TP 14227E

EVALUATION OF ADVANCED PEDESTRIAN DETECTION DEVICES (APDDs) FOR SCHOOL BUSES – PHASE 1

Prepared for the

TRANSPORTATION DEVELOPMENT CENTRE
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By

L-P TARDIF & ASSOCIATES INC.

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16. Abstract

This project focussed on the issue of pedestrian safety devices for school buses. A previous phase provided a better understanding of the risks children are exposed to when getting on or off a school bus, and resulted in the development of an evaluation tool to determine the advantages of advanced pedestrian detection systems (APDS) for school buses.

The purpose of this project was to review and validate the assessment criteria for APDS use around school buses defined in the previous phase, and to develop testing protocols that can be used at a later date when specific devices have been chosen for testing.

The main tools validated and/or developed for this project were:

- a fault tree to identify and quantify the risk that a child will be struck by the school bus;
- broad categories of criteria comprising risk factors of the same type, weighted proportionally to their value in preventing an accident;
- a theoretical evaluation grid to quantify the performance of detection devices.

Laboratory, closed-track and road testing procedures were also developed. The proposed laboratory testing procedure emphasized the difficulty of devising universal tests for all types of safety devices. The report also contains a user's guide to facilitate use of the evaluation grid.

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16. Résumé

Le présent projet s'intéresse à la problématique liée aux dispositifs de sécurité pour piétons autour d'autobus scolaires. Une phase précédente avait permis la compréhension des risques encourus par les enfants autour d'un autobus scolaire lors de l'embarquement et du débarquement, et l'élaboration d'une grille d'évaluation permettant de déterminer sommairement les avantages des dispositifs avancés de détection de piétons (DADP) autour d'un autobus scolaire.

Ce projet a pour but de revoir et de valider les critères d'évaluation de DADP autour d'autobus scolaires définis lors de la phase précédente, et de développer des procédures d'essais qui pourront être utilisées ultérieurement lorsque des dispositifs spécifiques auront été sélectionnés à des fins d'essais.

Les principaux outils validés et/ou développés lors de ce projet se résument ainsi :

- Un arbre de défaillances permettant d'identifier et de mesurer le risque qu'un enfant se fasse frapper par l'autobus scolaire;
- De grandes catégories de critères regroupant les facteurs de risque de même type et ayant une pondération proportionnelle à leur capacité à prévenir un accident;
- Une grille d'évaluation théorique permettant de quantifier la performance des dispositifs de détection.

Des procédures pour des essais en laboratoire, en circuit fermé et sur route ont aussi été développées. La procédure proposée d'essais en laboratoire souligne la difficulté de définir des essais universels pour tous les types de dispositifs de sécurité. Le rapport contient aussi un guide de l'utilisateur qui a pour but de faciliter l'utilisation de la grille d'évaluation.

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SUMMARY

Transport Canada initiated a two-phase research project to identify and assess advanced pedestrian detection devices (APDDs) that could help school bus drivers to detect the presence of children around their buses and to protect them.

The objectives of this phase were to review and amend, if necessary, the assessment criteria developed in a previous project, to set performance thresholds, and to develop a testing procedure and methodology.

Earlier work provided a better understanding of the risks to children in the vicinity of a school bus when getting on or off and resulted in the development of an evaluation grid for summary assessment of the ability of a safety device to detect and protect children outside school buses. This work led to the publication of a report entitled *Critères d'évaluation de dispositifs d'aide à la détection d'enfants aux arrêts d'autobus scolaires,* TP 13221F, which contains three key elements to assist in an empirical assessment of pedestrian detection devices:

- a fault tree to identify and quantify the risk that a child will be struck by a school bus;
- broad categories of criteria comprising risk factors of the same type, weighted proportionally to their value in preventing an accident;
- a theoretical evaluation grid to quantify the performance of detection devices.

These three key elements were reviewed in order to validate their relevance and determine whether any changes to them were required. The results are as follows:

- Fault tree:
  Few changes were made to the fault tree, which graphically represents the combination and probability of adverse events that may lead to an accident in which a bus strikes a child, also called the top event. This tree is made up of successive levels of events such that each is produced by the events at the next level down by means of logical operators (gates). These events include, in particular, human errors, equipment breakdown, equipment failures, worsening weather conditions, etc. The fault tree helps to clearly define the causal links that lead to the top event. Calculation of the probability that a given tree event will cause an event at the level immediately above is based on three data sources: statistical analysis, analysis of the driver's duties, and drivers' opinions, canvassed at a focus group meeting. These probabilities led to the establishment of criteria weighted by importance and relationship to the top event.

- Broad categories of criteria and weighting:
  Some changes were made to the broad categories of criteria identified and the weights assigned to them. The previous report had grouped the criteria into five categories: safety, ergonomics, technical considerations, economy and other factors, and environment. The technical and safety categories were combined and the

environment category was combined with "economy and other factors". The number of categories has therefore gone from five to three. The most significant change is probably the one made because of the importance of ergonomic criteria, in the eyes of technical experts, in selecting a pedestrian safety device. Thus, the weight assigned to the ergonomics category was raised from 25% to 40%. The weighting for this category was increased because of the negative impact of a safety device on the driver's duties, particularly in the event of a false alarm. The "safety" and "ergonomics" criteria now account for 90% of the weight, the last 10% being assigned to the "cost-effectiveness and other factors" category.

- Evaluation grid:
  A number of changes were made to the evaluation grid. The "safety" category was revised to include other criteria relating to the detection of children in the danger zones around the school bus or when devices are triggered. Particular attention was paid to false alarms and devices' nuisance potential. The weight assigned to the "cost-effectiveness" criteria was altered to better reflect the current situation of school bus operators and manufacturers. The evaluation grid content was reviewed by a group of experts and the functionality of the grid, which had first been developed as an Excel file, was verified using a mechanical prevention device: the crossing control arm.

Laboratory, closed-track and road testing procedures have been developed. The proposed laboratory testing procedure takes into account the difficulty of devising universal test procedure for all types of safety devices. To mitigate this difficulty, two procedures are suggested: one for detection devices and the other for mechanical devices. The report also contains recommendations for closed-track and road testing. The closed-track testing approach was validated during preliminary experimental trials with a commercially available detection device.

The report also contains a user's manual for those who would like to assess the performance of a safety device. Moreover, it suggests a strategy for a later phase that would involve use of the evaluation grid and testing of detection devices.

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1 Introduction

For a long time, safe transportation of schoolchildren has been a priority for Transport Canada and those involved in school transportation. Unfortunately, even though the number of accidents involving children in the vicinity of school buses is very small, such accidents do still occur. Each year, on average, nearly 4 children die in such accidents and more than 60 are injured.

Accordingly, Transport Canada has initiated a research program that seeks, among other things, to review technologies and procedures that could reduce and potentially eliminate such accidents.

This study aims to identify and assess advanced pedestrian detection devices (APDDs) that could help school bus drivers to detect the presence of children in the vicinity of their buses and to protect them.

In 1996 Transport Canada formed a task force on school bus safety that has, to date, looked at two issues related to school buses' stopping to let schoolchildren on or off. These issues are the effectiveness of advance stop signalling systems (flashing amber or red lights, or hazard warning lights), and onboard devices to detect and protect pedestrians moving around school buses.

This project is the task force's third study on safety devices for pedestrians in the vicinity of school buses. The first study sought to understand the risks to children in the vicinity of a school bus when getting on or off and resulted in the development of an evaluation grid to provide a rough estimate of the advantages of safety devices. This project led to the publication of the report entitled *Critères d'évaluation de dispositifs d'aide à la détection d'enfants aux arrêts d'autobus scolaires,* TP 13221F [1].

The second study was a survey of Canadian and American education authorities and transportation providers to identify the types of devices available and used on school buses. It also provided an opportunity to benefit from the operators' experience with these devices and solicit their appraisal of them. A report on this topic will be published soon.

The analytical grid developed in the first study enabled evaluation criteria to be empirically identified and their relative significance to be determined and weighted. These criteria allow for an evaluation of the capacity of a device to:

1. eliminate or reduce accident risk (safety aspect);
2. measure its impact on the driver's duties and the quality of the interface between device and child (ergonomic aspect);
3. meet technical requirements, such as performance, reliability, flexibility and compliance with standards and regulations (technical aspect);
4. meet economic requirements, in particular the total cost of the device, its useful life and its state of development (economic aspect);

5. function in various environments, taking into consideration the noise produced, visual impact and climatic variations (environmental aspect).

The grid and these criteria are the starting point of the current study. A revised and adjusted grid, coupled with performance requirements, will allow for the evaluation of APDDs and the elimination of those that are neither effective nor worthwhile, and may even be dangerous, without having to conduct more costly laboratory or field tests. The tool will also be used for a more thorough evaluation of the devices that pass the first phase of the evaluation.

This first evaluation will help identify the most promising APDDs. Some will then undergo controlled road and laboratory tests. These tests will be an opportunity to assess the capacity of an APDD to reduce the number of accidents where children are killed by their school bus. The tests will also provide regulators with data to help determine whether these devices should be required on school buses.

The purpose of this report is to review and validate the selection criteria established by the first study and to develop testing procedures to be used once devices have been selected for testing at a later stage.

2 Methodology

The methodology used was as follows:

- Creation of a technical advisory committee

- Review and validation of the technical content of Groupe Cartier's report [1], specifically:
  - the fault tree
  - risk factors and their weighting
  - performance thresholds
  - the evaluation grid for detection devices

- Development of testing procedures:
  - in the laboratory
  - on a closed track
  - on the road

- Validation of assessment criteria, i.e., evaluation of a detection mechanism and evaluation of the closed-track testing procedure

- Report production

3 Review of previous work

The report entitled *Critères d'évaluation de dispositifs d'aide à la détection d'enfants aux arrêts d'autobus scolaires,* TP 13221F, is a study of the development of evaluation criteria for school bus transportation safety devices. Its purpose was to give school transportation decision makers a tool to enable them to evaluate the range of safety devices available on the market. The study also included the following:

- A description of the context and issue of school transportation safety in Quebec (Quebec was the reference framework for the study);
- A review of the technologies and devices currently in use or that may be used in the field of school transportation;
- An ergonomic study of the school bus driver's duties;
- An analysis of the risk of accidents when stopping and starting and when letting passengers on and off;
- Following these analyses, the identification, definition, categorization and weighting of the criteria involved in analysing the devices;
- Formulation of recommendations for the next phase.

Regarding the central issue, Groupe Cartier's report mainly looked at the device's ability to detect children as they get on and off the bus.

According to this report, *the identification and analysis of the requirements of the bus driver's duties, as well as the types, circumstances and causal links of the accidents/incidents associated with the operations of stopping, starting and loading or unloading schoolchildren, will provide a comprehensive picture of the various influences on school transportation safety and so make it possible to decide on the essential criteria for evaluation of these devices.* [1—translation from original french]

The analysis of the driver's duties in this study considered a number of interacting elements. This analysis was carried out following a literature review and field observation sessions. It confirmed that assessment criteria ought to take into account a device's ability to adapt to drivers' different anthropometric, physical, sensory and mental characteristics, taking into account such factors as muscular strength, visual acuity, hearing acuity and learning ability.

The study of drivers' duties showed that external variables, such as the schoolchildren's characteristics, their numbers, the type of road, stopping characteristics, etc., had a big impact on safety. It also enabled all variables that could influence the physical, sensory or mental demands on the driver to be identified and listed by activity.

To understand the risks to children, two main data sources were used: accident statistics and records, and observation of the driver's duties. Using these data, we were able to identify the main risk factors for school transportation. This information led to the development of a fault tree presenting all adverse events that may lead to an accident, as well as the probability of occurrence of each of these adverse events.

This method is used to determine the various possible combinations of events or causes that bring about an adverse event. These combinations of events can then be graphically represented in a tree structure. An illustration of this fault tree is presented in Appendix A.

The fault tree is based on a thorough search for all possible proximate causes of adverse events. This search was done on the basis of three information sources: accident statistics, field observation and consultations with a focus group of school bus drivers.

The causes were then combined by means of logical links to describe the relationship between the various events. The adverse event is found at the top of the tree and corresponds to the event we wish to avoid. For each cause or event, a percentage was calculated representing the probability that this event would lead to the occurrence of the next higher level event, and thence to the top event.

The tree was built using the two main Boolean operators: "AND" and "OR". "AND" means that the events must occur simultaneously for the higher level event to occur, while the "OR" symbol is used when only one event must occur for the higher level event to occur.

Groupe Cartier's study illustrated all possible causes of accidents involving a school bus collision with a child, where the top event "child is struck by bus" occurs.

According to the fault tree, there are two necessary conditions for the school bus to strike a child: either the child moves into the path of the bus, or the bus moves toward the child. If neither condition holds, there cannot be an accident.

