

Translating Speed Limit Setting Expertise into a Systematic Practice in Developing Country

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Abstract: Speed management is a central element of road safety measure. Various methods have been proposed to define speed limits. The convenient software is present, e.g., USLIMITS. It requires various input data, so it is not applicable in developing country. Lack of efficient tool for speed limit setting has left highway authority set speed limit based on experience and practice. This study aims to examine rationale of expert judgment by developing a multinomial logit model with a case study in Bangladesh. The model is calibrated with the explanatory variables of roadside built-up characteristics are considered as attributes; and a choice variable of speed limit obtained by asking 10 highway management experts to evaluate 200-m segments for 40-km rural highway. The resulting model is possibly used to set a proper speed limit throughout the country in a systematic and consistent manner.

Keywords: Speed Limit, Discrete Choice, Multinomial Logit Model, Rural Highway

1. INTRODUCTION

Speed is a prime factor for road crashes and the resulting death and injury toll. Thus speed management, a set of measures to limit the negative effects of speeds, should be a central element of any road safety strategy, aims to achieve appropriate speeds on all parts of the road network. Within various strategies of managing driving speed, imposing speed limits is the primary method. It may be defined as setting an appropriate speed for a section of road taking into account safety, mobility and environmental considerations (Organisation for Economic Cooperation and Development/European Conference of Ministers of Transport (OECD/ECMT) 2006). Various methods are used to establish speed limits. But there are no fixed guidelines for defining appropriate speed limits. Few methodologies are available for determining the optimum speed limits for road segments. Although selection of variables of roadside characteristics is not difficult, the choice of speed limits according to roadside use is not clear. These steps in setting speed limit are basically based on the knowledge and expertise of the analyst.

1.1 Speed Limit

The necessity of setting criteria and methodology or identifying appropriate speed limits to each road segment is not a new concept. This concept gets importance from many speed related researches. Study shows that excessive or inappropriate speed is the main road safety problem, often contributing to as much as one third of fatal accidents (Transportation

Research Board 1998). Clear evidence of the relationship between higher vehicle speeds and crash involvement (Stuster et al. 1998). It has been found that small speed reductions (1 or 2 km/hr) produce a significant positive effect on road-accident probability (Aarts and van Schagen 2006). There it is consensus among highway management officials to manage the travel speed for reducing crash involvement.

A variety of measures already exist for managing speed (Organisation for Economic Cooperation and Development/European Conference of Ministers of Transport (OECD/ECMT) 2006). These measures include infrastructure related measures; speed limits; signs, signals and markings; vehicle technologies; education; enforcement; and new technologies such as ITS. The primary method of managing travel speed is by imposing speed limits. Many studies examined the effect of raising or lowering speed limits and consistently shown that crash incidence and injury severity declined with the reduced speed limits. However the increase of speed limits do not always produce a significant increase in the severity indicators (Malyshkina and Mannering 2008). These different views of the problem have been strengthening the need for developing decision-support method for setting the most appropriate speed limits for each specific case. Various methods are used for setting speed limits such as (a) statutory limits; (b) empirical method ; (c) 85th percentile speed; (d) computer program as examples VLIMITS, NLIMITS, QLIMITS, USLIMITS; and (e) variable speed limits method. The factors considered for setting speed limits are driver, vehicle, traffic flow and roadway characteristics; environmental and weather conditions; and crash probability. In addition, the roadside features also influence driver behavior in selecting speed, these are roadside hazard, buildup area, intersection, road surface condition, road geometry, access point, bus stop, parking space, and speed control measure.

The effectiveness of setting speed limits depends on trade-offs among road user safety, travel efficiency, and enforcement (Department for Transport 2006). The balance between safety and level of service is a difficult concern. Moreover, speed limits that differ greatly from drivers' expectations will devalue the posted speed limit and make no one respect them; often happen in developing countries. Presently, a compromising approach is used, in which the interests and needs of all the stakeholders are considered. Computer applications mentioned above are examples; however these systems were developed based on local specifications in Australia and USA. In the other words, use of these models requires a wide range of information that is not always available in developing countries, such as actual speeds distribution of road sections and historical crash data.

