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An Analysis of Factors Relating to Agricultural Machinery Farm-Work Accidents Using Logistic Regression

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Abstract

Purpose: In order to develop strategies to prevent farm-work accidents relating to agricultural machinery, influential factors were examined in this paper. The effects of these factors were quantified using logistic regression. **Methods:** Based on the results of a survey on farm-work accidents conducted by the National Academy of Agricultural Science, 21 tentative independent variables were selected. To apply these variables to regression, the presence of multicollinearity was examined by comparing correlation coefficients, checking the statistical significance of the coefficients in a simple linear regression model, and calculating the variance inflation factor. A logistic regression model and determination method of its goodness of fit was defined. **Results:** Among 21 independent variables, 13 variables were not collinear each other. The results of a logistic regression analysis using these variables showed that the model was significant and acceptable, with deviance of 714.053. Parameter estimation results showed that four variables (age, power tiller ownership, cognizance of the government's safety policy, and consciousness of safety) were significant. The logistic regression model predicted that the former two increased accident odds by 1.027 and 8.506 times, respectively, while the latter two decreased the odds by 0.243 and 0.545 times, respectively. **Conclusions:** Prevention strategies against factors causing an accident, such as the age of farmers and the use of a power tiller, are necessary. In addition, more efficient trainings to elevate the farmer's consciousness about safety must be provided.

Keywords: Accident Factor, Agricultural Machinery, Farm Work Accident, Logistic Regression, Multicollinearity

Introduction

Agricultural mechanization in Korea developed rapidly compared to other countries. The tractor stock, which was under five thousand in 1981, was over 267 thousand in 2011, a 50-fold increase in 30 years (Kim et al., 2013). Agricultural machinery has played an important role in Korean agriculture, giving farmers higher productivity, less laborious work, and more leisure time. However, these benefits were accompanied by negative effects as well, such as accidents. In the 1980s when agricultural machinery was introduced, the accident rate was high; for example, the number of power tiller accidents was 10.7 cases per 100 units in 1986. Since then, many measures such as providing protective guards, widening and paving farm roads, and safety training were implemented to reduce accidents. A recent survey showed that as a result, in 2012 the accident rate of power tiller decreased to 0.69 cases per 100 units, approximately only 6% of the number of accidents in 1986 (Kim et al., 2014). However, because accidents related to agricultural machinery are severer than car accidents, steady efforts to reduce accidents should be maintained.

The injury rate in the agricultural sector is high compared to other industrial sectors, even in advanced countries (Gerberich et al., 1998; Coury et al., 1999). Hence, studies on the causes and factors of accidents are necessary, and a great deal of research has been done worldwide. Layde et al. (1995) studied risk factors for machine-related farm

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injuries as part of a population-based case-control study. Case patients were 90 farm residents in central Wisconsin who experienced a farm injury associated with agricultural machinery, while controls were selected from an ad hoc survey of 221 farm residents in the same area. Telephone interviews regarding demographic characteristics, safety behaviors, and farming practices were conducted. Based on a logistic regression model, the authors reported that independent risk factors included hours worked per week (OR[1]) = 2.32), cows fed in barn in summer (OR = 0.28), and registered cows on farm (OR = 0.36).

Sohn et al. (2007) evaluated the risk factors associated with agricultural machinery-related injuries. The authors used data from the medical records of 148 patients who visited the emergency department of Chosun University Hospital in Korea from January 2005 to December 2006. They calculated injury severity by using multivariate regression, including factors of age, sex, pre-existing diseases, place and time of injury, type of accident, kind of machine and final diagnosis. The results showed that significant risk factors included age over fifty (OR = 0.854), transferred patient (OR = 0.746), accident on main road (OR = 0.814), and patients who were in the passenger seat or trunk when the accident occurred (OR = 0.796).

Costello et al. (2009) examined driver, vehicle, public road, and farm enterprise characteristics for their combined association with public road crashes of farm vehicles. They surveyed 200 North Carolina farms experiencing a public road crash from 1992 to 2003 and 185 from a non-crash control group. Using survey results and logistic regression, the authors concluded that five characteristics were associated with increased odds of experiencing a road crash: non-English speaking drivers (OR = 3.71), the use of hired drivers (OR = 4.25), types of non-farm vehicle (OR = 1.39), farm injury history (OR = 1.33), and young farm vehicle drivers (OR = 1.02).

