocked by trees while traveling up hill.

Figure 45 View of 12-inch right turn arrow from approximately 75 feet.

Figure 46 View of slow, winding section of trail just after right arrow turn.

Figure 47 View of 12-inch chevron coming off of slow section of trail in woods.

Figure 48 View of end of trail section after riding past chevron.

The 18-inch sign course was completed by going in the reverse direction on the same trail. The photograph's are not shown here but are similar to the photographs of the 12-inch trail. The first 18-inch stop ahead sign was a word sign 170 feet from the stop sign. The second stop ahead sign was a symbol type that was only 105 feet from the stop. The final stop ahead sign was a symbol type that was placed 185 feet from the stop sign.

4.2 Snowmobile Validation Test Results

A total of 26 riders took part in the snowmobile validation testing. Two females and 24 males rode the 12-inch sign trail once and the 18-inch sign trail once. The ages ranged from 19 to 62 years old. The experience ranged from novice to those who had raced snowmobiles. After each run the riders were questioned about the signs and sign placement. Subjective comments were just as important as the objective data collection.

4.2.1 Validation Study Subjective Comments

Most volunteer riders reported that the signs were easy to follow and that they had no problems with stop ahead sign placement distance from the stop sign. There were two comments that were very helpful in the analysis. The comments are listed below.

1) The chevron shown in Figure 33 and the right arrow in Figure 45 were at an intersection of four trails. To some of the riders the intersection was confusing. One rider said the chevron was confusing to them. Another said the right arrow in Figure 45 was too close to the intersection.
2) Another highly experienced rider said a stop sign was partially covered with brush. This was the first stop sign on the 18-inch course and it was, but the stop ahead sign

was 170 feet from the stop sign. The trail was narrow and stop sign was partially obscured by brush but nobody else made this comment.

The second stop ahead – stop sign combination in the 12-inch and 18-inch sections of the trail had the stop ahead signs placed closer to the stop sign than recommended by the Table 2. This was because it was a high speed section of trail that had a curve in it. If the stop ahead sign was placed where recommended the riders would probably have slowed down earlier and there would have been little high speed data collected. It was desired to get high speed data for this validation test because many trails do have high speed section. Even though these stop ahead signs were placed closer than Table 2 suggests, nobody missed a stop or had trouble stopping.

4.2.2 Snowmobile Validation Test Objective Data

The objective data recorded during the validation tests was not as clean as the braking data taken during the braking study or the sign recognition data study. In many, if not most of the rider data files, at least one of the three stop sign locations GPS speeds dropped out making it difficult to get an accurate speed at the brake application point and therefore an accurate stopping distance.

The data was thoroughly studied and the data analysis included going into each file and attempting to determine location at the braking point and the location at the stop to determine total stopping distance. Due to the GPS drop outs (most likely due to tree cover) a good stopping distance or deceleration analysis was difficult to perform. Maximum speeds with the long track on the 12-inch sign trail ranged from 25 to 54 mph and on the 18-inch sign trail they ranged from 22 to 58 mph. For the short track the maximum speeds ranged from 22 to 46 mph on the 12-inch sign trail and on the 18-inch sign trail they ranged from 23 to 51 mph. Deceleration values with the short track snowmobile ranged from less than 2 ft/sec^2 to 11.21 ft/sec^2 on either sign size trail. With the long track snowmobile the deceleration values ranged from 1.2 ft/sec^2 to 13.3 ft/sec^2. There were some deceleration rates that were so high they did not make sense and are attributed to the poor GPS signals in the woods and therefore are not included here. Because snowmobiles on snow have a low to medium coefficient of friction, very high deceleration rates would be difficult to achieve. All of the realistic deceleration rates were less than the 14.8 ft/sec^2 unexpected braking rate discussed in section 3.5.

No rider said he or she could not stop in time and from the data it appears that all participants were able to stop at each point although there were a few that did not come to a complete stop. Since all riders could stop in plenty of time, even with the 12-inch warning signs, the sign placement distances were considered acceptable.

5.0 SUMMARY AND CONCLUSIONS

Snowmobile braking data was measured and recorded for two typical types of snowmobiles on the market with both a novice and experienced rider. This was done for flat packed snow, a 9% packed snow grade and a 15% packed snow grade as well as flat ice. This data was used to form a table of average snowmobile braking distances and from that data the coefficient of friction was determined for typical trail surface types and grade ranges.

A sign recognition test was conducted to determine how signs were recognized by riders for different situations although there were not many high speed sections in the study. Riders could easily read signs 175 feet from the sign for a 12-inch sign. Most could be read at a greater distance unless the trail did not allow it. Symbol type signs could be comprehended sooner than word signs.

Finally, a sign placement table was developed following similar methods used by the MUTCD and AASHTO. The braking data and standard physics equations were used to calculate the coefficient of friction for each of the surfaces and then a safety factor was applied to lower the coefficients of friction using the physics equation to develop a sign placement table. See page 23, Table 2. A recognition/reaction time of 2.5 seconds following AASHTO's recommended PIEV time and a 175 foot recognition distance were used to determine the final warning sign placement distance that was presented in Table 2.

The sign placement distances in Table 2 were validated in a final validation study with a unique trail layout for both 12 and 18 inch signs. The data revealed that for general snowmobiling purposes the sign placement information in Table 2 was adequate and that 12-inch signs can be used for safe trail marking.

From this project some conclusions can be made:

1.) Even though most of the braking results are consistent and covered a broad range of rider types, the reader is cautioned that the coefficient of friction of the surfaces varies significantly depending on a number of factors. Therefore, the values shown in this report are not absolute and should not be understood to be absolute in value.

2.) Riders can easily read and understand signs 175 feet from a 12-inch sign.

3.) Symbol type signs are easier to recognize than worded signs.

4.) A table of warning sign placement distances from event signs was developed for this project, but because the braking distances were based on testing in a limited coefficient of friction range of surfaces, the values are not necessarily absolute but are recommended as a guide for the user.

REFERENCES

[1] "Analysis of the Effectiveness of Snowmobile Traction Products in Enhancement of Snowmobile Safety", Richard S. Hermance, Accident Reconstruction Expert, Collision Research Ltd., Winter of 1996-97.

[2] "Guidelines for Snowmobile Trail Signing & Placement 2000", International Association of Snowmobile Administrators.

[3] Fundamentals of Physics, David Halliday and Robert Resnick, Revised Printing, 1974, John Wiley & Sons, Inc., page 82.

[4] Manual on Uniform Traffic Control Design, 2003 Edition including Revision 1, November 2004 and Revision 2, December 2007.

[5] ADDENDA to the 1997 MassHighway Highway Design Manual, Interim Guidance for conformance with AASHTO "A Policy on Geometrid Design of Highways and Streets 2001", April 2003, pg. 6.

[6] National Cooperative Highway Research program, Report 400, "Determination of Stopping Sight Distances", pg. 19, D. B. Fambro, K. Fitzpatrick, R. J. Koppa, Texas Transportation Institute, Texas A&M University, College Station, TX, National Academy Press, Washington, D.C. 1997