Using the fault tree to make the link between events, as well as accident statistics and consultations and observations with drivers, Groupe Cartier's report then summarizes the probability that events will occur that will lead to an accident in which the school bus strikes a child. Using this information, we can rank adverse events and risk factors by relative seriousness, thus helping to define and weight the criteria relating to the device's ability to avert them.

Five types of criteria emerged from this analysis:

- Safety: elimination of risk;
- Ergonomics: impact on the driver's duties and the device/child interface;
- Economy: investment required;
- Technology: system performance, reliability and flexibility;
- Environment: integration of the system into the physical environment.

The "safety" aspect was considered the most important since, according to the study, it is the fundamental reason for the existence of safety devices in the school transportation sector. The criteria linked to the safety aspect are directly inspired by the adverse events that compose the fault tree.

Two main objectives were pursued under this aspect:

- To determine how the device reduces the risk that a bus will strike a child;
- To determine the device's range of action (zones covered) and protection or detection time.

The "ergonomic" aspect is concerned with the device's impact on driver and children. The ergonomic criteria emerged primarily from the knowledge acquired through the functional analysis conducted during Groupe Cartier's project. Specifically, the "ergonomic" aspect includes:

- the impact on the driver's duties;
- the quality of the device/child interface.

The "economy" aspect is based on:

- total device cost;
- service life;
- stage of development.

The "technology" aspect primarily affects safety devices' performance, reliability and efficiency. The results are based on previous studies of school bus devices.

The "environment" aspect was concerned with noise or visual pollution. Installation of a device should not produce any objectionable noise or visual effects.

The study then weighted the criteria in each of these categories. Table 1 shows the weighting.

Table 1. Categories of assessment criteria and their weighting – 1998 study

CATEGORIES OF CRITERIA	Weighting
SAFETY	**50%**
Means (one or the other)	
• Preventing a child's presence	100
• Detecting a child's presence	95
• Helping a driver see the child	70
• Helping a driver see the signals	20
Area covered	/100
• Location of regions covered	%
• Proportion of regions covered	%
• Time of action	%
ERGONOMICS	**25%**
• Impact on the driver's duties	70
• Quality of the device/child interface	30
TECHNICAL	**15%**
• Compliance with standards and regulations	«Go/No go»
• Device performance	60
• Device reliability	30
• Device flexibility	10
ECONOMICS	**8%**
• Total cost of device	40
• Useful lifespan of device	40
• Stage of development	20
ENVIRONMENT	**2%**
• Noise produced	70
• Visual impact	30

Source: Groupe Cartier, in co-operation with Consultants Génicom, *Critères d'évaluation de dispositifs d'aide à la détection d'enfants aux arrêts d'autobus scolaires*, TP 13221F, 1998.

With the suggested weights, the "safety" and "ergonomics" criteria represented 75% of the weighting. This relative weighting was selected because of the importance of these two categories. In the case of safety, emphasis is laid on the device's ability to help the driver detect the presence of children anywhere around the vehicle, and to give the driver a clear warning. In the “ergonomics” category, the important points were that the device not add to the driver’s duties, that it be safe and that it not cause the child to adopt risky behaviour.

As the weights specified in the report were largely arbitrary, as indicated in the Groupe Cartier study, these weights need to be reviewed and validated.

One of the objectives of the current project is indeed to review and validate the procedure and results of Groupe Cartier’s 1998 study in order to equip Transport Canada with a decision-making tool that will enable the Department to choose one or more safety devices for subsequent testing.

4 Validation of tools and user's manual

As mentioned in Chapter 2, the tools listed need to be validated. The first tool reviewed was the fault tree.

4.1 Fault tree

The original fault tree is presented in Appendix A. Appendix B contains all tree events in a more readable list.

A review of the events by the authors and the technical advisory committee showed that the fault tree is a very complete tool and can be improved, at this stage, by only two minor additions. These additions are not new events; rather, they add details to the content of two existing ones. The changes, which are shown in boldface, are as follows:

No. 20: Child wants to meet someone or get something, ***stops suddenly to pick something up or returns to pick something up***

Children may sometimes retrace their steps, either to get something they've forgotten on the bus, or just to pick something up that they've dropped. In these cases the driver may lose sight of the child for a fraction of a second or may simply assume that the child has continued on, never considering that the child may have quickly turned back.

62: Mirrors reflect a distorted image ***or are incorrectly adjusted***

A badly adjusted mirror can increase the risk of accident by reducing the driver's range of vision in the danger zones around the school bus.

These points have been added to the fault tree in Appendix A and are included in the list of tree events in Appendix B.

4.2 Probability of adverse events

The 1998 report also computed the probability of occurrence, as a percentage, of events that may lead to an accident in which the school bus strikes a child. This probability was computed on the basis of accident statistics, field observations and consultations with a focus group including drivers (sample of 14 drivers). The relative probability that an event related by a logical operator "AND" or "OR" would be the cause of an event at the next level up was also evaluated. This procedure was followed for all fault tree events in order to arrive at a percentage representing the role of each tree event in producing the top event: child is struck by bus.

The probability table for adverse events is reproduced in Appendix C. This table shows the drivers' perception of risks, the percentage as calculated according to statistics of accidents involving school buses, the synthesis of these two analyses, and the percentage of the role of each of the events leading to the tree's top event, namely a child being struck by a bus.

No changes were made to these probabilities. After being analysed by the authors and the technical advisory committee, these probabilities appeared to be representative of the role of each event in an accident scenario.

4.3 Assessment criteria and their weighting

As discussed in the review of previous work (Chapter 3), Groupe Cartier's report suggested five categories of evaluation criteria, with a weighting for each of the categories and each of the criteria. Following a review of these criteria, it is suggested that the categories and the weighting be changed as shown in Table 2.

Table 2. Revised categories of a assessment criteria and their weighting

CATEGORIES OF CRITERIA	Weighting
SAFETY	**50%**
Type of action (any one)	
• Prevention of child's presence	100
• Detection of child's presence	95
• Helping driver see child	70
Coverage	/100
• Front	72
• Sides	24
• Rear	4
Device's protection or detection time	/100
• Beginning of protection or detection	60
• End of protection or detection	40
ERGONOMICS	**40%**
• Impact on driver's duties	50
• Quality of device – child interface	40
• Other ergonomic factors	10

CATEGORIES OF CRITERIA	Weighting
COST EFFECTIVENESS AND OTHER FACTORS	**10%**
• Total cost of device • Reliability cycle • Guarantee • Other factors	40 40 20 10

When this approach is compared to that of Groupe Cartier, we note that the "safety" category keeps its 50% weighting while the weight assigned to the "ergonomics" category increases to 40% from 25%. The "cost effectiveness and other factors" category is assigned a weight of 10%. This category actually combines the "economy" and "environment" categories, which are separate entries on the old evaluation grid. It should be noted as well that a number of elements within each category have changed. The changes are as follows:

The modified evaluation grid comprises three broad categories of criteria:

- **Safety**
- **Ergonomics**
- **Cost effectiveness and other factors**

"Safety" category

It is recommended that a weighting of 50% be kept for this category, supporting Groupe Cartier's thesis that safety criteria were the most important aspect of improving pedestrian safety in the vicinity of school buses.

It is also suggested that the technical elements, previously forming their own category, now be brought into the "safety" category, as a number of these elements may be measured and linked directly to the activation of safety devices. These technical criteria may be evaluated in terms of the way or means available to the device of reducing the risk that a bus will strike a child. They may also serve to define the device's coverage.

The coverage is evaluated in terms of the device's coverage of the danger zones. These zones are defined in Groupe Cartier's report, and are illustrated in Figure 1.

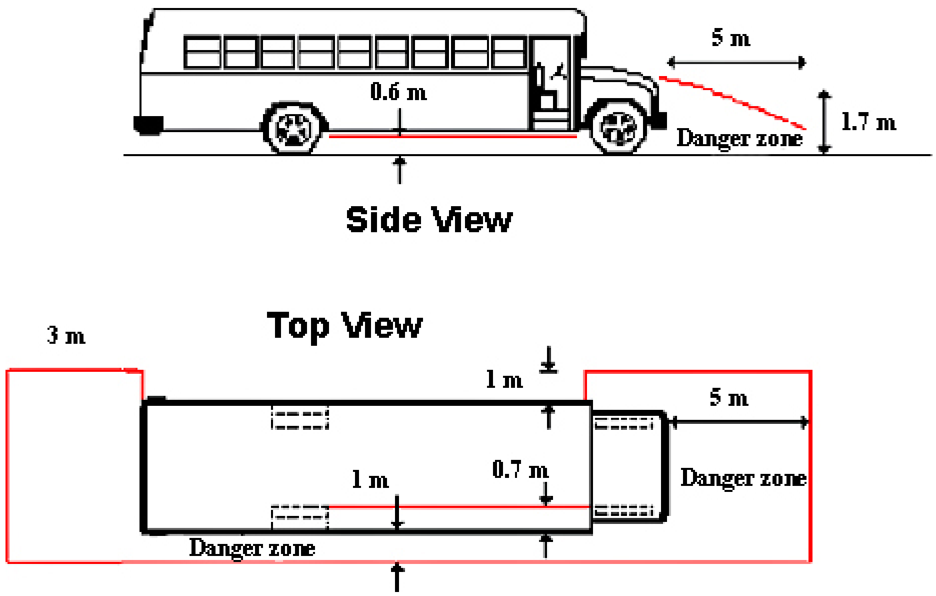


Figure 1. Danger zones around the school bus

The danger zones are in front of, behind and beside the bus. The weight for each zone in the assessment criteria reflects an analysis of the accidents involving children struck by school buses included in Groupe Cartier's report. According to this analysis, in most cases the child is struck by the front of the bus (weight of 72%), but the child is often killed by its rear wheel. Hence the emphasis, in the weighting, on the space beside and beneath the bus (24%). The incidence of accidents involving the rear of the bus is less, and its weighting (4%) reflects this.

Another important addition under the "safety" category is the greater emphasis on the device's protection or detection time. The evaluation grid now contains assessment criteria on the activation time of the protection or detection system. The focus is no longer just on the bus's movement or stopping, but on the activation sequence.

Other elements were added to the "safety" category for information. These are criteria that, though measurable, are not quantified in the evaluation grid. Criteria such as a device's recording memory, its response time, its sound and radiation emissions, component self-checking and an external sound signal are all elements not identified either in the fault tree or in the analysis of the driver's duties, but which do represent technical characteristics of some devices. Accordingly, these criteria are part of the evaluation grid but are not recorded.

"Ergonomics" category

It is suggested that the weight assigned to the "ergonomics" category be increased from 25 to 40%. This aspect is deemed as important as the criteria in the "safety" category". For example, the false alarms a device produces may have a negative effect on the behaviour of the driver, who may ignore or deactivate the device if it malfunctions.

Use of a safety device will, in some cases, add to the driver's already numerous duties. This must therefore be reflected in the weights assigned to these criteria, for a device that complicates the driver's job must be penalized for that in the comprehensive assessment. The technical advisory committee deemed this aspect very important.

The analysis of the driver's duties conducted by Groupe Cartier was considered to be complete, and no new elements were added except as regards false alarms triggered by detection devices and other nuisances that could annoy the driver.

The "safety" and "ergonomics" categories by themselves now represent 90% of the entire weight.

"Cost effectiveness and other factors" category

Even though the devices' affordability is not part of an evaluation that may one day lead to regulations on this subject, the economic factor is nonetheless one that cannot be neglected, for decision-makers must always consider the cost of purchase and maintenance of a device before making their choice. The weighting of this factor was reduced to 10%. In addition, other criteria, such as visual and sound effects, were included in this category. It should be noted that the fault tree has never contained any economic factors.

Without wishing to minimize the importance of this category, the selected criteria are based on the limited and sometimes subjective experience of the members of the technical advisory committee. Changes could be made to this category at a later date once experience has been acquired through the use and evaluation of devices.

4.4 Evaluation grid

The three categories of criteria described in Section 4.3 are the essential elements of the revised evaluation grid. Under each of them there are new criteria and sub-criteria that identify and define the elements relevant to the "safety", "ergonomics", and "cost effectiveness and other factors" categories. The revised evaluation grid is presented in Appendix D.

"Safety" aspect

This category addresses the following elements:

- The device's ability to detect and prevent a child's presence in the danger zones, as well as its ability to warn the driver thereof and enable him or her to differentiate between a child and any other object, such as an animal or a schoolbag;
- The area of coverage of each device, which takes into account its ability to cover the whole area of the danger zones defined in Figure 1. The assigned weight is proportional to the percentage of the zones covered;

- The protection or detection time (onset and duration) of each device. In this case, the emphasis is on those devices that turn on or off when the bus is moving. It should be noted that the weighting is higher if the device works when the bus is about to stop or pull away from the loading or unloading zone. In these situations, the bus is moving slowly and covering relatively short distances. The technical advisory committee considers that a system that does not work when the school bus is in motion (immediately before and after it stops) is a less effective system.