In order to understand the importance of safety practices as potential determinants of injury, Narasimhan et al. (2010) examined two safety practices as risk factors for injury, the presence of safety devices on machinery, and low levels of routine machinery maintenance. The authors used the Saskatchewan Farm injury data (n = 2,390 farms) and multiple Poisson regression models. The authors concluded that the former was associated with higher risks for injury (RR[2]) = 1.94) and the latter was associated with significantly reduced risks (RR = 0.54).

The above literature review discussed regressions that had been used to identify factors associated with agricultural machinery accidents, and to quantify the influence of these factors. These regression models, however, did not include many potential factors related to agriculture. In this study, many potential factors related to agriculture, as well as demographic characteristics, were examined. Influential factors and their quantified influence were subsequently evaluated using logistic regression in order to develop strategies to prevent farm work accidents.

Materials and Methods

Data source and selection of significant factors

The data source for this study was a survey completed by the National Academy of Agricultural Science (NAAS). The NAAS has conducted periodic surveys on farm work accidents and traffic accidents of agricultural machinery since 1982 in order to acquire basic statistics to support accident prevention. The last survey on farm-work accidents was completed in 2013. In that survey, each farmer who experienced a farm-work accident in 2012 in the 300 sample villages was interviewed about the farm's characteristics, the farmer's ownership of agricultural machinery, and for details of the accident. Farm-work accidents were defined as occurring during farm operations, or during activities related with farm operations, such as repair, transport, adjustment, and so on. The survey was limited to accidents that resulted in hospitalization, treatment of two days or more, or that resulted in monetary damage over a certain amount. A control group of farmers with no accidents reported were also interviewed about same items, except for accident details.

Among the surveyed items, accident occurrence was used as a dependent variable and 21 factors, which were potentially associated with accidents, were selected as

1) An odds ratio (OR) is a measure of association between an independent variable and a dependent variable. The OR represents the odds that a dependent variable (an accident) will occur in the existence of a particular independent variable, compared to the odds of the dependent variable occurring in the absence of the independent variable.

2) A risk ratio (RR) is another way of a measure of association between an independent variable and a dependent variable. It is determined in a way similar to the odds ratio, but uses probabilities instead of odds.

Table 1. Description of dependent variable and tentative independent variables

Variable	Symbol	Description	Value/unit
Dependent	ACDT	Accident occurrence	0 = not occurred, 1 = occurred
Independent	MT	Mountainous area	0 = not mountainous area, 1= mountainous area
	GD	Gender	0 = female, 1 = male
	AGE	Interviewee's age	Year
	CRE	Duration of farming	Year
	SIZ	Farming area	Hectare
	UPL	Upland farming	0 = not upland farming, 1 = upland farming
	ORC	Orchard farming	0 = not orchard farming, 1 = orchard farming
	PRO	Protected farming	0 = not protected farming, 1 = protected farming
	LIV	Livestock farming	0 = not livestock farming, 1 = livestock farming
	TRA	Tractor ownership	0 = not having a tractor, 1 = having a tractor
	PWT	Power tiller ownership	0 = not having a power tiller, 1 = having a power tiller
	RT	Rice transplanter ownership	0 = not having a rice transplanter, 1 = having a rice transplanter
	CB	Combine harvester ownership	0 = not having a combine harvester, 1 = having a rice transplanter
	WD	Weeder ownership	0 = not having a weeder, 1 = having a weeder
	CUL	Cultivator ownership	0 = not having a cultivator, 1 = having a cultivator
	SS	Speed sprayer ownership	0 = not having a speed sprayer, 1 = having a speed sprayer
	CAR	Car ownership	0 = not having a car, 1 = having a car
	TR5	Experience of safety training within recent 5 years	0 = no experience of training, 1 = having experience of training
	PR	Contact with safety promoting material	0 = not contacted, 1 = having been contacted
	PLC	Cognizance of government's safety policy	0 = not cognize, 1 = cognize
	CNC	Consciousness of safety	0 = not conscious, 1 = conscious

candidate independent variables. Table 1 shows these 21 variables and their descriptions.

It is necessary to test for multicollinearity in multivariate regression. Variables are defined as being collinear when two or more independent variables are highly correlated. If multicollinearity is present, the model may not reach convergence and estimated parameters can be influenced erratically in response to small changes in the model or data. Three methods were used to detect multicollinearity in this study, 1) examining the correlation coefficient between pairs of variables, 2) checking the significance of simple linear regressions between each independent variable and dependent variable, and 3) calculating the variance inflation factor (VIF). The VIF was calculated using Eq. (1).

$$VIF = \frac{1}{1 - R_i^2} \tag{1}$$

where R_i is the determination coefficient of a regression of *i*-th independent variable on all the other independent variables.