1.2 Objective

In this context, it is vitally important to develop a less complicated tool that could fit the context of developing countries where data availability is always concerned. This study aims to develop an analytical model to determine the relationship between the expert choice of discrete speed limit on certain road section to different characteristics of the road and its measurable surrounding environment. It is noted that the other factors than physical road environment such as vehicle, road user, weather condition, or crash statistics are not considered. Since the speed limit choice set is naturally discrete, the model is developed based on discrete choice analysis. A case study is presented with two-lane two-way rural highways in Bangladesh. The resulting model can be used as a systematic tool to set speed limit for similar road environment in the country.

The rest of the paper is organized as follows. The next section describes the modeling framework and defines the utility expression of each speed limit alternative. The section that follows presents a case study of two highway routes in Bangladesh: data collection, variables, calibration, validation, and model implication are presented. The last section concludes the paper with some recommendation for future development.

2. DISCRETE CHOICE ANALYSIS

Discrete choice models have a long history of application in the economic, transportation, marketing, and geography fields, among other disciplines. For a given individual n , $n=1,\dots,N$ where N is the number of individual decision-makers, and an alternative i , $i=1,\dots,J_n$ where J_n is the number of alternatives in the choice set C_n of individual n , the discrete choice model can be written as follows.

$$y_{in} = \begin{cases} 1 & \text{if } U_{in} > U_{jn} \text{ , for } j = 1, \dots, J_n \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

$$U_{in} = \mathbf{X}_{in}\beta + \varepsilon_{in} \quad (2)$$

where y_{in} indicates the observed choice, and U_{in} is the utility of alternative i as perceived by individual n . \mathbf{X}_{in} is a $(1 \times K)$ vector of observed explanatory variables describing individual n and alternative i such as attributes of the alternatives, socioeconomic characteristics of the respondent, etc. β is a $(K \times 1)$ vector of coefficients and ε_{in} is a random disturbance, which is i.i.d Gumbel distributed. When the choice set composes of two alternatives, the resulting model is known as binary Logit model; while it is called a multinomial logit model (MNL) when there are more than two choices. In random utility theory it is assumed that an individual will derive utility from alternatives. The decision maker chooses the alternative with the highest utility. The term $\mathbf{X}_{in}\beta$ is known as the deterministic or systematic component of the utility function, denoted as \mathbf{V} in matrix form, its element may be express as below.

$$V_i = \beta_i + \sum_{k=1}^j \beta_{k_i} x_k \quad (3)$$

Since the choice probability depends only on the difference in utility and not its absolute level, the utility of an alternative may be set constant as a reference.

2.1 Utility of Speed Limit Choice

Since the speed limit choice is discrete, a discrete speed choice model is developed. Some studies employs discrete choice model to examine the relationship between expert decision of speed limit and the corresponding road elements (Correia and Silva 2011). This study presents a multinomial logit model of selecting among three choices of speed limit: 40, 60, and 80 kilometers per hour (kph). Because only difference of the utility level matter in choice decision, a reference alternative is defined for 80 kph speed choice. As a result, the coefficients of attributes will indicate why the maximum speed limit cannot be applied in some segments. The deterministic part of the utility expression is defined as follows.

$$V_{40kph} = \beta_{40kph} + \sum_{k=1}^{k_{40kph}} \beta_{k40kph} x_k \quad (4)$$

$$V_{60kph} = \beta_{60kph} + \sum_{k=1}^{k_{60kph}} \beta_{k60kph} x_k \quad (5)$$

$$V_{80kph} = 0 \quad (6)$$

where k is the number of significant variables in each utility function, β_{k40kph} is the independent coefficient of each variable x_k for the utility of setting speed limit of 40 km/hr, β_{k60kph} is the coefficient for the case of speed limit of 60 km/hr. β_{40kph} is the alternative specific constant (ASC) for the utility 40 km/hr, and β_{60kph} is the alternative specific constant (ASC) for the utility 60 km/hr. These ASCs are to capture the weight of other factors not translated in the attributes.

3. CASE STUDY IN BANGLADESH

Injury and death rates from road accidents in Bangladesh are among the highest in the world. The fatality rate, i.e. the number of road traffic accident fatalities per 10,000 motor vehicles, for Bangladesh is very high by international standards. The fatality index, which is deaths divided by total casualties expressed as a percentage in Bangladesh is also very high, nearly 50 and one of the highest in developing countries. This signifies probably two important characteristics viz. widespread under-reporting of less serious accidents as well as the lower level of emergency medical services available to the accident victims. It is believed that fatality index depends crucially on medical facilities. In Bangladesh with present level of medical services there is little scope to provide prompt and necessary medical attention to injured people, particularly during the initial hours of an accident.