"Ergonomics" aspect

This category addresses the following elements:

- The device's potential detrimental effect on the driver's duties;
- The device's sensory, tactile and visual impact, the dexterity and knowledge required, and the level of effort required of the driver;
- The quality of the device-child interface, to minimize risk or risky behaviours;
- Ergonomic aspects other than those relating to the driver's duties or the device/child interface, such as false alarms or unwanted, annoying noise that may be produced by the device.

"Cost effectiveness and other factors" aspect

This category addresses three elements:

- The cost of acquisition, installation and maintenance of the device;
- The reliability of the device;
- Any excessive noise produced by the device outside the bus, which could disturb people not concerned with its operation.

The revised evaluation grid is in Excel format. This computerized version enables the theoretical performance of a safety device to be evaluated and enters additions automatically on the basis of evaluations.

4.5 Assessment tools user's manual

The assessment tools included in this report were designed to help researchers, school boards, government representatives and school transportation providers to identify and measure a given safety device's capacity to reduce or eliminate the risk that a child will be struck by a school bus. The grid was designed to assess an almost infinite variety of devices, ranging from gates and sophisticated mirrors to radar detectors and cameras. To properly understand the contents of the evaluation grid and how it should be applied, it is important for the evaluator or user to have functional knowledge of the elements considered when it was being developed.

It is important, therefore, before using the evaluation grid, to study the contents of the fault tree and understand the role of each of the factors and how it relates to the top event, which is the accident we want to avoid.

If one knows how the risk factors relate to the driver's duties, it is easier to understand the revised evaluation grid and measure the importance assigned to the "safety" and "ergonomics" elements in terms of weighting.

In the evaluation grid, each of the criteria is formulated as a question with multiple-choice answers. These answers are then rated to come up with an overall mark on each criterion in each of the categories and, finally, on the whole set of criteria for a given device.

The evaluation grid is a tool that combines the fault tree items with other qualitative criteria that were added to it as described in section 4.4. So, if we review the operating principles of the grid, it has three main categories:

1. Safety, weighted 50%;
2. Ergonomics, weighted 40%;
3. Cost effectiveness and other factors, weighted 10%.

The total of these three categories gives a possible final overall mark of 100% for each device evaluated.

Each category is further divided into criteria and sub-criteria. As an example, the "safety" category comprises three criteria:

1. Impact (type of action) of the safety device, weighted 100%;
2. Coverage (portion of the danger zone covered), weighted 100%;
3. Device's protection or detection time, weighted 100%.

These three criteria are based on the assumption that a given device will usually have only one type of action: the device prevents the child from falling under the wheels of the bus, or it keeps the child out of the danger zone, or it detects the child's presence and alerts the driver, or it simply helps to detect a child's presence. Only in very exceptional cases will a device act in more than one way.

The overall mark for this category is therefore: (100*100*100/100*100). The total for this "safety" category is then adjusted to 50% of the overall evaluation, i.e., 100*50/100 = 50%.

The user will then note that each criterion also comprises sub-criteria. Under the "safety" category, for example, criterion 1 "Impact of the safety device" includes three assessment sub-criteria:

1.1 The device prevents the child from falling under the wheels of the bus, weighted 100%;
1.2 The device prevents the child from being in the danger zones, weighted 100%;
1.3 The device detects or assists the driver in detecting the presence of a child in the danger zones, weighted 95%.

Because the ultimate goal is always to eliminate the event(s) leading to an accident, i.e., to prevent children from falling under the wheels of the bus and/or to keep them out of the danger zones, a device that prevents either scenario or both is assigned a 100% score.

Where a device only helps the driver to detect a child's presence (criterion 1.3), the evaluator shall answer another set of questions. If the device does not meet criteria 1.1. and 1.2, and only helps detect a child's presence but does nothing to prevent a potential accident, then a mark of 95% is assigned. Sub-criteria under 1.3 further define the detection aspect. The content and weighting of these sub-criteria are taken from the fault tree (events 11 and 13) or observation of school bus drivers. Some sub-criteria are evaluated differently and are assigned weights that may vary from 15% to 35 or 45%. The sum of these weights comes to 95%.

A similar logic applies to the sub-criteria under 1.3.2, which read as follows:

1.3.2.1 The device amplifies the image of a child in the danger zones (the score assigned to this sub-criterion is 15%; the event to be prevented is reduced visibility, event 52 in the fault tree);
1.3.2.2 The device improves the driver's vision in the danger zones (the score assigned to this sub-criterion is 70%; the event to be prevented is the driver not seeing the child, event 13 in the fault tree);
1.3.2.3 The device can differential between a child and an object (the score associated with this sub-criterion is 15%).

The total score for sub-criterion 1.3.2 is 100%. To obtain the score, we take the sum of the three sub-criteria, i.e., 15+70+15= 100%. This total is then prorated to the total percentage for sub-criterion 1.3.2, i.e., 70%.

Sub-criterion 1.3.2.2 is assigned an overall mark of 70% and itself has four sub-criteria:

1.3.2.2.1 Does the device improve contrast? (the score assigned to this sub-criterion is 8%; the events to be prevented are too high or too low contrast, events 59 and 60 in the fault tree);
1.3.2.2.2 Does the device make it easier to see clearly? (the score assigned to this sub-criterion is 7% and the events to be prevented are the effects of inclement weather, a mirror that reflects a distorted image, or a dirty window and/or mirror, events 61, 62 and 63 in the fault tree);
1.3.2.2.3 Does the device help the driver pay close attention to the area where the child is (the score assigned to this sub-criterion is 30%, and the event to be

prevented is the driver's not looking in the area where the child is, events 53 and 54 in the fault tree);

1.3.2.2.4 Does the device help the driver notice signals from witnesses at the scene? (the score assigned to this sub-criterion is 40%, and the event to be prevented is a signal that is not perceived by, or not clear to, the driver, events 35 and 36 in the fault tree).

The total score for these sub-criteria is therefore: 8+7+30+40 = 85% of a possible total of 70%. To obtain the final weighting, the following calculation must be done: 8*70/85 or 7*70/85 or 30*70/85 or 40*70/85.

Criteria 4 to 8 under the "safety" category (see Appendix D) are included only for information, with the goal of making the completest possible evaluation; they do not affect the score.

The "ergonomics" category is made up of three criteria, each with its own weight:

1. Impact on driver's job, weighted 50%;
2. Device-child interface, weighted 40%;
3. Other ergonomic factors, weighted 10%.

The total score is therefore 50+40+10 = 100%, which must then be prorated to a base weight of 40%, the percentage weight assigned to the "ergonomics" category. The overall score is calculated as follows: 50*40/100 or 40*40/100 or 10*40/100.

Few criteria or sub-criteria included in this category are related to the fault tree, and they are sometimes qualitative in nature. For example, the choices under a sub-criterion are often summarized as follows:

- Never – 100%
- Seldom – 75%
- Usually – 50%
- Very often – 25%
- Always – 0%

The same is true of the "cost effectiveness and other factors" category, which represents 10% of the total mark. As in the case of the "ergonomics" category, the greater the impact of the criterion, the lower the percentage will be and vice versa. Consequently, if the "cost effectiveness" category has only a small role in device evaluation, the percentage a device may have in this category will be high.

The calculations are done automatically in the Excel sheet. The score can therefore be seen to change as the user fills in the evaluation grid, so that the breakdown of the score can be more readily understood.

Thus, to perform an evaluation of a safety device, a user need only place an “x” in the appropriate fields of the grid in the column marked with an “x”. Users will rely on the information provided by the manufacturer or operator, their own experience, or any other source of pertinent information. Each question in the grid is explicit and gives a choice of answers. Only one answer should be given to each question. The sum of the answers chosen will result in a final score out of 100%.

One of the main difficulties users may encounter is the qualitative aspect of certain questions. As previously mentioned, a number of questions relating to the “ergonomics” category allow for subjective answers that leave the user a good deal of latitude. Users should answer to the best of their knowledge, but only subsequent road or laboratory testing can really confirm and validate the answers.

As an example, question number 2, which concerns the proportion of the danger zones covered by the device, is very difficult to evaluate without advance trials. Testing will confirm or invalidate the choices made during the initial evaluation.

Once the evaluation grid is filled in, users may use the general table of criteria categories in Table 2 as a summary and insert the results obtained using the evaluation grid.

Users may then decide to submit the devices that score highest for laboratory, closed-track and road testing.

5 Selection strategy for detection devices that may be tested

In the context of a national committee on the identification and review of safety devices, we suggest that the approach to device selection for purposes of testing include the following:

- Send a letter of interest to manufacturers and distributors of detection devices inviting them to provide technical information on their technologies;
- Establish a selection committee;
- Provide an electronic copy (Excel format) of the evaluation grid to manufacturers and distributors, and ask them to fill it in and send it to the selection committee;
- Evaluate devices using the evaluation grid (selection committee);
- Invite manufacturers or distributors to come and present the merits of their devices to the evaluation committee. (This presentation will enable the two parties to discuss devices' ability to meet the requirements of the evaluation grid.);
- Re-evaluate the devices following the manufacturer's or distributor's presentation;
- Select two or three devices that may potentially undergo laboratory, closed-track and road testing;
- Check whether a special permit or authorization is needed for the road tests by the province or territory where the testing will be held.

6 Testing program for selected devices

6.1 General test characteristics

One of the project objectives was to develop a methodology for laboratory, closed-track and road testing of safety devices already evaluated by means of the analytical grid.

Two testing methods were developed for technical evaluation of the devices chosen. This evaluation is in two stages:

- Laboratory tests
- Field tests
- Closed-track tests
- Road tests (school bus route)

It is important to remember that detection devices must allow the driver to detect a situation that is potentially dangerous to children in the immediate vicinity of the school bus. To provide a better explanation of these danger zones, Figure 2 shows a school bus driver's field of vision.

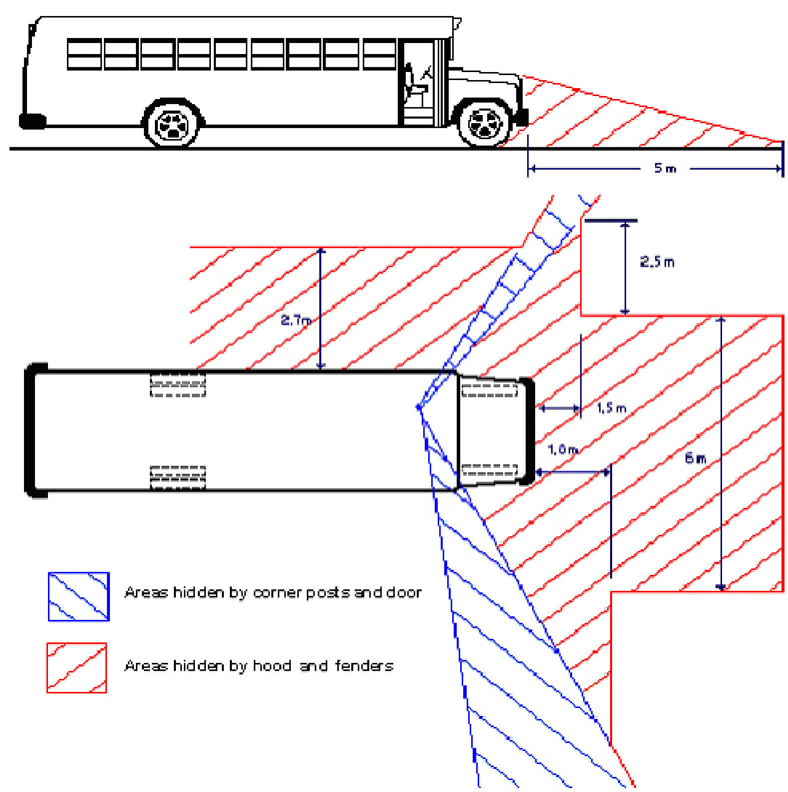


Figure 2. Zones not visible by the driver

As you can see from Figure 2, the driver cannot see anything on the ground closer than 5 m in front of the bus. The riskiest zones, where accidents are most likely, are the areas directly in front of the bus and in front of the right rear wheel. These danger zones are shown in Figure 3. They are classified as dangerous because the driver cannot see a child in these zones. Thus, anyone who is in the danger zones when the bus pulls away is potentially in danger. The greatest danger, of course, is from the bus's wheels. A detection device must be able to identify children in these zones.