Any variable not satisfying the following criteria was excluded in the logistic regression analysis: 1) correlation coefficient of 0.7 or above (Choi et al., 2013), 2) p-value of 0.45[3] or above (Layde et al., 1995), and 3) a VIF of 10 or above (O'Brien, 2007).

The tool used for the logistic regression analysis was SAS 9.2 (SAS Institute Inc.).

Logistic regression model

When the outcome of interest is a binary variable, logistic regression is appropriate (Ingram, 2003). A variable is referred to as binary when it can take only two possible outcomes such as "yes" and "no." In this study, "yes" represents accident occurrence. Independent variables can be one or more categorical or continuous variables.

A mathematical model for logistic regression can be derived as following (Song et al., 1993). A general regression

3) The cutoff value was set as 0.45 though Layde et al. used 0.25 because some variables such as age, regarded as explanatory, were excluded in that case.

model has a mathematical form of Eq. (2).

$$Y=\beta_0+\beta_1 x_1+\cdots+\beta_n x_n \quad (2)$$

where Y denotes a dependent variable, x_i independent variables, and β_i model parameters. Because the value of Y can be negative or larger than one, a logistic regression model has a form of Eq. (3) so that Y has a value between zero and one.

$$Y=\frac{e^{\beta_0+\beta_1 x_1+\cdots+\beta_n x_n}}{1+e^{\beta_0+\beta_1 x_1+\cdots+\beta_n x_n}} \quad (3)$$

Rearranging Eq. (3) and taking natural log on both sides, Eq. (4) can be derived. The coefficients in Eq. (3) are usually estimated using the maximum likelihood method.

$$\ln\left[\frac{Y}{1-Y}\right]=\beta_0+\beta_1 x_1+\cdots+\beta_n x_n \quad (4)$$

Goodness-of-fit in linear regression models is generally measured using the R^2. Since this has no direct analog in logistic regression, various methods such as likelihood ratio test, pseudo-R^2s and Hosmer-Lemeshow test are used instead. In this study, the likelihood ratio test is used to evaluate goodness-of-fit because it is most widely used in the literature. A likelihood ratio test means computation of deviance using Eq. (5), where the saturated model is one with a theoretically perfect fit. Likelihood is a function of the parameters of a statistical model defined as follows: the likelihood of a set of parameter values given some observed outcomes is equal to the probability of those observed outcomes given those parameter values. The smaller deviance is, the better the model's fit.

$$Deviance=-2\ln\frac{Likelihood\ of\ the\ fitted\ model}{Likelihood\ of\ the\ saturated\ model} \quad (5)$$

Results and Discussion

In order to analyze the factors associated with farm-work accidents, the tentative independent variables were examined using the NAAS survey data and a logistic regression model.

Table 2. Descriptive statistics of dependent variable and tentative independent variables

Variable	Case group (n=95)	Control group (n=1,451)	Variable	Case group (n=95)	Control group (n=1,451)
MT	0 = 68 (71.6)[i] 1= 27 (28.4)	0 = 995 (68.6) 1= 456 (31.4)	GD	0 = 6 (6.3) 1= 89 (93.7)	0 = 185 (12.7) 1= 1266 (87.3)
AGE	66.1 years (SD[ii]: 9.6)	64.8 years (SD: 10.6)	CRE	40.8 years (SD: 13.2)	39.0 years (SD: 15.6)
SIZ	2.6 ha (SD: 3.5)	2.1 ha (SD: 2.8)	UPL	0 = 64(67.4) 1= 31(32.6)	0 =1027(70.8) 1= 424(29.2)
ORC	0 = 87 (91.6) 1= 8 (8.4)	0 =1274 (87.8) 1=177 (12.2)	PRO	0 = 87 (91.6) 1= 8 (8.4)	0 = 1322 (91.1) 1= 129 (8.9)
LIV	0 = 90 (94.7) 1= 5 (5.3)	0 =1404 (96.7) 1= 47 (3.2)	TRA	0 = 45 (47.4) 1= 50 (52.6)	0 = 834 (57.5) 1= 617 (42.5)
PWT	0 = 4 (4.2) 1= 91 (95.8)	0 = 371 (25.6) 1= 1080 (74.4)	RT	0 = 53 (55.8) 1= 42 (44.2)	0 = 940 (64.8) 1=511 (35.2)
CB	0 = 70 (73.7) 1= 25 (26.3)	0 = 1225(84.4) 1= 226 (15.6)	WD	0 = 12 (12.6) 1= 83 (87.4)	0 = 177 (12.2) 1= 1274 (87.8)
CUL	0 = 41 (43.2) 1= 54 (56.8)	0 = 636 (43.8) 1= 815 (56.2)	SS	0 =91 (95.8) 1= 4 (4.2)	0 = 1316 (90.7) 1= 135 (9.3)
CAR	0 = 45 (47.4) 1= 50 (52.6)	0 = 633 (43.6) 1= 818 (56.4)	TR5	0 = 63 (66.3) 1= 32 (33.7)	0 = 1055 (72.7) 1= 396 (27.3)
PR	0 = 44 (46.3) 1= 51 (53.7)	0 =725 (50.0) 1= 726 (50.0)	PLC	0 = 91 (95.8) 1= 4 (4.2)	0 = 1265 (87.2) 1= 186 (12.8)
CNC	0 = 16 (16.8) 1= 79 (83.2)	0 = 200 (13.8) 1= 1251 (86.2)			