In terms of vehicle ownership Bangladesh has one of the highest fatality rate internationally, over 100 deaths per 10,000 motor vehicles. The principal factors of accidents in Bangladesh are adverse roadway roadside environment and excessive or inappropriate speed (Bangladesh Road Transport Authority 2011). But in Motor Vehicle Ordinance 1983, only vehicle types were considered for setting speed limits (113 km/hr for light vehicle, 56 km/hr for passenger vehicle, and 48 km/hr for heavy vehicle). Most of the national highways are the undivided two-lane highways having pavement width 7.3 m with or without paved or unpaved shoulder. The mode of traffic is mixed mode. These highways pass through rural areas, small towns, and bazaar areas. As a flood prone country, many bridges and culverts are constructed.

3.1 Data and Variables

The case study is carried out along 40 km (20 km from each road) of two different national highways namely; N5 and N6. The location of the study area of N5 was from LRP (Linear Reference Point) 043 to LRP 063 (link no 33 and 34). The location of N6 was from LRP 111 to LRP 131 (link no 49). As shown in Table 1, according to high fatal accident rate and fatal accident index, these links were selected. The study sections have two lanes of width 7.3 m and remain paved shoulder on both sides of the pavement. A multinomial logit model was applied to a sample of data collected along the selected roads. These routes were divided into a number of segments of equal length of 200 m; and for each segment, a detail physical evaluation of the roadside environment was done. It was considered that 200 m would be a sufficient length for the segments as those characteristics them relatively homogeneous.

Various candidate explanatory variables that are the most important factors in determining speed limits are listed up and examined. Table 2 shows 31 variables that are considered and specified in the model. To name a few, highly commercially development area (HLA) is situated right next to the highway and the obstacles (including trees, light posts, etc) are at a close distance to the highway. Medium commercially development area (MLA) has a reserve space separating the obstacles from the roadway, so they are not so closed. Buildup area (BUILDAR) means the presence of school, college, factory, or worship place at the roadside. Depth of ditches more than 1.5 m is considered as deep ditches (DDITCHB & DDIDCHS). It is worth to note that this study limits to consider only the existence of conditions, the road geometry or maintenance condition are beyond the scope

As a choice variable, 10 experts working in the Department of Highway in Bangladesh having 10 to 30 years of experience in road design and road safety were asked to evaluate each road segment and to set a speed limit for each section; only three choice are available: 40, 60, and 80 km/hr. That is, 40 km/hr is the lowest speed for highly hazardous location and 80 km/hr is the highest speed for two-lane highways in the country; while the intermediate 60 km/hr is introduced to represent more realistic speed limit at which drivers feel safe while driving.

Table 1. Summary of the Case Study Rural Highway Routes

	Route N5	Route N6
AADT	15,016	10,912
Average width	6.96 m	7.38 m
Total Length	507 km	150 km
Fatal Accident Rate	6.1 and 6.5	20.8*
Fatality Index	1.5 and 2.7*	0.5
Length of the study segment	20 km	20 km
Location of the study segment	LRP 043 to 063 (2 links)	LRP 110 to 130 (1 link)
Sample picture		