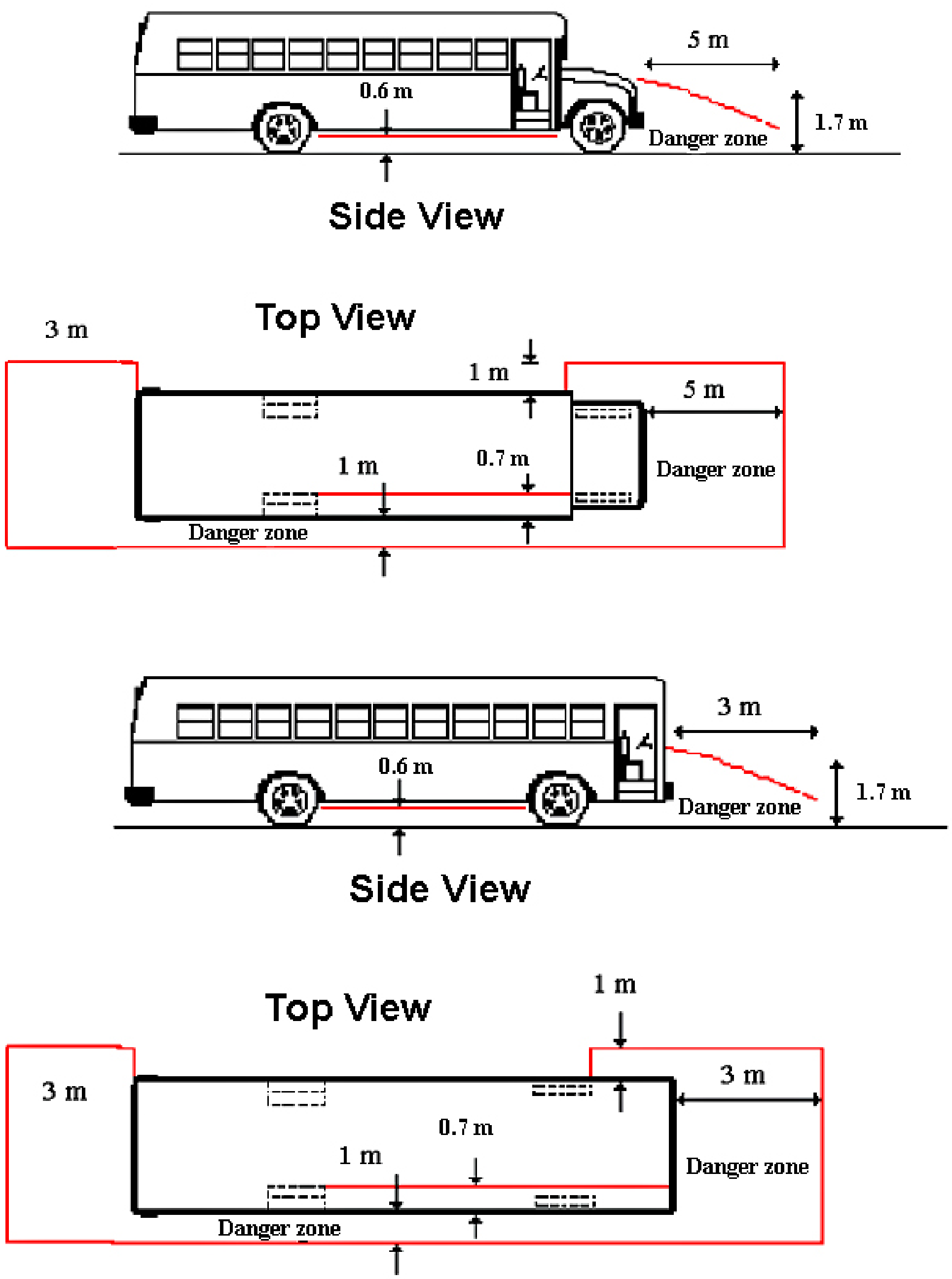


Figure 3. Danger zones around school buses

The dimensions of the danger zones were established in a study on security systems for school buses conducted in 1996 by Dubé and Kaffel [2]. These zones were reviewed and validated by the technical advisory committee for this project.

This study holds that the evaluation procedure for detection devices is based on a number of rules and that it is difficult to institute universal laboratory tests for all detection devices, as the technologies used vary enormously. However, some basic principles may be advanced. These principles are given in Appendix E.

6.2 Laboratory assessment procedure

The goal of laboratory evaluation is to verify device operation and measure the actual performance of the chosen devices, which will afterward be evaluated in the field. The performance of the devices as advertised by the manufacturers and their ability to function properly under conditions similar to the Canadian climate will be assessed.

This short-term testing will demonstrate whether the chosen devices may be safely installed on a school bus and tested for a certain period of time in severe and normal weather.

The following resources will be necessary to carry out the laboratory test procedures:

Human resources: Testing will be conducted by a mechanical technician and an electronics technician with no children present.

Material resources: The devices will be installed on a long-nose bus and a flat-nose bus inside a warehouse or garage.

Expected duration: Two weeks.

6.2.1 Laboratory assessment procedure for mechanical devices

- Install the mechanical device on a school bus;
- Check that the protection device is automatically deployed when the bus stops or before;
- Check that its deployment or retraction poses no danger to the schoolchildren's physical health;
- Check that it fulfils one of the following functions, depending on the type of device:
    a) Protective skirts must push back a dummy the size of a child between 6 and 12 lying on the ground and keep it from being run over by the front wheels of the bus or its right rear wheel. The device must sound an alarm to warn the driver when the skirts come in contact with the dummy. In addition, the dummy must not sustain any impact that would cause serious injuries when pushed aside by the device. The dummy should be a manufactured object of a size, weight and flexibility similar to a child's.

b) Barriers must force the child to walk outside the danger zones at the front of the vehicle. In addition, the barriers must not have sharp edges that could injure a child.

- Check that when the school bus pulls away, the protection device returns to its zero position.

6.2.2 Laboratory assessment procedure for detection devices

- Install the detection device on a school bus;
- Check that the device is operating within the manufacturer's parameters;
- Turn the detection device on;
- Check that the device is active at the critical stages in the process of taking on and letting off schoolchildren. This means within 20 m of the vehicle's coming to a full stop, at any time while it is stopped, and during the first 20 m after the bus moves away from the pick-up or drop-off area;
- Check that the detection device does not trigger an alarm for any object located outside the danger zones;
- Check that the device does detect a child or other moving object resembling a stooping child in the vehicle's danger zones. The speed at which such an object moves shall be comparable to that of a walking child in the following scenarios:
  - A child walks across the road from left to right or from right to left,
  - A child turns back into the danger zones in front of or beside the bus,
  - A child runs through the danger zones,
  - A child is lying on the ground in the danger zones at angles of between 0° and 90° to the school bus,
  - A child is leaning into the danger zones;
- Check that the device detects any object similar in size to a child's body that is immobile on the ground in the danger zones when the vehicle is moving between 0 and 5 km/h and does not trigger false alarms;
- Check that extreme conditions do not affect device performance:
  - Precisely measure object detection time,
  - Determine what factors cause false alarms (rubberized materials, wood, plastic, composites, metal, concrete, snow, absorbent materials, lighting, fire hydrants, wireless telephones),
  - Determine which factors block detection (child running very quickly, child lying down, angle of movement, several children in a group, adult with children).

Once the device under review has been found effective and safe for children, it can then be subjected to severe environmental conditions in an environmental chamber. The following resources are required:

Human resources: A technician.

Material resources: An environmental chamber and the devices, installed on a long-nose or flat-nose bus.

Expected duration: One week.

The following tests will then be done:

- Correct operation at temperatures from -30°C to 35°C;
- Correct operation in heavy rain;
- Insensitivity to normal conditions of dust, rain, snow and ice on its external surfaces.

6.3 Closed-track testing program

When laboratory tests are finished and device evaluation has produced satisfactory and reliable results, the device may then undergo closed-track testing.

6.3.1 Testing in a traffic-free place (deserted schoolyard or parking lot)

The goal of this exercise is the systematic verification of the device (in operation) as it detects the presence of pedestrians around a school bus in a parking lot at least 50 m x 50 m, free of traffic and obstacles. The school bus shall be immobile at the centre of the testing zone. No other vehicle is necessary for this testing.

Expected duration: half a day.

Equipment required:
- a bus equipped with the detection device (pre-installed);
- materials required:
  - measuring tape,
  - chalk line and asphalt chalk,
  - walkie-talkie,
  - still or video camera.

Human resources:
- a bus driver,
- two testers,
- two children, one small (age 5-7), the other larger (age 9-10), both of average size for their age.

Test site: a deserted schoolyard (or a big, deserted parking lot).

<u>**Description of tests**</u>

Parameters of test grid according to the test grid described in Table 3.

- distance to subject (relative to bus),
- approach angle,
- pedestrian size.

Table 3. Distribution of parameters regarding pedestrian angle and distance from bus and pedestrian size

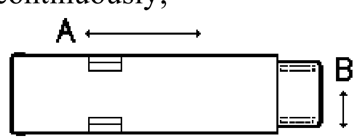
Angle	Distance	Pedestrian
30 degrees	- 1 m	adult
30 degrees	- 1 m	adult
30 degrees	- 1 m	adult
45 degrees	1 to 3 m	child 1
45 degrees	1 to 3 m	child 1
45 degrees	1 to 3 m	child 1
60 degrees	3 m +	child 2
etc.	etc.	etc.
180 degrees		

Suggested method

It is recommended that a drawing of a grid laid out in square metres be made on the ground to determine the precise spots around the school bus where the driver can detect the presence of children, whether by direct vision, in his mirrors or by means of one or more detection systems. This will pinpoint the places where detection is impossible.

The grid is to be marked around a parked bus with a chalk line representing the danger zones for pedestrians (see Figure 4).

- Child will move from one 0.25 m x 0.25 m (1 pi^2) square to the next in a systematic manner and in a pre-arranged order. This "run" shall be done twice: parallel to the length of the bus (A) and perpendicular to it (B). In addition, these runs shall be done with a stop in each square and continuously;



- Mapping: for each square, note whether the child is detected by the driver (direct vision or in his mirrors) or by the device (or both);
- Two or three trials: 1 – with a younger child (aged 5 to 7), 2 – with an older child (aged 9 to 11), 3 – possible trial with a adult.

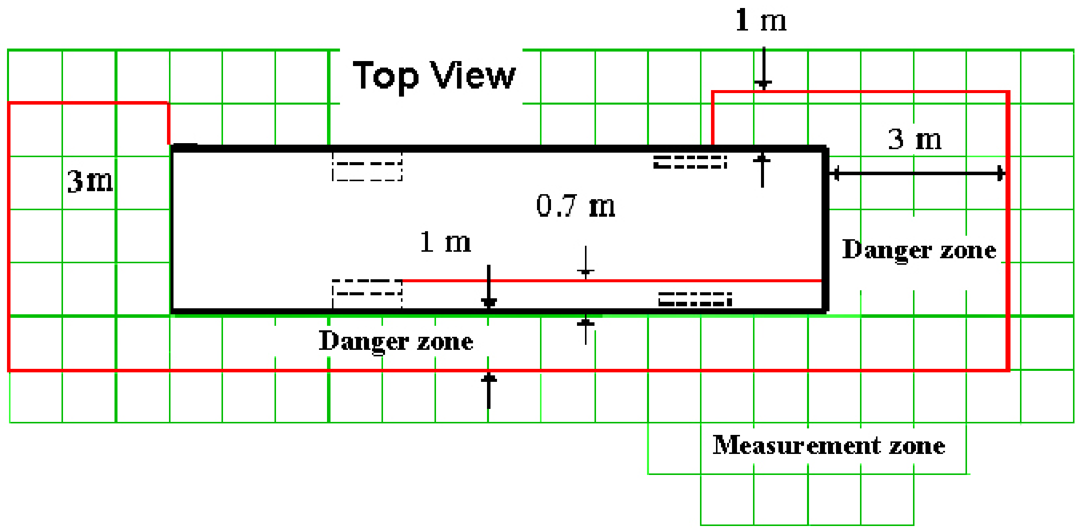


Figure 4. Measurement grid to cover danger zones

6.3.2 Supplementary tests (inclement weather)

Repeat of previous tests (in a deserted schoolyard) in more difficult environmental conditions:

- darkness,
- rain/snow,
- fog.

Expected duration: two half-days (depending on the weather).

Equipment required:
- a bus equipped with the detection device (pre-installed);
- observation equipment: video recorder, walkie-talkie, stop watches, observation and recording charts prepared in advance.

Human resources:
- a bus driver;
- two testers, one of whom travels with the driver and takes notes on the behaviour of the schoolchildren and the driver;
- two children, one small (age 5-7), the other larger (age 9-10), both of average size for their age.

Test site: a deserted schoolyard (or a big, deserted parking lot).

6.4 Road testing program

Following the closed-track tests, and after corrections and adjustments to the detection systems (if necessary), road tests will be done using a bus equipped with detection systems on regular school bus routes.

Expected duration: three to four weeks (depending on possibility of rotating drivers and routes).

Equipment required:
- a bus equipped with an installed detection device that has already been validated in laboratory and closed-track testing;
- observation equipment: video recorder, walkie-talkie, stop watches, observation and recording charts prepared in advance.