[i] Numbers in the parentheses indicate percentage, [ii] Standard deviation

Descriptive statistics of independent variables

The size of the case group, consisting of farmers who experienced accidents in 300 villages, was 95. The control group included 1,451 farmers. The descriptive data of each group are shown in the Table 2. The case group was older by 1.3 years than the other group, had larger farm size by 0.5 ha, and had a higher ratio of male by 6.4%. The case group had a slightly greater tendency to run upland farming and livestock farming, but tended less toward orchard farming and protected farming. As for the ownership of agricultural machinery, the case group had more machines than the control group except for weeders and speed sprayers. The ownership ratio for power tillers was the most different; 95.8% owned them in the case group, while 74.4% in the control group. The case group had more experience participating in safety training and contact with safety promotion material, while they had less consciousness of safety and lower cognizance of the government's safety policy.

Examining multicollinearity of the independent variables

Correlation coefficients between all variables were calculated as the first method used here to examine multicollinearity of the independent variables. Calculation results showed that only the 'AGE' and 'CRE' variables had a high correlation coefficient of 0.7463, as shown in Table 3. Because the farmer's age is a more important factor than the duration of farming, the 'CRE' variable was excluded.

The second step for examining multicollinearity was to compute the significance of simple linear regressions between each independent variable and dependent variable. Regression results showed that seven tentative independent variables should be excluded because their p-values were greater than 0.45, the given criterion. The results are shown in the Table 4 with excluded variables shadowed.

The results for the final test to examine multicollinearity are shown in Table 5. In this test, there was no excluded variable because all variables had values smaller than 3. From the results of the three methods stated above, the final variables included were gender (GD), age (AGE), farm size (SIZ), orchard farming (ORC), livestock farming (LIV), having a tractor (TRA), having a power tiller (PWT), having a rice transplanter (RT), having a combine harvester (CB), having a speeder sprayer (SS), completing safety training within the past 5 years (TR5), knowing the governmental policy related with safety (PLC), and consciousness about safety (CNC).

Table 3. Correlation coefficients between independent variables

	MT	GD	AGE	CRE	SIZ	UPL	ORC	PRO	LIV	TRA	PWT
MT	1	0.0453	-0.0670	-0.1089	-0.0943	0.1618	0.1471	-0.0776	0.0058	-0.0546	-0.0223
GD		1	-0.1729	-0.1105	0.1333	0.0453	0.0453	0.0479	0.0373	0.1604	0.1957
AGE			1	0.7463	-0.3282	0.0654	-0.0670	-0.1401	-0.1052	-0.4004	-0.1160
CRE				1	-0.2052	-0.0080	-0.0383	-0.0908	-0.0765	-0.2120	0.0550
SIZ					1	-0.0995	-0.0573	-0.0506	-0.0436	0.4290	0.1435
UPL						1	-0.2381	-0.2014	-0.1205	-0.1212	-0.1610
ORC							1	-0.1150	-0.0688	-0.1039	0.0459
PRO								1	-0.0582	0.1604	0.0703
LIV									1	0.1562	0.0051
TRA										1	0.2065
PWT											1

Table 4. P-values of simple linear regressions between each independent variables and dependent variable

