Automatic Controls for Salt and Abrasive Spreaders

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A limited study to determine whether automatic discharge controls for salt and abrasive spreaders exhibit performance characteristics superior to those of conventional manual controls is described. Only a long-term investigation could accurately predict actual savings, but the study gave the order of magnitude of potential savings. Manual controls now used to maintain desired spreading rates were found to provide some potential savings over no controls, but savings provided by using automatic controls were much greater because of considerable improvement in the uniformity of spreading. In every case, the automatic system showed significant materials savings in comparison with the manual system. The automatic system did a much better job of eliminating areas of overspreading and underspreading—especially when the speed history of a truck varied considerably. The automatic system will maximize the safety and uniformity of driving conditions for the public and minimize environmental damage and unnecessary expense to the taxpayer.

The objectives of maintenance operations for snow and ice control are to provide highway users with roadways that are (a) passable, (b) safe at some reasonable speed depending on storm conditions, and (c) uniform—that is, having no unforeseen changes in condition. A state highway should not be closed to traffic except in unusually adverse weather. Safe driving conditions should be maintained and should be constant enough so that frequent speed changes are not required to maintain a uniform level of safety. Certainly, unsafe conditions should not be encountered without adequate warning.

A major maintenance operation directed toward meeting these objectives is the spreading of chemicals or abrasives on the roadway. If it is done properly—that is, efficiently, economically, and uniformly—spreading will tremendously aid in meeting these objectives. If it is done improperly, it can waste money and may be the direct or indirect cause of accidents and environmental damage.

Chemicals and abrasives are now applied in New York mainly by means of the hopper type of spreader. These are self-contained units mounted in dump trucks with a full-length feed belt driven by a hydraulic motor whose speed is controlled by an adjustable valve in the cab of the truck. A constant speed determined by the control valve setting in the cab causes a constant amount of material to be dispensed per unit of time. To obtain the spreading rate, time rate must be divided by truck speed, as follows:

$$R = \rho A(V_B/V_T) \quad (1)$$

where

- R = spreading rate,
- ρ = material density,
- A = gate opening area,
- V_B = feed-belt speed, and
- V_T = truck speed.

Quite obviously, for any given control valve setting, only one truck speed yields the correct spreading rate and vice versa. Thus, the control valve setting must be adjusted whenever truck speed varies. Since the available settings are discrete, some degree of nonuniformity is inevitable even if the system is operated perfectly. Random and systematic operator errors compound this nonuniformity.

Two types of automatic control have been developed to eliminate these sources of error:

1. The open-loop type monitors truck speed and adjusts the control valve to a predetermined setting that should provide correct belt speed and thus correct spreading rate. Any changes in the hydraulic system parameters, however, cause this belt speed to be in error.
2. The closed-loop type monitors both truck speed and belt speed and adjusts the control valve until a predetermined value of the ratio of the two speeds V_B/V_T is obtained. Because of the greatly reduced chance of systematic error, this is the type of control system that was evaluated in this study, and all statements in this paper refer to the closed-loop type.

Four advantages cited for automatic control systems are that (a) they need only one manual setting at the start of a spreading operation (to set the value of V_B/V_T to be obtained), (b) they continuously monitor operating conditions, (c) they provide continuously variable—not discrete—adjustment of the control valve, and (d) by eliminating the need for driver or operator intervention, they free drivers and operators for other tasks and eliminate them as a source of error.

FIELD TESTS AND DATA COLLECTION

From Equation 1, the variables that affect the spreading rate of a given material can be seen to be (a) area of gate opening, (b) feed-belt speed, and (c) truck speed. Since gate opening height is a one-time adjustment (at calibration) and is not changed at any time during spreading, this was eliminated as an operating variable. Thus, to determine the actual spreading rate obtained under field conditions, instrumentation had to be provided for continuous recording of truck speed and feed-belt speed. To do this, one tachometer generator was attached to a speedometer cable at the truck transmission and another belted to the feed-belt hydraulic motor drive shaft. To record outputs of these transducers, a two-channel oscillograph recorder was located in the cab of the truck. The spreader and instruments could then be calibrated together.