Human resources:
- 20 bus drivers,
- two testers, one of whom travels with the driver and takes notes on the behaviour of the schoolchildren and the driver.

Test site: regular school bus routes.

Description of tests

- The 20 drivers take turns using the detection-system-equipped bus on their regular routes (with the system on), each doing two runs;
- After each road test, the driver is questioned about the system's performance and his or her impressions of the device (5 to 7 minutes).

Parameters evaluated by driver interviews:

- drivers' overall degree of satisfaction with the use of the system,
- perceived advantages of the system, according to drivers,
- disadvantages of the system, according to drivers,
- situations in which the device may prevent the undesirable event,
- impression of detection in danger zones.

At the conclusion of the road testing, the data recorded on video and, for certain devices, on computers, will be analysed and compared with the information obtained in the field.

7 Verification of the functionality of the electronic version of the revised evaluation grid and validation of the proposed closed-track trials

The functionality of the revised evaluation grid was checked using the crossing control arm, a mechanical device used on many school buses. The results of this check are presented in Appendix F. The evaluation grid did give the expected results in this check. A complete cumulative result was obtained and it was possible to change or correct the choices at any time. Moreover, the evaluation grid did not allow more than one answer to a given question. From the functional viewpoint, the evaluation grid gave the expected results for each of the three main criteria: “safety”, “ergonomics” and “cost effectiveness and other factors”.

In order to validate the proposed closed-track testing procedure, tests were conducted on a test track at Blainville,[1] Quebec. A 2001 model school bus was equipped with a radar detection device and sensors to alert the driver to the presence of objects and persons around the vehicle. The driver could also turn the device off if desired. A visual and auditory system alerted the driver to the presence of objects and persons.

The goal of these tests was not to evaluate the device, but rather to validate the recommended closed-track testing procedure. It was shown that pedestrian movements around the vehicle needed to be slow in order to allow better measurement of movement coverage in the danger zones. This validation also confirmed that the recommended closed-track testing procedure is suitable.

It should be noted that it was impossible to do road testing, for it would have been necessary to obtain legal authority in advance from the relevant provincial departments.

[1] PMG Technologies, Test and Research Centre, 100 du Landais Street, Blainville, Quebec, Canada, J7C 5C9.

8 Conclusion

The objective of this study was to review and validate the evaluation criteria established in a previous project and to develop testing procedures to be used at a later stage once the technical advisory committee has made a choice of devices.

The earlier project used three sources of information to understand the risks to children in the vicinity of a school bus and the causes of school bus accidents: accident statistics, field observation and consultations with a focus group consisting of school bus drivers. This resulted in the development of a fault tree, which is presented in Appendix A. This report suggests only a few minor additions to this fault tree.

The first project also included a weighted evaluation grid. A few changes were made to this original grid:

- Assessment criteria and weighting
  The five original categories of evaluation criteria were combined into three categories, i.e., safety, ergonomics, and cost effectiveness and other factors. The most significant change is probably the greater weighting given to the "ergonomics" category, which went up from 25% to 40%. This increase is justified by the importance of ergonomic factors in the use of pedestrian detection devices and by the impact of any increase in the driver's duties and the nuisance potential of false alarms.

- Evaluation grid
  A number of changes were made to the evaluation grid. The "safety" category was reviewed and enriched with several important technical criteria relating to pedestrian detection in the danger zones around the vehicle; in addition, device activation time is henceforth taken into account. There was little change in the content of the "ergonomics" category, but the serious problem of the false alarms sometimes produced by the devices was given greater weight. The "cost effectiveness and other factors" category now contains elements and weights that better reflect the real conditions operators and manufacturers deal with.

To meet the project objectives, laboratory, closed-track and road testing procedures were developed. The proposed laboratory testing procedure takes into account the difficulty of devising universal tests for all types of safety device. Hence, different procedures are proposed for mechanical and electronic devices. The laboratory testing procedure also recognizes the need to subject the devices to the rigours of our climate.

The report also contains recommendations for closed-track and road testing. Suggestions are made with respect to evaluation of safety devices' performance in order to measure their effectiveness under various possible scenarios. The importance of good coverage of the danger zones is emphasized.

The functionality of the electronic version of the revised evaluation grid was verified using one of the commercially available mechanical detection devices. This verification showed that the grid is functional and gives the expected results. Appendix F gives the results of the verification. The proposed closed-track testing procedures were also validated using a commercial pedestrian detection device.

This report contains a user's manual to explain the elements of the evaluation grid and facilitate its use. Finally, a procedure is proposed for a later phase that would consist of a theoretical evaluation of devices by means of the evaluation grid and laboratory, closed-track and road testing.

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2. Dubé, Y. & Kaffel, M., *Systèmes de sécurité pour autobus scolaire*, Ministère des Transports du Québec, 101 p., 1996.

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APPENDIX A

Fault tree


Child is injured by the bus 1
Child is in the path of the bus 2
Bus is moving 3
Child is obliged to move into the path 4
Child moves intentionally into the path 5
Child is dragged involuntarily into the path 6
Bus starts moving 7
Bus has not fully stopped 8
Driver steps on the gas pedal 9
Bus is moving on its own 10
Driver does not detect the presence of the child 11
Driver does not see any signal 12
Driver does not see the child 13
Child must cross 14
Bus is not on the side of the child's home or school 15
Instructions oblige the child to cross in front of the bus 16
Child is arriving at school (exiting - school) 17
Child is returning home (exiting - home) 18
Child is going to the bus (boarding - school, home) 19
Child wants to meet someone or get something, stops suddenly to pick something up [...] 20
The person or thing is in front or on the other side of the path 21
Child is pushed or shoved by someone or something 22
Child is caught on the bus 23
Child slips 24
Child stumbles or trips 25
Child is close to the bus 26
Piece of child's clothing or accessories get caught 27
Pieces of bus act as hooks 28
Obstacles in the way 29
Child runs into or walks on the obstacle 30
Roadway is slippery 31
Child's shoes do not have enough traction 32
Child is moving too fast 33
No signal is transmitted 34
Driver receives the signal but it is not clear 35
Signal is transmitted but does not reach the driver 36
Witnesses are unable to warn the driver 37
No one is aware of or a witness to the scene 38
Driver is not paying attention 39
Signal is blocked 40
Not enough time to react 41
Witnesses are paralyzed by what they see 42
Sound signal is lower than the surrounding noise 43
Visual signal is obstructed by something 44
Children are shouting 45
Motor is noisy 46
Outside noise other than noise from children or motor 47
Signal is similar to usual sounds or signs 48
Signal is lost in the noise 49
Child cannot be seen either directly or indirectly 50
Driver is looking without paying attention to the presence of the child 51
Visibility is reduced 52
Driver is not looking in the direction of the child 53
Driver is no longer looking in the direction of the child 54
Presence of blind spots 55
Child is in a blind spot 56
Contrast is not adequate 57
Image is blurred 58
Contrast is too sharp 59
Contrast is too weak 60
Bad weather 61
Mirrors reflect a distorted image or are incorrectly adjusted 62
Windows and/or mirrors are dirty or damaged 63
Very bright light (sun in the background) 64
There is no filter to reduce the intensity of the light 65
Insufficient lighting system 66
Lack of lighting 67
Colour of clothing blends in with the environment 68
Dark area 69
The sun has set 70
Presence of undesirable shadows 71
Handbrake is not activated 72
Brakes are not working 73
Something overpowers the bus 74
Brake defect 75
Driver removes foot from the brake unintentionally 76
Driver does not step on the brake pedal 77
Driver's shoe slips off the pedal 78
Transmission is running 79
Bus is on a hill with the transmission in neutral 80
Bus is hit by another vehicle 81
Transmission is engaged 82
Driver's foot slips off the clutch pedal 83
Not enough time to react and brake properly 84
Driver makes a driving error 85
Bus has a mechanical problem 86
Bus is moving too fast for the road conditions 87
Driver is not careful 88
Driver makes a poor assessment of the situation 89
Driver chooses to take a risk 90
Driver lacks information 91
Driver lacks experience 92
Driver is distracted 93
Driver is not paying complete attention 94
Driver is under stress 95
Driver is tired 96
Driver forgets to check 97
Driver does not think that checking is required 98
Driver is sure of having followed the children's movements 99
Child crosses the path in a different place than usual 100
Child does not know the safety rules 101
Child does not follow the safety rules 102
Child forgets or does not know the rules 103
Child is not aware of the danger 104
Child intentionally takes a risk 105
Driver looks in another direction 106
Child is not in the driver's line of vision 107
Child and the new focus are seen in two different mirrors 108
Child and the new focus are far apart 109
Event attracts the attention of the driver 110
Driver must check 111
Driver must get back into traffic 112
Driver must ensure that no one is in danger 113
Driver must ensure that the children on the bus are sitting down 114

APPENDIX B

Events included in the fault tree

Events included in the fault tree

1	Child is injured by the bus
2	Child is in the path of the bus
3	Bus is moving
4	Child is obliged to move into the path
5	Child moves intentionally into the path
6	Child is dragged involuntarily into the path
7	Bus starts moving
8	Bus has not fully stopped
9	Driver steps on the gas pedal
10	Bus is moving on its own
11	Driver does not detect the presence of the child
12	Driver does not see any signal
13	Driver does not see the child
14	Child must cross
15	Bus is not on the side of the child's home or school
16	Instructions oblige the child to cross in front of the bus
17	Child is arriving at school (exiting - school)
18	Child is returning home (exiting - home)
19	Child is going to the bus (boarding - school, home)
20	Child wants to meet someone or get something, ***stops suddenly to pick something up, or returns to pick something up***
21	The person or thing is in front or on the other side of the path
22	Child is pushed or shoved by someone or something
23	Child is caught on the bus
24	Child slips
25	Child stumbles or trips
26	Child is close to the bus
27	Piece of child's clothing or accessories get caught
28	Pieces of bus act as hooks
29	Obstacles in the way
30	Child runs into or walks on the obstacle
31	Roadway is slippery
32	Child's shoes do not have enough traction
33	Child is moving too fast
34	No signal is transmitted
35	Driver receives the signal but it is not clear
36	Signal is transmitted but does not reach the driver
37	Witnesses are unable to warn the driver
38	No one is aware of or a witness to the scene
39	Driver is not paying attention
40	Signal is blocked
41	Not enough time to react
42	Witnesses are paralyzed by what they see

43	Sound signal is lower than the surrounding noise
44	Visual signal is obstructed by something
45	Children are shouting
46	Motor is noisy
47	Outside noise other than noise from children or motor
48	Signal is similar to usual sounds or signs
49	Signal is lost in the noise
50	Child cannot be seen either directly or indirectly
51	Driver is looking without paying attention to the presence of the child
52	Visibility is reduced
53	Driver is not looking in the direction of the child
54	Driver is no longer looking in the direction of the child
55	Presence of blind spots
56	Child is in a blind spot
57	Contrast is not adequate
58	Image is blurred
59	Contrast is too sharp
60	Contrast is too weak
61	Bad weather
62	Mirrors reflect a distorted image ***or are incorrectly adjusted***
63	Windows and/or mirrors are dirty or damaged
64	Very bright light (sun in the background)
65	There is no filter to reduce the intensity of the light
66	Colour of clothing blends in with the environment
67	Lack of lighting
68	Insufficient lighting system
69	Dark area
70	The sun has set
71	Presence of undesirable shadows
72	Handbrake is not activated
73	Brakes are not working
74	Something overpowers the bus
75	Brake defect
76	Driver removes foot from brake unintentionally
77	Driver does not step on the brake pedal
78	Driver's shoe slips off the pedal
79	Transmission is running
80	Bus is on a hill with the transmission in neutral
81	Bus is hit by another vehicle
82	Transmission is engaged
83	Driver's foot slips off the clutch pedal
84	Not enough time to react and brake properly
85	Driver makes a driving error
86	Bus has a mechanical problem
87	Bus is moving too fast for the road conditions

88	Driver is not careful
89	Driver makes a poor assessment of the situation
90	Driver chooses to take a risk
91	Driver lacks information
92	Driver lacks experience
93	Driver is distracted
94	Driver is not paying complete attention
95	Driver is under stress
96	Driver is tired
97	Driver forgets to check
98	Driver does not think that checking is required
99	Driver is sure of having followed the children's movements
100	Child crosses the path in a different place than usual
101	Child does not know the safety rules
102	Child does not follow the safety rules
103	Child forgets or does not know the rules
104	Child is not aware of the danger
105	Child intentionally takes a risk
106	Driver looks in another direction
107	Child is not in the driver's line of vision
108	Child and the new focus are seen in two different mirrors
109	Child and the new focus are far apart
110	Event attracts the attention of the driver
111	Driver must check
112	Driver must get back into traffic
113	Driver must ensure that no one is in danger
114	Driver must ensure that the children on the bus are sitting down