* The highest in the country

Table 2. Variable Description

No	Variable	Descriptions	Value
1	SRB	Side roads (both sides)	Value between 0 and 2
2	SRS	Side roads (one side)	Value between 0 and 2
3	MLA	Medium commercial development area	1 if present; 0 otherwise
4	HLA	High commercial development area	1 if present; 0 otherwise
5	BUILDAR	Build up area	1 if present; 0 otherwise
6	TREE	Trees at road sides	1 if present; 0 otherwise
7	BRIDG	Presence of bridges	Value up to 200m if present; 0 otherwise
8	CULVER	Presence of culverts	Value between 0 and 2 if present; 0 otherwise
9	BUSB	Bus stop (both sides)	1 if present; 0 otherwise
10	BUSS	Bus stop (one side)	1 if present; 0 otherwise
11	GRADE	Grade at road alignment	1 if present; 0 otherwise
12	CURVE	Curvature at road alignment	1 if present; 0 otherwise
13	HUMP	Speed humps	Value between 0 and 2
14	RUMBLE	Rumble strips	1 if present; 0 otherwise
15	SDITCHB	Road side shallow ditches (both sides)	1 if present; 0 otherwise
16	SDITCHS	Road side shallow ditches (one side)	1 if present; 0 otherwise
17	DDITCHB	Road side deep ditches (both sides)	1 if present; 0 otherwise
18	DDITCHS	Road side deep ditches (one side)	1 if present; 0 otherwise
19	PATHBB	Access path to nearby buildings (both sides)	1 if present; 0 otherwise
20	PATHBS	Access path to nearby buildings (one side)	1 if present; 0 otherwise
21	INTER	Intersection	1 if present; 0 otherwise
22	PATHP	Pedestrian access path	Value between 0 and 2
23	ONPARKB	On road parking spaces (both sides)	1 if present; 0 otherwise
24	ONPARKS	On road parking spaces (one side)	1 if present; 0 otherwise
25	OFFPARKB	Off road parking spaces (both sides)	1 if present; 0 otherwise
26	OOFPARKS	Off road parking spaces (one side)	1 if present; 0 otherwise
27	FSB	Filling Station (both sides)	Value between 0 and 2
28	FSS	Filling Station (one side)	Value between 0 and 2
29	EARTSB	Inadequate earthen shoulder (both sides)	1 if present; 0 otherwise
30	EARTHS	Inadequate earthen shoulder (one side)	1 if present; 0 otherwise
31	NONML	Presence of non-motorized lane	1 if present; 0 otherwise

3.2 Results

As it is known that when variables are highly correlated (usually a cutoff 0.8 correlation in absolute value is used as a limit (Hensher 1994)), it is not possible to measure the true effect of each variable on the choice. Thus the correlations of the variables were computed. The values are consistently low. The absolute correlation value ranges from 0.00111 (HUMP vs. BRIDGE) to 0.67281 (NONML vs. HLA). None of the variables is excluded from consideration based on the correlation value. The calibration was done by employing the maximum likelihood method in the software Nlogit4 (Greene 2008). There are 1,500 statistical cases corresponding to 150 segments \times 10 experts. All 31 variables shown in Table 1 are considered and entered the model. Then variables with significance level lower than a 5% are individually removed to increase the model robustness. The final variables that remained in the final model specification are shown in Table 3 along with their estimated coefficients. The overall model fit is evaluated by the pseudo-R² of 0.32179, which falls in a considerable range (Louviere et al. 2000).

It is expected from the model that the coefficients of the variables of the utility of 40 kph have higher value than that of 60 kph. This effect is immediately noticeable in the values of the alternative specific constants. The values of the two coefficients of the ASCs are negative having a very high value for 40 km/hr. Also comparing values of coefficients for the same variables, it is shown that they are higher for the 40 km/hr.

Table 3. The Model Results

Variables	$U_{60\text{ kph}}$		$U_{40\text{ kph}}$	
	Coefficient	t-stat	Coefficient	t-stat
ASC	-1.29070623	-8.741	-2.58445014	-13.574
SRB	1.34112189	3.763	1.473243	3.984
SRS	1.69576038	7.498	2.19205079	8.83
MLA	3.1136839	3.737	4.48014065	5.367
HLA	<i>Not significant</i>		5.52119132	4.013
BUILDAR	2.11979479	6.373	2.52551552	7.108
BRIDG	0.01681031	4.233	0.02021913	4.844
BUSB	2.104683	1.964	3.13055392	2.924
CURVE	2.17629549	9.491	2.58171009	10.234
HUMP	2.3034184	2.898	5.29341065	6.915
RUMBLE	2.05102099	3.867	3.04056178	5.655
SDITCHB	1.21813057	5.314	1.36597912	4.813
SDITCHS	0.685656	2.136	<i>Not significant</i>	
DDITCHB	2.42113342	3.89	2.56231134	3.864
DDITCHS	1.2227173	3.731	1.11940969	3.071
PATHBB	1.1902271	2.471	1.53339054	3.008
PATHP	1.16814609	3.417	1.5856969	4.384
ONPARKS	<i>Not significant</i>		3.89085339	2.06
FSS	2.56006724	4.327	2.65681371	4.271

Another 5 km of each road is used to validate the model estimation, i.e., 50 segments of 200-meter length are analyzed. The speed limit with the highest probability of each segment found from the model was compared with the frequency of answers of the experts for this specific predicted speed limit. Among the 50 segments, 4 segments got very consistent judgment from all experts by setting the same speed limit as model predicted, i.e., marked 100% in the graph in Figure 1; 6 segments got 90% hit, 5 segments got 80% hit, and so on. Simply taking average of these hit percentage got 68%; making a certain confidence that the model validation is acceptable.