Calibration of Spreader and Recording Instruments

The sensitivity of the recorder to truck speed was calibrated by driving the truck at several constant speeds indicated by the speedometer and noting the pen deflection of the recorder. The driver had noted that the speedometer indicated excessive speeds in normal traffic, and a 20 percent error in speed was found. Had this error not been detected and accounted for, actual spreading rates would have been about 25 percent greater than the amount determined by normal calibration procedures.

Rather than trying to calibrate belt-speed sensitivity in meters per minute, the entire numerator of Equation 1 (time rate of material discharge) was determined by measuring the amount of material discharged by the spreader per unit of time at each manual control valve setting and noting the corresponding pen deflection. The truck was emptied, the bottom of the hopper sealed, and the hopper refilled with a sand-salt mixture for ballast. The system was then operated with the belt empty to determine any difference in belt speed. A 3 percent increase was found. Finally, the truck was operated at two road speeds, and the spreading rate was determined for each setting of the automatic controller.

Field Tests

The experiment was designed to determine, for both control systems,

1. Ease of controlling the spreading rate,
2. Accuracy of controlling the spreading rate,
3. Ease of controlling the uniformity of the spreading pattern, and
4. Amount of material used during snow and ice control operations.

One must thus control, fix, or test for all variables that might affect the spreading rate. Equation 1 shows four variables that affect spreading rate. In this experiment, material density ρ and gate opening area A were fixed by calibrating the system for one value of each and then eliminating these variables during the field test by blocking off the hopper. Feed-belt speed V_B and truck speed V_T were allowed to vary under controlled conditions. V_B was controlled by the control valve for two nominal spreading rates to test whether the control setting had an effect on the system's control characteristics. V_T was allowed to vary but under controlled conditions. The driver—a very significant source of variation in truck speed—was the same for all testing. Truck type was by necessity the same: a relatively new diesel-powered Mack. This truck is not typical of the current fleet but will become predominant as more gasoline-powered vehicles are replaced. The truck's ballast load was the same for all testing. The route of travel was fixed, but the four sections tested were intended to be representative of different driving conditions.

The two nominal spreading rates were 169.1 kg/lane-km (600 lb/lane-mile)—designated "high"—and 84.5 kg/lane-km (300 lb/lane-mile)—designated "low"—assuming a two-lane spreading pattern. Control valve settings to be used during testing were determined from the calibrations and are given in Table 1. (It should be noted that these settings are for the particular gate opening used during calibrations; changing the gate opening would change the spreading rate.) The automatic control system was operated on settings 7 (169.1 kg/lane-km or 600 lb/lane-mile) and 3 (95.8 kg/lane-km or 340 lb/lane-mile).

The routes tested were chosen to represent four general categories: Interstate, suburban, rural, and urban. The first was a mainline section of NY-85 with limited access, controlled grade and curvature, and no stops. The suburban was a section of NY-85 with two lanes, uncontrolled access, reduced speed limit, houses and businesses fronting the highway, and few stops. The rural was two-lane sections of NY-85 and NY-157 with uncontrolled access, numerous hills and curves, and few stops. The urban included parts of State Street, Washington Avenue, and several side streets in downtown Albany; it included numerous stops and speed changes for traffic signals, cornering maneuvers, and a hill.

To test for the effect of the type of control system, three control conditions were used:

1. The baseline test was essentially an uncontrolled condition in which the manual control valve was set for the correct spreading rate for anticipated speeds of 43.3 km/h (30 mph) for Interstate, suburban, and rural runs, and 32.2 km/h (20 mph) for the urban. No adjustments were made during testing, and the target speeds were maintained as well as possible. These tests provided the data necessary to compare the relative benefits of both the manual and automatic control systems.
2. Manual tests were performed for the same target speeds, but the operator adjusted the control valve according to Table 1 to account for speed variations.
3. Automatic testing was performed by setting the automatic control dial to the desired setting with no other adjustments. The same target speeds were attempted.

This testing was done under ideal conditions—daytime, clear, dry roadway, and no other tasks to be performed.