APPENDIX C

Probability of adverse events

Probability of adverse events

Number	Previous level (%)			Top event (%)
	Drivers' perception of risk & (.) standard deviation	Analysis of accident history	Synthesis	
1	-	-	-	-
2			100	100
3			100	100
4	21(21.38)	54	50	50
5	54(25.15)	13	20	20
6	26(21.07)	33	30	30
7	51(25.90)	87	80	80
8	49(25.90)	13	20	20
9	81(25.33)	90	85	68
10	19(24.33)	10	15	12
11			100	68
12			100	68
13			100	68
14			100	50
15			100	50
16			100	50
17	8(5.10)	0	5	2.5
18	63(26.22)	58	80	40
19	30(25.65)	15	15	7.5
20			100	20
21			100	20
22	31(17.81)	20	20	6
23	16(19.65)	20	15	4.5
24	29(16.39)	50	45	13.5
25	23(15.41)	10	20	6
26			100	4.5
27			100	4.5
28			100	4.5
29			100	6
30			100	6
31			100	13.5
32			100	13.5
33			100	13.5
34	43(24.08)		40	27
35	32(17.72)		30	20.5
36	28(14.11)		30	20.5
37	38(17.95)		35	9.5
38	63(17.95)		65	18
39	43(26.87)		35	7

Number	Previous level (%)			Top event (%)
	Drivers' perception of risk & (.) standard deviation	Analysis of accident history	Synthesis	
40	58(26.87)		65	13.5
41	66(21.09)		65	6
42	34(21.09)		35	3.5
43	58(21.55)		60	8
44	42(21.55)		40	5.5
45	58(18.99)		60	5
46	30(18.65)		30	2.5
47	13(12.36)		10	1
48	50(15.99)		50	10
49	50(15.99)		50	10
50	24(16.85)		25	17
51	10(3.65)		10	7
52	24(12.31)		20	14
53	15(10.28)		15	10
54	27(16.72)		30	20
55			100	17
56			100	17
57	52(18.77)		55	8
58	48(18.77)		45	6
59	63(14.77)		65	5
60	37(14.77)		35	3
61	60(18.55)		60	3.5
62	13(8.02)		15	1
63	28(13.97)		25	1.5
64			100	5
65			100	5
66	48(24.24)		45	1.5
67	52(24.24)		55	2
68			100	2
69			100	2
70	61(18.44)		65	1.25
71	39(18.44)		35	0.75
72			100	12
73			100	12
74			100	12
75	42(34.07)		45	5.5
76	39(28.68)		40	5
77	19(12.00)		15	2
78			100	5
79	46(28.95)		45	5.5
80	27(16.83)		25	3

Number	Previous level (%)			Top event (%)
	Drivers' perception of risk & (.) standard deviation	Analysis of accident history	Synthesis	
81	30(24.53)		30	4
82			100	5.5
83			100	5.5
84	50(16.23)		50	10
85	38(18.84)		40	8
86	20(29.31)		10	2
87	59(16.85)		60	5
88	41(16.85)		40	3
89	53(15.64)		50	2.5
90	47(15.64)		50	2.5
91	47(14.94)		50	1.25
92	53(14.94)		50	1.25
93	60(12.40)		60	2
94	40(12.40)		40	1
95	64(15.17)		60	0.6
96	35(15.69)		40	0.4
97	24(10.89)		30	3
98	76(10.89)		70	7
99	40(25.12)		40	3
100	60(25.12)		60	4
101			100	4
102			100	4
103	33(10.84)		35	1.4
104	43(13.31)		40	1.6
105	24(14.93)		25	1
106			100	20
107			100	20
108	45(16.53)		50	10
109	55(16.53)		50	10
110	41(14.47)		40	8
111	59(14.47)		60	12
112	32(14.90)		30	3.5
113	37(11.70)		40	5
114	31(20.40)		30	3.5

APPENDIX D

Evaluation grid

Evaluation grid

Answer the questions by marking an X in the appropriate blank boxes in column D and marked with an X heading.

		Rating %	X	Mark %	Cumulative score %	Overall rating %
A	**SAFETY**	**100**			**50.0**	**50%**
1	**Impact of the safety device (must answer 1.1, 1.2 and 1.3)**	100				
1.1	Does the device prevent the child from falling under the wheels of the bus?	*100*				
1.2	Does the device prevent the child from being in the danger zones? (see drawing of danger zones)	*100*				
1.3	Does the device detect or assist the driver in detecting the presence of a child in the danger zones?	*95*				
1.3.1	Does the device detect the presence of a child in the danger zones?	95				
1.3.1.1	Does the device detect the presence of an immobile child?	45				
	Yes	100				
	No					
1.3.1.2	Does the device detect the presence of a moving child?	35				
	Yes	100				
	No					
1.3.1.3	Does the device differentiate between an object and a child?	15				
	Yes	100				
	No					
1.3.2	Does the device assist the driver in detecting the presence of a child in the danger zones?	70				
1.3.2.1	Does the device amplify the image of a child in the danger zones?	15				
	Yes	100				
	No					
1.3.2.2	Does the device improve the driver's vision in the danger zones?	70				

		Rating %	X	Mark %	Cumulative score %	Overall rating %
1.3.2.2.1	Does the device improve contrast? If yes, in what way?	8				
	It increases brightness.	*5*				
	It prevents glare.	*3*				
1.3.2.2.2	Does the device make it easier to see clearly? If yes, in what way?	7				
	It eliminates or satisfactorily reduces the effects of bad weather on visibility.	*4*				
	It makes images reflected in the mirrors clearer.	*1*				
	It keeps mirrors and windows clean and free of condensation, frost, ice or other.	*2*				
1.3.2.2.3	Does the device help the driver pay close attention to the area where the child is? If yes, in what way?	30				
	It forces or reminds the driver to pay attention to all potential danger zones.	*17*				
	It reduces the number of angles from which the driver must make customary checks.	*13*				
1.3.2.2.4	Does the device help the driver notice signals from witnesses at the scene? If yes, in what way?	40				
	It amplifies signals.	*20*				
	It makes signals more distinct.	*20*				
1.3.2.3	Does the device differentiate between a child and an object?	15				
	Yes	100				
	No					
2	**What is the device's area of coverage around a bus?**	**100**				
	What percentage of the danger zones does the device cover? (see attached diagram)	100				
2.1	Front	*72*				
	All	100				
	Vast majority	75				
	Half	50				
	A little	25				
	Very little					

		Rating %	X	Mark %	Cumulative score %	Overall rating %
2.2	Sides	*24*				
	All	100				
	Vast majority	75				
	Half	50				
	A little	25				
	Very little					
2.3	Back	*4*				
	All	100				
	Vast majority	75				
	Half	50				
	A little	25				
	Very little					
3	**What is the device's protection or detection time?**	**100**				
3.1	The device begins protecting or detecting when the bus is	*60*				
	Slowing down before coming to a complete stop	100				
	Coming to a complete stop	90				
	Starting to mave	80				
3.2	The device ends protection or detection when the bus is	*40*				
	Travelling at a certain speed	100				
4	**Does the device have a memory to record information?**					
	Yes					
	No					
5	**What is the device's response time?**					
	Less than 10 milliseconds					
	Between 10 milliseconds and 1 second					
	Between 1 second and 2 seconds					
	More than 2 seconds					
6	**Does the device emit dangerous waves or radiation?**					
	Yes					
	No					
7	**Does the device perform a self-check of its basic components?**					
	Yes					
	No					

		Rating %	X	Mark %	Cumulative score %	Overall rating %
8	**Does the device emit an audible exterior signal to the child?**					
	Yes					
	No					
B	**ERGONOMICS**	**100**			**10.0**	**40%**
9	**Does the device have an impact on the driver's job? If yes,**	50				
	No	100				
9.1	Can the device impair the driver's ability to carry out his or her duties? If yes,	*60*				
	No	100				
9.1.1	Can the device impede the driver's freedom of movement?	25				
	Never	100				
	Seldom	75				
	Usually	50				
	Very often	25				
	Always					
9.1.2	Can the device impede access to the bus controls?	25				
	Never	100				
	Seldom	75				
	Usually	50				
	Very often	25				
	Always					
9.1.3	Can the device interfere with the proper functioning of bus equipment?	25				
	Never	100				
	Seldom	75				
	Usually	50				
	Very often	25				
	Always					
9.1.4	Can the device obstruct the driver's vision?	25				
	Not at all	100				
	Somewhat	75				
	Moderately	50				
	A lot	25				
	Completely					
9.2	Does the device impose additional demands on the driver's job? If yes,	*40*				
	No	100				

		Rating %	X	Mark %	Cumulative score %	Overall rating %
9.2.1	What type of demand does the device impose on the driver's job?	70				
9.2.1.1	Is there a mental challenge? If yes,	45				
	No	100				
9.2.1.1.1	How many steps are required to use the device?	20				
	None or very few	*100*				
	A few	*75*				
	A moderate number	*50*				
	A fairly large number	*25*				
	Many					
9.2.1.1.2	Can the commands or information transmitted by the device be confusing?	20				
	Never	*100*				
	Seldom	*75*				
	Sometimes	*50*				
	Often	*25*				
	Always					
9.2.1.1.3	Does the device require specific knowledge or mental skills?	20				
	None or very few	*100*				
	Some	*75*				
	Moderate amount	*50*				
	Fairly substantial amount	*25*				
	Substantial amount					
9.2.1.1.4	Does one need training to use the device? If yes, how long would this training take?	20				
	None required	*100*				
	Small amount of time	*75*				
	Moderate amount of time	*50*				
	Large amount of time	*25*				
	A very long time					
9.2.1.1.5	Is the device easy to operate if the driver is tired or under stress?	20				
	Very easy	*100*				
	Fairly easy	*50*				
	Difficult					
9.2.1.2	Is there a sensory challenge? If yes, does it involve	40				
	No	100				

		Rating %	X	Mark % 	Cumulative score %	Overall rating %
9.2.1.2.1	A visual challenge for the driver? If yes,	60				
	No	*100*				
9.2.1.2.1.1	How clear is the visual information transmitted by the device?	*25*				
	Very clear	100				
	Clear	75				
	Fairly clear	50				
	Poor	25				
	Very poor					
9.2.1.2.1.2	Can this visual information be obstructed in any way?	*25*				
	Never	100				
	Sometimes	75				
	Usually	50				
	Very often	25				
	Always					
9.2.1.2.1.3	Is the device in the driver's normal field of vision?	*25*				
	Yes	100				
	No					
9.2.1.2.1.4	How long is the visual attention span required by the device?	*25*				
	Very short	100				
	Short	75				
	Average	50				
	Long	25				
	Very long					
9.2.1.2.2	A hearing challenge for the driver? If yes,	30				
	No	*100*				
9.2.1.2.2.1	How would you describe the sound range of the device?	*50*				
	Excellent	100				
	Good	75				
	Fair	50				
	Poor	25				
	Unacceptable					

		Rating %	X	Mark %	Cumulative score %	Overall rating %
9.2.1.2.2.2	Is the sound transmitted by the device distinct enough to be able to distinguish from the background noise?	*50*				
	Very distinct	100				
	Moderately distinct	75				
	Fairly distinct	50				
	Not very distinct	25				
	Not distinct at all					
9.2.1.2.3	A tactile challenge for the driver? If yes,	*10*				
	No	100				
9.2.1.2.3.1	What degree of tactile sensitivity is required by the device?	*100*				
	Low	100				
	Average	50				
	High					
9.2.1.3	A physical challenge for the driver? If yes,	15				
	No	100				
9.2.1.3.1	How many limbs are needed to operate the device?	*25*				
	1	100				
	More than 1					
9.2.1.3.2	Does the device affect the driver's postural comfort from an anthropometric standpoint?	*25*				
	Not at all	100				
	A little	75				
	Moderately	50				
	Rather a lot	25				
	A lot					
9.2.1.3.3	What levels of dexterity and accuracy are required by the device?	*25*				
	Low	100				
	Average	50				
	High					
9.2.1.3.4	What is the level of effort required by the average driver to operate the device?	*25*				
	Low	100				
	Average	50				
	High					
9.2.2	When is this additional activity carried out?	30				

		Rating %	X	Mark %	Cumulative score %	Overall rating %
9.2.2.1	When the bus is approaching to pick up children?	20				
	Yes	100				
	No					
9.2.2.2	When the bus is picking up or letting off children? If yes,	50				
	As the driver prepares to pick up / let off children.	25				
	As the driver monitors the picking up / letting off of children.	35				
	As the driver prepares to leave.	40				
9.2.2.3	When the bus is moving away?	30				
	Yes	100				
	No					
10	**How would you describe the quality of the device-child interface?**	**40**				
10.1	How well suited is the device to children's needs?	*60*				
10.1.1	Is the device suitable for small children?	20				
	Yes	100				
	No					
10.1.2	Does a child's posture (bent over, kneeling, lying on the ground) affect the device's effectiveness?	20				
	No	100				
	Yes					
10.1.3	Does the device suit the speed with which children move?	20				
	Yes	100				
	No					
10.1.4	Can the device be circumvented or outsmarted by children?	20				
	Never	100				
	Not easily	75				
	Probably	50				
	Easily	25				
	Very easily					
10.1.5	Does the device make children follow special instructions? If yes,	20				
	No	100				