Variable	MT	GD	AGE	CRE	SIZ	UPL	ORC
P-value	0.5406	0.0649	0.2739	0.2780	0.0829	0.4801	0.2721
Variable	PRO	LIV	TRA	PWT	RT	CB	WD
P-value	0.8762	0.2894	0.0540	0.0000	0.0765	0.0059	0.9007
Variable	CUL	SS	CAR	TR5	PR	PLC	CNC
P-value	0.8980	0.0928	0.4766	0.1775	0.4910	0.0133	0.4051

Table 5. VIFs for all tentative independent variable

Variable	MT	GD	AGE	CRE	SIZ	UPL	ORC
VIF	1.15375	1.14564	2.91394	2.47919	1.58878	1.31786	1.72744
Variable	PRO	LIV	TRA	PWT	RT	CB	WD
VIF	1.22452	1.12126	1.82070	1.24831	1.60867	1.63315	1.13746
Variable	CUL	SS	CAR	TR5	PR	PLC	CNC
VIF	1.29776	1.49281	1.80074	1.27025	1.29676	1.12081	1.13809

Table 6. Results of parameter estimation and their statistics

Variable	Parameter estimate	Standard error	Wald chi-square	P-value	Estimated odds ratio
GD	0.5682	0.4470	1.6158	0.2037	1.765
AGE	0.0262	0.0119	4.8618	0.0275*	1.027
SIZ	0.0389	0.0398	0.9579	0.3277	1.040
ORC	-0.0710	0.4203	0.0285	0.8658	0.931
LIV	0.4479	0.5109	0.7687	0.3806	1.565
TRA	0.2140	0.2690	0.6333	0.4262	1.239
PWT	2.1408	0.5300	16.3143	<.0001*	8.506
RT	-0.1857	0.2665	0.4853	0.4860	0.831
CB	0.5093	0.3211	2.5156	0.1127	1.664
SS	-0.7470	0.5669	1.7361	0.1876	0.474
TR5	0.2779	0.2385	1.3584	0.2438	1.320
PLC	-1.4152	0.5270	7.2109	0.0072*	0.243
CNC	-0.6061	0.3022	4.0218	0.0449*	0.545

* Statistically significant at a 95% confidence level

Results of the logistic regression analysis

Because the logistic regression model had a p-value less than 0.0001, meaning that the null hypothesis which assumed all parameters (β_i) were zero could be rejected, the model was proved to be highly significant. Furthermore, the model was well fitted because its deviance, 714.053, was acceptable compared to those of other models in previous studies; 533.1 (Costello et al., 2009) and 6624.869 (Valent et al., 2002).

Results of the parameter estimation are shown in the Table 6. They showed that only 4 variables were significant at a 95% confidence level. In the logistic regression, the change of a dependent variable due to a unit change of an independent variable can be estimated using odds ratios. Hence, it can be inferred that the odds of an accident is 1.027 times higher for each additional year of a farmer's age. Similarly, the model predicted that ownership of a power tiller increases the odds of an accident by 8.506 times. This is related to the observation that the case group had more power tillers, as shown in the Table 2. Power tillers accounted for 60% of farm-work accidents (Kim et al, 2014). The results also showed that farmers who knew the government's policy on safety or were conscious about safety were expected to be less likely to have an accident at the ratios of 24.3% or 54.5%, respectively. The result that those who knew safety policy had lower accident possibility means that they were more conscious about safety and relatively younger.

Conclusions

In this paper, a logistic regression model was constructed in order to identify factors associated with agricultural machinery accidents and to quantify the influence of these factors. Multicollinearity among the independent variables was also examined, based on the results of a survey on farm-work accidents conducted by the NAAS. Among 21 tentative factors, 13 variables were selected and applied in the model in light of the multicollinearity identified. The model indicated that 4 factors significantly influenced the occurrence of accidents: age, ownership of a power tiller, cognizance of government's safety policy, and consciousness of safety. According to these results, it can be concluded that it is necessary to establish prevention strategies especially for aged farmers and for those with power tillers. In addition, trainings and promotions to elevate the farmer's consciousness about safety must be provided to reduce accidents.

Though the logistic model in this study was fitted well and predicted factors appropriately, this study has a limit. There could be a factor not dealt with in this study but influential on an accident like annual hours of used of agricultural machinery. However, this study can contribute to developing the methodology for analysis of causes and factors of agricultural machinery accidents.

Conflict of Interest

The authors have no conflicting financial or other interests.

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