ANALYSIS OF DATA

The continuously recorded truck and feed-belt signals (Figure 1) were reduced to numerical form at 5-s intervals for each run. These data, which represent distances along the roadway from 11.3 m at 8.0 km/h (37 ft at 5 mph) to 67.0 m at 48.3 km/h (220 ft at 30 mph), were then used to calculate vehicle speed, spreading rate, distance traveled, cumulative distance, material spread, and cumulative material used. Histograms were constructed for truck speed and spreading rate (high rate only, shown in Figure 2) for the separate test conditions.

The speed histograms showed that no two runs had identical speed histories (as expected), but the differences between runs of similar conditions were not major. Because these speed histories could not be exactly reproduced, comparisons of spreading rates will not be exact but, because of their similarities, they will generally be valid. Suburban run speed histories also were clearly not much different than those for Interstate runs, which indicated that the suburban route was not representative of the conditions intended. Even rural runs showed more central tendency than expected, undoubtedly as a result of ideal driving conditions and superior truck performance.

Histograms of spreading rate (Figure 2) show a decidedly superior degree of central tendency for the automatic control mode. Both the baseline and manual control modes show considerably more dispersion about the target spreading rate. These histograms represent the variation caused by the speed histories of each run plus the random variations inherent in the machine itself and the experimental error associated with recording and reducing the data. The estimates of standard deviation s shown in Figure 2 indicate the progressive improvement in uniformity obtained by the manual and automatic controls. Low standard deviations indicate greater central tendency and thus better uniformity.

To use these data to compare the three control modes, one must assume an acceptable range of spreading rates. The exact target value, of course, cannot be maintained during spreading, and some range above and below the target will have to be accepted. For this application, with its many unknowns (e.g., snow and ice depth, temperature, and traffic), a rather large variation would appear acceptable. A figure of ±10 percent of the target rate was chosen as an acceptable variation of spreading rate. Any spreading rate above 110 percent of the target rate was considered wasteful, and any below 90 percent was considered deficient, requiring respreading.

The most important comparison that can be made is to determine for each control type the amount of material that would be used in addition to the minimum theoretical value. To do this, two assumptions must be made:

1. When deficient spreading occurs, one must respread. What is the spreading rate used in respreading? No strict value is adhered to in the field because on-the-spot evaluation of conditions governs the respreading rate. Estimates vary widely, and a respreading rate equal to half the original rate is assumed here.
2. The percentage of time that deficient rates occur will equal the percentage of total distance traveled.

Total additional material used is calculated by taking the excess percentage of material that results from overspreading, subtracting the deficient percentage of material, and adding the percentage of material used for respreading (equal to half the original rate times the fraction of the total distance). These calculations are summarized in Table 2. Generally, these figures show that the manual control method is not much better than the uncontrolled baseline method, and a clear advantage is gained by using the automatic control system. For the conditions tested, savings over the manual control method were found to range from 2.4 to 25.4 percent.

A great deal of caution should be used in drawing further conclusions from these data. This study was limited in scope. Some variables were fixed, and others were allowed to vary within a limited range. As such,

Table 1. Manual control valve settings.

Control Valve Setting	Spreading Rate by Truck Speed (kg/lane-km)[a] 8.0 km/h	16.1 km/h	24.1 km/h	32.2 km/h	40.2 km/h	48.3 km/h	56.3 km/h	
1	0	0	0	0	0	0	0	
2	169.0	84.5	56.4	42.3	33.8	28.2	24.2	
3	338.2	169.1	112.7	84.5	67.6	56.4	48.5	
4	439.6	219.8	146.5	109.9	87.9	78.9	62.8	
5	508.7	304.3	202.9	152.2	121.7	101.4	86.8	Low
6	765.9	383.0	255.3	191.6	153.3	127.6	109.3	
7	967.1	483.6	322.4	241.8	193.3	160.9	138.1	
8	1082.1	541.0	360.7	270.5	216.4	180.4	154.4	
9	1107.5	553.7	369.2	276.7	221.5	184.6	158.1	High

Note: 1 kg/lane-km = 3.55 lb/lane-mile; 1 km = 0.62 mile.
[a]Gate open at position 1.