		Rating %	X	Mark %	Cumulative score %	Overall rating %
10.1.5.1	Are the instructions clear and easily understood by all children?	50				
	Very clear and easy to understand	100				
	Quite clear and easy to understand	75				
	Fairly clear and easy to understand	50				
	Unclear and difficult to understand	25				
	Very unclear and difficult to understand					
10.1.5.2	Can the instructions be easily forgotten or disobeyed by children?	50				
	Not at all easily	100				
	Not easily	75				
	Fairly easily	50				
	Easily	25				
	Very easily					
10.2	Does the device pose a risk to children? If yes,	*40*				
	No	100				
10.2.1	Can children get hurt (cuts, bumps, scratches, etc.) if they come in contact with the device?	25				
	Never	100				
	Not likely	75				
	Likely	50				
	Very likely	25				
	Always					
10.2.2	Can the device encourage children to engage in risky behaviour?	25				
	Never	100				
	Not very likely	75				
	Likely	50				
	Very likely	25				
	Always					
10.2.3	Does the device attract the attention of children?	25				
	Not at all	100				
	To a small degree	50				
	To a large degree					
10.2.4	Can the device cause children to lose their balance, fall or slip?	25				
	Not at all	100				
	To a small degree	50				
	To a large degree					

		Rating %	X	Mark %	Cumulative score %	Overall rating %
11	**Other Ergonomic Factors**	**10**				
11.1	Is the device likely to produce false alarms? If yes,	*80*				
	No	100				
11.1.1	What is the expected frequency of the false alarms produced by the device?	50				
	None	100				
	Low	75				
	Moderate	50				
	High	25				
	Very high					
11.1.2	What is the level of annoyance produced by the device's false alarms?	50				
	None	100				
	Low	75				
	Moderate	50				
	High	25				
	Very high					
11.2	Is the device likely to produce a noise involuntarily? If yes,	*20*				
	No	100				
11.2.1	What is the noise level of this involuntary noise?	50				
	None	100				
	Low	75				
	Moderate	50				
	High	25				
	Very high					
11.2.2	What is the annoyance level of this involuntary noise?	50				
	None	100				
	Low	75				
	Moderate	50				
	High	25				
	Very high					

		Rating %	X	Mark %	Cumulative score %	Overall rating %
C	**COST EFFECTIVENESS AND OTHER FACTORS**	**100**				**10%**
12	**What does the device cost?**	35				
12.1	What is the purchase price of the device in dollars?	*20*				
	$0-500	100				
	$501-1000	75				
	$1001-2000	50				
	> $2001	25				
12.2	What are the maintenance costs of the device?	*20*				
	None	100				
12.3	What are the installation costs of the device?	*20*				
	1 hour per bus	100				
	2 hours per bus	75				
	3 hours per bus	50				
	4 hours per bus	25				
12.4	What are the operating costs (slow down operation of school transport) of the device?	*20*				
	None	100				
12.5	What are the training costs for the device?	*20*				
	1 hour for a group of 10 drivers or more	100				
	2 hours for a group of 10 drivers or more	75				
	3 hours for a group of 10 drivers or more	50				
	4 hours for a group of 10 drivers or more	25				
13	**What is the mean cycle failure on components of the device?**	35				
	Reliability cycle as related to possible failure of components is known	100				
	Reliability cycle related to possible failure of components is unknown					
14	**Is the device guaranteed?**	20				
	Life warranty on original vehicle	100				
	10 years	75				
	5 years	50				
	1 year	25				
	No warranty					

		Rating %	X	Mark %	Cumulative score %	Overall rating %
15	**Other Factor**	10				
	Does the device operate without making excessive noise outside the vehicle?	10				
	Yes	100				
	No					
	Final result					

APPENDIX E

Basic criteria – laboratory evaluation

Basic criteria – laboratory evaluation

- **Basic physics:** This is a very important criterion in that it may tell us whether this technology suits our application's requirements. For example, capacitance sensors and sensitive skin sensors, by virtue of their basic physics, do not seem suited to the requirements and application conditions for school buses because they have too short a range.

- **Nature of information:** It must be determined whether the signal is electrical, mechanical, thermal, etc. How the measurement is done depends on the type of signal.

- **Static or dynamic measurement type:** Some detectors require the object to be detected to be moving, while others require it to be stationary. For example, the Doppler-effect microwave sensor used in the ForeWarn system can only detect moving objects. Below a certain speed threshold, the microwave detector fails to detect any object.

- **Field of vision and range:** It is essential for a safety device to have the right detection volume. The sensor's range and field of vision absolutely must be great enough to give the driver plenty of time to avoid a collision. For that reason, tactile sensors alone are not suitable in applications for children and adults.

- **Blind spots:** A safety device must not have any blind spots in the danger zones. A blind spot is a time (or distance) at which the system is unaware of what is going on around it. For example, an ultrasound detector with an integrated transceiver has a blind spot of around 15 cm. In the 0- to 15-cm range, no objects can be detected – a clear danger in the case of school transportation.

- **Precision and resolution:** Precision is not a very important factor for the subject application. Accurate, reliable detection of a pedestrian is much more important than the pedestrian's precise location within the danger zone. A precision of a few centimetres is sufficient. In other applications, however, such as robotics, a highly precise detector is essential.

- **Data connection ability:** A detector must produce data that can be easily processed and transferred from the acquisition unit to the processing unit. Very low-strength signals will be very sensitive to external noise and noise from the bus, possibly skewing measurements.

- **Measurement time:** Some detectors are very slow at acquiring data. For the application considered here, it is essential to obtain the measurement in the shortest possible time so that the system will analyse the information and sound an alarm almost instantaneously.

- **Ruggedness:** The sensor must be rugged enough to withstand weather, vibrations and the effects of shocks and handling. Some types of detector are fragile and cannot be used in a hostile environment.

- **Complexity:** A safety device must not be complicated. To avoid loss of reliability, it must use detectors with a low level of complexity. The simpler the system, the easier it is to maintain.

- **Size and weight:** It is very important for the safety device not to be too bulky. It must be as light and compact as possible so as to be easily installed and protected from the elements or from accidental impact.

- **Service life and reliability:** A device's service life is a very important criterion for decision-making at the time of purchase. A longer service life is very advantageous. Measurement reliability means that the system must always detect an in-range object.

- **Effect of changing atmospheric conditions:** Because the system to be implemented must operate in a real and very rigorous environment, it is absolutely required to be as resistant as possible to variations of temperature, sunlight or lighting, impurities, snow, rain, mist and motor noise or noise from other electrical circuits. Lasers, for example, are affected by heavy mist and rain.

- **Impact on health (pedestrians, schoolchildren):** A safety device must be able to detect persons in the danger zone and protect them from collisions. However, the system must never cause side effects such as burns to the skin or eye injury... For example, because laser devices may have health side effects, they must be avoided even though they have detection characteristics superior to those of ultrasound devices, which present no risk.

- **Efficiency and false alarm rate:** A school bus safety device must be triggered only in the event of potential danger. A system that produces a large number of false alarms may be disturbing to the driver and even the passengers.

Assessment criteria for processing technologies: The assessment criteria for processing technologies are different from those for detection technologies. The main criteria are:

- **Information interpretation technique:** Interpretation time depends on the technique used. It must be quick enough for the task to be performed.

- **Degree of processing intelligence:** There are processing techniques that make use of very advanced artificial intelligence concepts, while other techniques are at a simpler, more elementary level. These concepts depend on the processing to be done.

- **Real time:** A safety device must operate in real time so that action (whether manual or automatic) may be taken in time, before a collision occurs. Therefore, the time required by the processing algorithm must be as short as possible to ensure that the operation takes place in real time.

- **Implementation:** Implementation of these algorithms must not require high-end memories or computers. The system cost will be correlated with the type of processor used.

- **Activation/Deactivation – Manual or automatic:** Assess the system activation and deactivation procedure and how susceptible it is to human error. Most of the safety devices proposed are activated and deactivated by the opening and closing of the door. Activation may also occur on the basis of vehicle speed or direction.

The following tables summarize the results of laboratory tests carried out by M. Dubé of the Université du Québec à Trois-Rivières, setting out the characteristics of the various detection technologies tested at that time. Qualitative assessment indicators were established on the following scale: very low, low, good, very good, high, very high. All criteria must be "high" except for cost and size.

	Cameras and passive IR sensors	Laser range-finders and imagers	Radars	Ultrasound range-finders
Active/Passive	passive	active	active	active
With/Without contact	without	without	without	without
Measurement	temperature variation	distance	distance	distance
Measurement principle	detection of IR waves emitted by the body	time-of-flight, AM modulation	time-of-flight, many forms of modulation, Doppler effect	time-of-flight
Full scale	all temperatures	metres to kilometres	metres to kilometres	centimetres to decametres
Precision and resolution	low to very high	very high	good to high	low
Acquisition frequency	very high	very high	very high	low
Reliability	low: false alarms	depends on subsequent processing	depends on subsequent processing	low to good
Mechanical strength	low to good	low to good	good	very good
Resistance to environmental variations	low	low	very high	good
Cost	low to high	high	very high	very low
Dimensions	small	small	large	small

	Proximity detectors	**Flexible bumpers**	**2D vision**	**3D vision**
Active/Passive	passive and active	passive	passive	active and passive
With/Without contact	without	with	without	without
Measurement	presence	presence	luminosity	presence
Measurement principle	Hall effect, magnetism	mechanical contact	imaging	imaging, triangulation
Full scale	range: millimetres to centimetres	–	–	distance: decametres
Precision and resolution	low to very high	–	good to high	good to high
Acquisition frequency	very high	high	low to high	very low to high
Reliability	high	high	depends on subsequent processing	depends on subsequent processing
Mechanical strength	very good	very good	good	low to good
Resistance to environmental variations	low to good	very high	low	low
Cost	very low to high	very low	low	high to very high
Dimensions	small	very large	small	small to large

Source: Dubé, Y. & Kaffel, M., *Systèmes de sécurité pour autobus scolaire*, Ministère des Transports du Québec, 1996.

APPENDIX F

Check on the functionality of the electronic version of the evaluation grid
Mechanical devices: the crossing control arm

Check on the functionality of the electronic version of the evaluation grid – Mechanical devices: The crossing control arm

Specification:

- Crossing control arm at front of school bus
- Crossing control arm activates when school bus stops
- Crossing control arm deactivates when school bus moves

Answer the questions by marking an X in the appropriate blank boxes in column D and marked with an X heading.