3.3 Presence of Certain Conditions

The coefficients in Table 3 inform that presence of single side road (SRS); buildup area (BUILDAR); curvature (CURVE); and deep ditches at both sides (DDITCHB) has positive coefficient for the utility of 60 km/hr. The presence of highly commercially developed area (HLA); and on road parking spaces (ONPARKS) has positive coefficient for 40 Km/hr. Thus these cases the lowest speed limit is reasonable. Moreover, it is noticed that presence of double side roads (SRB & SRS); bus stops (BUSB); rumble strips (RUMBLE); double

pedestrian access path (PATHP); and filling station (FSS) has positive coefficient for the both utilities (40 km/hr and 60 km/hr) but higher for the utility of 60 km/hr. Again the existence of medium commercially developed area (MLA) and speed hump (HUMP) has a positive coefficient for the both utilities but higher for 40 km/hr. In addition the bridge length more than 77 meter has positive value for 60 km/hr. Moreover the presence of deep ditches at one side (DDITCHS); shallow ditches (SDITCHB & SDITCHS); access path to nearby buildings (PATHBB); and single pedestrian access path (PATHP) has no positive coefficient for both utilities. It indicates that when these variables exhibit alone; there is no need to decrease speed. These allow us to suggest a suitable speed limit when a certain condition is present as shown in Table 4. This may provide a quick response for highway authority in selecting a speed limit for a portion of the rural highway in Bangladesh.

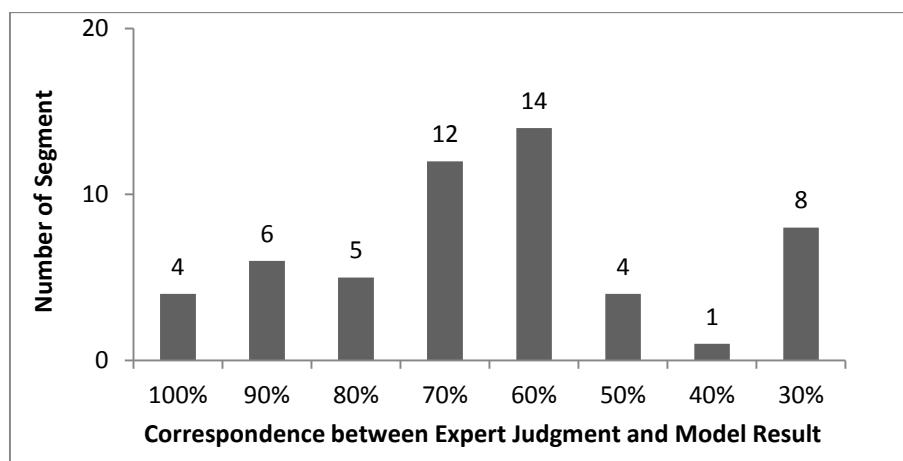


Figure 1. Correspondence between Expert Judgment and Model Result

Table 4. Suggested Speed Limit for Presence of Certain Condition

Speed Limit	Variable	Description (Presence of Certain Condition)
40 kph	HLA	Medium commercial development area
	MLA	High commercial development area
	HUMP	Speed humps
	ONPARKS	On road parking spaces (one side)
60 kph	SRS	Side roads (one side)
	SRB	Side roads (both sides)
	BUILDAR	Build up area
	CURVE	Curvature at road alignment
	DDITCHB	Road side deep ditches (both sides)
	BUSB	Bus stop (both sides)
	RUMBLE	Rumble strips
	PATHP(Double)	Pedestrian access path
	FSS	Filling Station
80 kph	BRIDG(77-200 m)	Presence of bridges of length 77-200 m
	BRIDG<77m	Presence of bridges of length less than 77 m
	DDITCHS	Road side deep ditches (one sides)
	SDITCHB	Road side shallow ditches (both sides)
	SDITCHS	Road side shallow ditches (one side)
	PATHP(Single)	Pedestrian access path
	PATHBB	Access path to nearby buildings (both sides)