Figure 1. Sample recordings of truck and feed-belt speed.

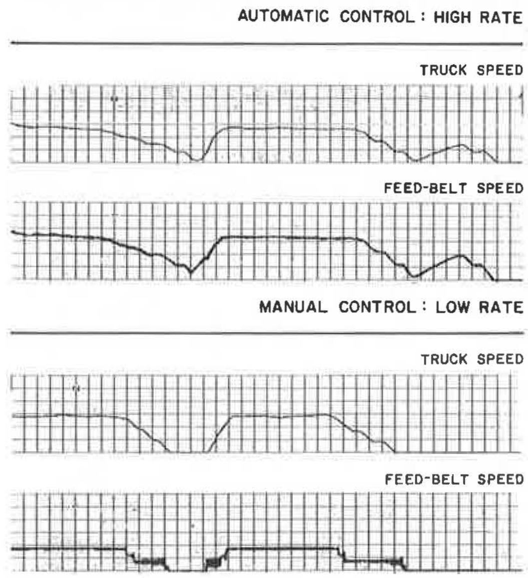

Figure 2. Distributions for high spreading rate (scored bars are percentages of observations outside ranges shown).

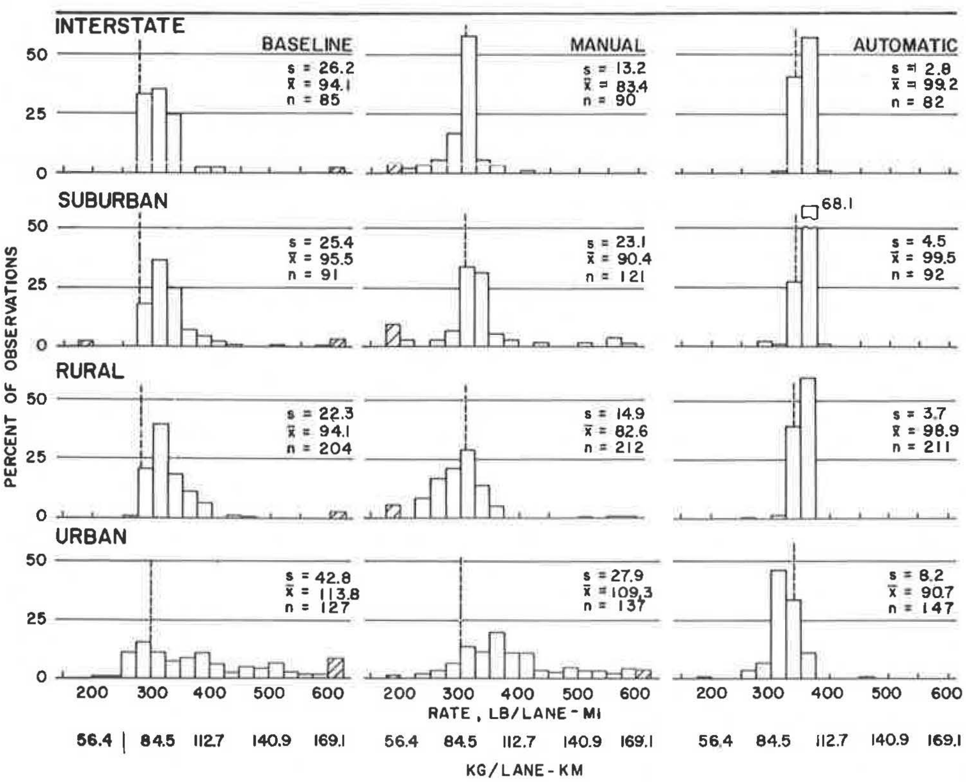

Table 2. Percentage of material wasted and saved for the three types of control systems.