		Rating %	X	Mark %	Cumulative score %	Overall rating %
A	**SAFETY**	**100**		**72.0**	**86.0**	**50%**
1	**Impact of the safety device (must answer 1.1, 1.2 and 1.3)**	100		100.0		
1.1	Does the device prevent the child from falling under the wheels of the bus?	*100*				
1.2	Does the device prevent the child from being in the danger zones? (see drawing of danger zones)	*100*	**X**	100.0		
1.3	Does the device detect or assist the driver in detecting the presence of a child in the danger zones?	*95*				
1.3.1	Does the device detect the presence of a child in the danger zones?	95				
1.3.1.1	Does the device detect the presence of an immobile child?	45				
	Yes	100				
	No		**X**			
1.3.1.2	Does the device detect the presence of a moving child?	35				
	Yes	100				
	No		**X**			
1.3.1.3	Does the device differentiate between an object and a child?	15				
	Yes	100				
	No		**X**			
1.3.2	Does the device assist the driver in detecting the presence of a child in the danger zones?	70				
1.3.2.1	Does the device amplify the image of a child in the danger zones?	15				
	Yes	100				
	No		**X**			

		Rating %	X	Mark %	Cumulative score %	Overall rating %
1.3.2.2	Does the device improve the driver's vision in the danger zones?	70				
1.3.2.2.1	Does the device improve contrast? If yes, in what way?	8				
	It increases brightness.	*5*				
	It prevents glare.	*3*				
1.3.2.2.2	Does the device make it easier to see clearly? If yes, in what way?	7				
	It eliminates or satisfactorily reduces the effects of bad weather on visibility.	*4*				
	It makes images reflected in the mirrors clearer.	*1*				
	It keeps mirrors and windows clean and free of condensation, frost, ice or other.	*2*				
1.3.2.2.3	Does the device help the driver pay close attention to the area where the child is? If yes, in what way?	30				
	It forces or reminds the driver to pay attention to all potential danger zones.	*17*				
	It reduces the number of angles from which the driver must make customary checks.	*13*				
1.3.2.2.4	Does the device help the driver notice signals from witnesses at the scene? If yes, in what way?	40				
	It amplifies signals.	*20*				
	It makes signals more distinct.	*20*				
1.3.2.3	Does the device differentiate between a child and an object?	15				
	Yes	100				
	No		**X**			
2	**What is the device's area of coverage around a bus?**	**100**		72.0		
	What percentage of the danger zones does the device cover? (see attached diagram)	100		72.0		
2.1	Front	*72*		72.0		
	All	100	**X**	100.0		
	Vast majority	75				
	Half	50				
	A little	25				
	Very little					

		Rating %	X	Mark %	Cumulative score %	Overall rating %
2.2	Sides	*24*				
	All	100				
	Vast majority	75				
	Half	50				
	A little	25				
	Very little		X			
2.3	Back	*4*				
	All	100				
	Vast majority	75				
	Half	50				
	A little	25				
	Very little		X			
3	**What is the device's protection or detection time?**	**100**		100.0		
3.1	The device begins protecting or detecting when the bus is	*60*		60.0		
	Slowing down before coming to a complete stop	100	X	100.0		
	Coming to a complete stop	90				
	Starting to mave	80				
3.2	The device ends protection or detection when the bus is	*40*		40.0		
	Travelling at a certain speed	100	X	100.0		
4	**Does the device have a memory to record information?**					
	Yes					
	No		X			
5	**What is the device's response time?**					
	Less than 10 milliseconds					
	Between 10 milliseconds and 1 second		X			
	Between 1 second and 2 seconds					
	More than 2 seconds					
6	**Does the device emit dangerous waves or radiation?**					
	Yes					
	No		X			
7	**Does the device perform a self-check of its basic components?**					
	Yes					
	No		X			

		Rating %	X	Mark %	Cumulative score %	Overall rating %
8	**Does the device emit an audible exterior signal to the child?**					
	Yes					
	No		X			
B	**ERGONOMICS**	**100**		**85.2**	**80.1**	**40%**
9	**Does the device have an impact on the driver's job? If yes,**	50		47.2		
	No	100				
9.1	Can the device impair the driver's ability to carry out his or her duties? If yes,	*60*		60.0		
	No	100	X	100.0		
9.1.1	Can the device impede the driver's freedom of movement?	25		25.0		
	Never	100	X	100.0		
	Seldom	75				
	Usually	50				
	Very often	25				
	Always					
9.1.2	Can the device impede access to the bus controls?	25		25.0		
	Never	100	X	100.0		
	Seldom	75				
	Usually	50				
	Very often	25				
	Always					
9.1.3	Can the device interfere with the proper functioning of bus equipment?	25		25.0		
	Never	100	X	100.0		
	Seldom	75				
	Usually	50				
	Very often	25				
	Always					
9.1.4	Can the device obstruct the driver's vision?	25		25.0		
	Not at all	100	X	100.0		
	Somewhat	75				
	Moderately	50				
	A lot	25				
	Completely					

		Rating %	X	Mark %	Cumulative score %	Overall rating %
9.2	Does the device impose additional demands on the driver's job? If yes,	*40*		34.5		
	No	100				
9.2.1	What type of demand does the device impose on the driver's job?	70		67.4		
9.2.1.1	Is there a mental challenge? If yes,	45		45.0		
	No	100				
9.2.1.1.1	How many steps are required to use the device?	20		20.0		
	None or very few	*100*	**X**	100.0		
	A few	*75*				
	A moderate number	*50*				
	A fairly large number	*25*				
	Many					
9.2.1.1.2	Can the commands or information transmitted by the device be confusing?	20		20.0		
	Never	*100*	**X**	100.0		
	Seldom	*75*				
	Sometimes	*50*				
	Often	*25*				
	Always					
9.2.1.1.3	Does the device require specific knowledge or mental skills?	20		20.0		
	None or very few	*100*	**X**	100.0		
	Some	*75*				
	Moderate amount	*50*				
	Fairly substantial amount	*25*				
	Substantial amount					
9.2.1.1.4	Does one need training to use the device? If yes, how long would this training take?	20		20.0		
	None required	*100*	**X**	100.0		
	Small amount of time	*75*				
	Moderate amount of time	*50*				
	Large amount of time	*25*				
	A very long time					
9.2.1.1.5	Is the device easy to operate if the driver is tired or under stress?	20		20.0		
	Very easy	*100*	**X**	100.0		
	Fairly easy	*50*				
	Difficult					

		Rating %	X	Mark %	Cumulative score %	Overall rating %
9.2.1.2	Is there a sensory challenge? If yes, does it involve	40		40.0		
	No	100	X	100.0		
9.2.1.2.1	A visual challenge for the driver? If yes,	60		37.5		
	No	*100*				
9.2.1.2.1.1	How clear is the visual information transmitted by the device?	*25*		25.0		
	Very clear	100	X	100.0		
	Clear	75				
	Fairly clear	50				
	Poor	25				
	Very poor					
9.2.1.2.1.2	Can this visual information be obstructed in any way?	*25*		25.0		
	Never	100	X	100.0		
	Sometimes	75				
	Usually	50				
	Very often	25				
	Always					
9.2.1.2.1.3	Is the device in the driver's normal field of vision?	*25*				
	Yes	100				
	No		X			
9.2.1.2.1.4	How long is the visual attention span required by the device?	*25*		12.5		
	Very short	100				
	Short	75				
	Average	50	X	50.0		
	Long	25				
	Very long					
9.2.1.2.2	A hearing challenge for the driver? If yes,	30				
	No	*100*	X	100.0		
9.2.1.2.2.1	How would you describe the sound range of the device?	*50*				
	Excellent	100				
	Good	75				
	Fair	50				
	Poor	25				
	Unacceptable					

		Rating %	X	Mark %	Cumulative score %	Overall rating %
9.2.1.2.2.2	Is the sound transmitted by the device distinct enough to be able to distinguish from the background noise?	*50*				
	Very distinct	100				
	Moderately distinct	75				
	Fairly distinct	50				
	Not very distinct	25				
	Not distinct at all					
9.2.1.2.3	A tactile challenge for the driver? If yes,	*10*				
	No	100	**X**	100.0		
9.2.1.2.3.1	What degree of tactile sensitivity is required by the device?	*100*				
	Low	100				
	Average	50				
	High					
9.2.1.3	A physical challenge for the driver? If yes,	15		11.3		
	No	100	**X**	100.0		
9.2.1.3.1	How many limbs are needed to operate the device?	*25*				
	1	100				
	More than 1					
9.2.1.3.2	Does the device affect the driver's postural comfort from an anthropometric standpoint?	*25*		25.0		
	Not at all	100	**X**	100.0		
	A little	75				
	Moderately	50				
	Rather a lot	25				
	A lot					
9.2.1.3.3	What levels of dexterity and accuracy are required by the device?	*25*		25.0		
	Low	100	**X**	100.0		
	Average	50				
	High					
9.2.1.3.4	What is the level of effort required by the average driver to operate the device?	*25*		25.0		
	Low	100	**X**	100.0		
	Average	50				
	High					

		Rating %	X	Mark %	Cumulative score %	Overall rating %
9.2.2	When is this additional activity carried out?	30		18.8		
9.2.2.1	When the bus is approaching to pick up children?	20		20.0		
	Yes	100	X	100.0		
	No					
9.2.2.2	When the bus is picking up or letting off children? If yes,	50		12.5		
	As the driver prepares to pick up / let off children.	25	X	25.0		
	As the driver monitors the picking up / letting off of children.	35				
	As the driver prepares to leave.	40				
9.2.2.3	When the bus is moving away?	30		30.0		
	Yes	100	X	100.0		
	No					
10	**How would you describe the quality of the device-child interface?**	**40**		28.0		
10.1	How well suited is the device to children's needs?	*60*		30.0		
10.1.1	Is the device suitable for small children?	20		20.0		
	Yes	100	X	100.0		
	No					
10.1.2	Does a child's posture (bent over, kneeling, lying on the ground) affect the device's effectiveness?	20				
	No	100				
	Yes		X			
10.1.3	Does the device suit the speed with which children move?	20		20.0		
	Yes	100	X	100.0		
	No					
10.1.4	Can the device be circumvented or outsmarted by children?	20		10.0		
	Never	100				
	Not easily	75				
	Probably	50	X	50.0		
	Easily	25				
	Very easily					
10.1.5	Does the device make children follow special instructions? If yes,	20				
	No	100	X	100.0		

		Rating %	X	Mark %	Cumulative score %	Overall rating %
10.1.5.1	Are the instructions clear and easily understood by all children?	50				
	Very clear and easy to understand	100				
	Quite clear and easy to understand	75				
	Fairly clear and easy to understand	50				
	Unclear and difficult to understand	25				
	Very unclear and difficult to understand					
10.1.5.2	Can the instructions be easily forgotten or disobeyed by children?	50				
	Not at all easily	100				
	Not easily	75				
	Fairly easily	50				
	Easily	25				
	Very easily					
10.2	Does the device pose a risk to children? If yes,	*40*		40.0		
	No	100	**X**	100.0		
10.2.1	Can children get hurt (cuts, bumps, scratches, etc.) if they come in contact with the device?	25		18.8		
	Never	100				
	Not likely	75	**X**	75.0		
	Likely	50				
	Very likely	25				
	Always					
10.2.2	Can the device encourage children to engage in risky behaviour?	25		18.8		
	Never	100				
	Not very likely	75	**X**	75.0		
	Likely	50				
	Very likely	25				
	Always					
10.2.3	Does the device attract the attention of children?	25		12.5		
	Not at all	100				
	To a small degree	50	**X**	50.0		
	To a large degree					
10.2.4	Can the device cause children to lose their balance, fall or slip?	25		25.0		
	Not at all	100	**X**	100.0		
	To a small degree	50				
	To a large degree					

		Rating %	X	Mark %	Cumulative score %	Overall rating %
11	**Other Ergonomic Factors**	**10**		10.0		
11.1	Is the device likely to produce false alarms? If yes,	*80*		80.0		
	No	100	**X**	100.0		
11.1.1	What is the expected frequency of the false alarms produced by the device?	50		50.0		
	None	100	**X**	100.0		
	Low	75				
	Moderate	50				
	High	25				
	Very high					
11.1.2	What is the level of annoyance produced by the device's false alarms?	50		**50.0**		
	None	100	**X**	100.0		
	Low	75				
	Moderate	50				
	High	25				
	Very high					
11.2	Is the device likely to produce a noise involuntarily? If yes,	*20*		20.0		
	No	100	**X**	100.0		
11.2.1	What is the noise level of this involuntary noise?	50		50.0		
	None	100	**X**	100.0		
	Low	75				
	Moderate	50				
	High	25				
	Very high					
11.2.2	What is the annoyance level of this involuntary noise?	50		50.0		
	None	100	**X**	100.0		
	Low	75				
	Moderate	50				
	High	25				
	Very high					

		Rating %	X	Mark %	Cumulative score %	Overall rating %
C	**COST EFFECTIVENESS AND OTHER FACTORS**	**100**		**73.0**	**77.4**	**10%**
12	**What does the device cost?**	35		28.0		
12.1	What is the purchase price of the device in dollars?	*20*		20.0		
	$0-500	100	**X**	100		
	$501-1000	75				
	$1001-2000	50				
	> $2001	25				
12.2	What are the maintenance costs of the device?	*20*		20.0		
	None	100	**X**	100.0		
12.3	What are the installation costs of the device?	*20*				
	1 hour per bus	100				
	2 hours per bus	75				
	3 hours per bus	50				
	4 hours per bus	25				
12.4	What are the operating costs (slow down operation of school transport) of the device?	*20*		20.0		
	None	100	**X**	100.0		
12.5	What are the training costs for the device?	*20*		20.0		
	1 hour for a group of 10 drivers or more	100	**X**	100.0		
	2 hours for a group of 10 drivers or more	75				
	3 hours for a group of 10 drivers or more	50				
	4 hours for a group of 10 drivers or more	25				
13	**What is the mean cycle failure on components of the device?**	35		35.0		
	Reliability cycle as related to possible failure of components is known	100	**X**	100.0		
	Reliability cycle related to possible failure of components is unknown					
14	**Is the device guaranteed?**	20				
	Life warranty on original vehicle	100				
	10 years	75				
	5 years	50				
	1 year	25				
	No warranty		**X**			

		Rating %	X	Mark %	Cumulative score %	Overall rating %
15	**Other Factor**	10		10.0		
	Does the device operate without making excessive noise outside the vehicle?	10		10.0		
	Yes	100	**X**	100.0		
	No					
	Final result		[redacted]	[redacted]	[redacted]	[redacted]

Final result was 77.39%