3.4 Model Application

Using the calibrated model, the probabilities of the choices of speed limits of each 200 m road segment could be determined. The choice with highest probability is the preferred speed limit of that segment. But practically it is not justified for setting speed limits for 200 m length. That is, it is recommended to set a speed limit for at least 600 m length (Department for Transport 2006). Thus a suitable length of nearly same roadside characteristics was identified for setting speed limit. The average probability for the choices of the segments of that length was determined. The choice with highest average probability (Ben-Akiva and Lerman 1985) is the speed limit of that road length. As a result, the speed limits to be posted for each route are illustrated in Figure 2.

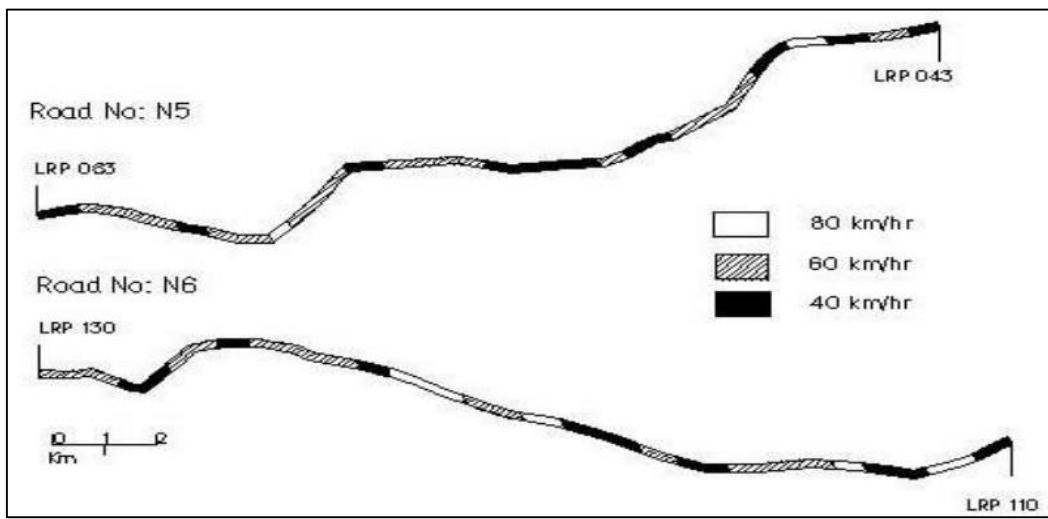


Figure 2. Speed Limit Setting along the Case Study Roads

4. CONCLUDING REMARKS

Within the MNL model framework it is judged for selecting practical speed limits on segmental basis without considering speed related traffic and geometric characteristics along rural highways. This method allows a cautious and expert-opinion-based choice of legal speed limits, balancing safety and people's expectations, improving driving and risk perception related with the different road environments. From the case study, the result shows that only 13.5% of studied road length is appropriate for setting highest speed limit (80 km/hr); whereas 49.5% is suitable for 60 km/hr and 37% is 40 km/hr. It is also revealed that 40 km/hr speed limit is appropriate for commercially development area such as bazaar area. At curvature, side roads, access path, educational institutions, industry, and deep ditches at roadside, the speed must be reduced, i.e., the suitable speed limit is 60 km/hr. Furthermore, when these attributes present with the other factors, the speed limit should be set at less than 60 km/hr.

This paper has shown that it is not possible to attain the highest speed limit (80 km/hr) at most part of route. This is the reason for the presence of a lot of obstacles along the roadsides. It is believed that there must be many similar cases on the other highways in Bangladesh, as well as in the other developing countries. Finally, it is recommended for the future study to recognize the other roadside variables as well as road user or drivers perception with respect to safety and convenience viewpoints. In terms of methodological development, the MNL model provide sufficient information for the analysis of discrete choices. However when the

choices are ordered, i.e., ordinal variable, the analyst may need more information about how the choice is made with respect to the increment in the dependent variable in an ordered way. The ordered logit model framework would fit this and is again left for the future works. In addition, this study is based on a result of interviewing 10 experts; a larger number would be more preferable in the future.

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