				Excess		Deficiency				
Roadway	Spreading Rate	Control	Target Rate (kg/lane-km)	Time Exceeding 110 Percent Target[a] (%)	Material Wasted (%)	Time Less Than 90 Percent Target[b] (%)	Material Saved (%)	Material Wasted Because of Respreading (%)	Total Material Wasted (%)	Material Saved by Using Automatic Controls (%)
Interstate	High	Baseline	160.6	29.2	9.9	10.4	1.4	5.2	13.7	12.5
		Manual	169.1	6.9	1.5	6.7	1.2	3.3	3.6	2.4
		Automatic	169.1	1.2	0.4	2.4	0.4	1.2	1.2	-
	Low	Baseline	78.9	55.9	14.0	0.0	0.0	0.0	14.0	13.4
		Manual	87.4	2.4	0.6	18.2	5.0	9.1	4.7	4.1
		Automatic	95.8	1.2	0.2	1.0	0.1	0.5	0.6	-
Suburban	High	Baseline	160.6	15.7	3.6	6.1	1.0	3.0	5.6	5.6
		Manual	169.1	2.4	0.6	43.7	5.8	21.8	16.6	16.6
		Automatic	169.1	0.0	0.0	1.2	0.7	0.6	0.0	-
	Low	Baseline	78.9	63.6	20.2	0.0	0.0	0.0	20.2	19.2
		Manual	87.4	26.3	7.7	15.1	5.6	7.5	9.6	8.6
		Automatic	95.8	1.1	0.2	2.4	0.4	1.2	1.0	-
Rural	High	Baseline	160.6	51.0	14.1	9.4	1.2	4.7	17.6	16.2
		Manual	169.1	3.8	0.6	61.5	10.5	30.7	20.8	19.4
		Automatic	169.1	4.9	0.7	2.1	0.3	1.0	1.4	-
	Low	Baseline	78.9	64.3	15.0	0.0	0.0	0.0	15.0	14.8
		Manual	87.4	10.0	2.5	41.6	8.1	20.8	15.2	15.0
		Automatic	95.8	0.0	0.0	0.8	0.2	0.4	0.2	-
Urban	High	Baseline	152.2	67.5	35.4	9.9	1.2	4.9	39.1	32.5
		Manual	152.2	64.1	19.8	14.3	4.4	7.1	22.5	15.9
		Automatic	169.1	0.8	0.1	18.1	2.6	9.1	6.6	-
	Low	Baseline	84.5	55.3	33.6	2.5	1.2	1.2	33.6	27.3
		Manual	84.5	72.6	30.4	4.5	0.9	2.2	31.7	25.4
		Automatic	95.8	0.7	0.3	20.0	4.0	10.0	6.3	-

Note: 1 kg/lane-km = 3.55 lb/lane-mile.
[a]Upper acceptable limit = 110 percent target. [b]Lower acceptable limit = 90 percent target.

the data are just a small sampling of possible real-life occurrences. No allowance was made for unique or problem areas encountered in normal operations. In addition, the values given in Table 2 were calculated on the basis of the two assumptions given above, and the accuracy of those assumptions affects the values obtained.

In short, it has been qualitatively proved that the automatic control system is clearly superior and should bring about material savings. These data, however, are not statistically reliable enough for quantitative determination of those savings. A much more sophisticated and expensive experiment would be required to provide quantitative data.

SUMMARY

This experiment answered four questions in comparing the current manual control system with a new automatic control system for spreading salt and abrasives on highways:

1. Ease of controlling spreading rate—For the manual system, truck speed must be continually monitored, a calibration chart consulted, and the control valve set accordingly. For the automatic system, a calibration chart is consulted before spreading, the appropriate setting is made on the controller, and no further adjustments are needed.
2. Accuracy of controlling the spreading rate—For manual controls, the accuracy and precision of controlling the spreading rate are not much better than when no controls are used. The automatic controls exhibit much better accuracy and precision.
3. Ease of controlling the uniformity of the spreading pattern—The accuracy and precision of controlling the spreading rate directly determine uniformity (items 1 and 2 above).
4. Amount of material used during snow and ice control operations—Material savings were shown to result from use of automatic controls. These data could not be extrapolated to provide total statewide expected savings, however, because of the limited size of the experiment and the restraints placed on the variables.

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