

ShakeAlert® and schools: Incorporating earthquake early warning in school districts in Alaska, California, Oregon, and Washington

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ABSTRACT

The U.S. Geological Survey-managed ShakeAlert® earthquake early warning system is the first public alerting system in the United States to provide rapid mass notification when an earthquake is detected. Although public alert delivery via mobile phones began in California in 2019 followed by Oregon and Washington in 2021, little is known about what might drive widespread implementation in at-risk institutional settings such as schools. For example, there has been limited research on how to best integrate earthquake early warning into existing emergency plans, alert systems, and drills to keep school children and personnel safe in an earthquake. To address this gap, in the spring of 2022, every school district superintendent in Alaska, California, Oregon, and Washington was sent a 15-min online survey. The survey assessed superintendent knowledge of ShakeAlert, preferences for alert messaging, and perceived opportunities and barriers to incorporating the system in schools. The results showed that superintendents had low awareness of ShakeAlert but held positive perceptions of the system's potential to enable life-saving protective actions. A major barrier to adoption included the perceived financial cost of implementing and maintaining the system. There were some statistically significant differences in state responses, and future research could investigate the specific needs of each state based on school district size and composition, hazard exposure, and earthquake experience. Together these findings can help inform targeted strategies to increase ShakeAlert adoption in schools and ultimately improve the safety of school children and staff during earthquakes.

1. Introduction

In the United States, most children ages five and older spend the majority of their waking hours outside the home at school [1]. Schools provide students with curriculum-based education, nutrition, physical and mental health care, and opportunities for play and socialization with peers and adults [2]. Schools are also essential to disaster management as they serve as family and community hubs for preparedness and emergency response [3]. When disaster strikes, children are especially at risk to death, injury, displacement, and long-term disruption to their educational trajectories [4,5].

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Children in the United States are legally required to attend school.¹ Therefore, these institutions have the responsibility to protect the welfare of children and to follow protocols to maintain their safety while on campus [2]. This involves preparing students, teachers, and other school staff for different types of emergencies, including fires, a nuclear or chemical release, active shooters, and a variety of natural hazards such as earthquakes and floods [6,7]. Preparedness activities educate the school community about what to do during potential emergency situations [8]. Participating in regular drills and responding to scheduled alerts can improve preparedness, as these activities provide the opportunity to practice life-saving skills and behaviors before an event occurs [9].

Protective action guidance during earthquake drills and actual events varies by country. In the United States, the corpus of evidence shows that “drop, cover, and hold on” is the safest behavior to take, given the engineering standards and age of most existing buildings [10–12]. In the nation's earthquake-prone regions, students and staff regularly participate in earthquake-specific drills that provide opportunities for practicing protective actions [11,12]. For example, thousands of U.S. schools participate in the annual Great ShakeOut drill, where millions of people worldwide rehearse dropping to their hands and knees, covering their head and neck, and finding a sturdy piece of furniture to crawl under and hold onto [13]. These drills are critical for building behavioral self-efficacy [9] and developing muscle memory, so that people can act quickly and instinctually as soon as they feel a tremor or receive an alert [14,15].

Unlike many other natural hazards, earthquakes occur with little to no warning [16]. In recent years, however, seismic sensor technology has advanced enough to detect ongoing earthquakes in the early stage of fault rupture. By combining these real-time seismic detectors with fast telemetry capability and data processing software, this information can be transmitted into an alert through a system known as earthquake early warning (EEW) [17]. The ShakeAlert® EEW System—operated by the U.S. Geological Survey (USGS)—is the first public alerting system in the United States to provide rapid mass notification when an earthquake is detected, potentially offering seconds to tens of seconds of warning before strong shaking arrives [18]. ShakeAlert entails a partnership between USGS and the three states where it is operational: California, Oregon, and Washington. A fourth state, Alaska, has received Congressional approval and funding to work with USGS on developing an implementation plan for possible future expansion of the ShakeAlert System.²

When ShakeAlert detects ground motion, the information is sent to USGS processing centers to quickly estimate the location, magnitude, and shaking intensity of the earthquake [19,20]. These estimates are published by USGS as a data product called a ShakeAlert Message. USGS has worked with technical partners to establish earthquake magnitude (M) thresholds for sending alerts, such as M5.0 set for Wireless Emergency Alert (WEA)-capable devices sent to the public and M4.5 set for smart phone applications downloaded by individuals [19,21]. If the estimates reach a predesignated alert delivery threshold, USGS-licensed operators use ShakeAlert Message data to deliver alerts through cell phone applications or public address systems [19]. Recipients include institutional users such as public transportation systems, hospitals, and schools.

Public alert delivery to cell phones by ShakeAlert began in California in 2019, followed by Oregon and Washington in 2021 [11]. While anyone with a mobile phone can receive an alert on their smart or non-smart phone devices from the WEA system [22], institutional users—including schools or entire school districts—that wish to formally connect to ShakeAlert can pursue one of two options. One option allows for a school (or school district) to become a USGS License to Operate (LtO) technical partner and operate their own in-house system. Another approach is for the school to become the customer of an existing LtO technical partner that sells and/or distributes ShakeAlert-powered products and services. The first option allows free access to the ShakeAlert Message data feed and all testing and development tools. However, in-house development requires considerable time, effort, technical expertise, and the ability to meet USGS-mandated performance standards. In the second option, schools are responsible for the cost of the installation and integration of equipment that receives alerts and triggers automated actions such as activating a public address system to play a drop, cover, and hold on message. These alerting services are subject to recurring subscription fees to ShakeAlert LtO technical partners [23] USGS, 2022a, [24].

At present, there is little publicly available information on the cost of adopting ShakeAlert at the school or school district level, as costs can vary dramatically depending on, for example, the size of the school or the district, the number of buildings, and the age of the school public address system. A USGS-published case study, however, indicates that one district in Washington upgraded their public address network to adopt ShakeAlert for under \$100,000, with grants covering most of the initial expenses [25]. Ongoing implementation costs to maintain ShakeAlert were reported to be about \$150 per month [25].

2. Previous research on earthquake early warning and schools

ShakeAlert research initially focused on the technology itself, with teams, for example, conducting performance testing to evaluate the effectiveness of different algorithms to estimate earthquake origin time, magnitude, and epicentral location [18,26,27]. With the ShakeAlert System operational in California, Oregon, and Washington and with possible future expansion into Alaska and other states, USGS and its partners have worked to establish a comprehensive social science research agenda [11,16,22,28]. Based on this body of research, an education and training program is being developed so that diverse members of the public receive information on how to respond to alerts [29,30]. Further, social scientists have begun to explore topics related to the end-user experience, including examining preferences for alert thresholds and pre- and post-event alert messaging, tolerance for false or missed alerts, and perceived

¹ A very small percentage of children in the U.S. legally attend home school or take online classes and therefore are not required to spend time in school buildings [59]. However, for the purposes of this research, we are referring to the approximately 90 % of U.S. school-age children who are enrolled in public schools and regularly occupy these physical spaces.

² Explanatory Statement, Division G – Department of the Interior, Environment, and Related Agencies Appropriations Act, FY2022 to accompany H. Rept. 117-83 for P.L. 117-103.

usefulness of ShakeAlert [16,28,31,32]. Only limited case study research, however, has examined whether schools in earthquake-prone regions are taking steps to adopt ShakeAlert and how school leaders perceive the technology and barriers to adopting it [33].

Research on other EEW systems in schools outside the United States shows that these technologies can provide lifesaving warnings to school children and staff. In Mexico City, for example, which initially prioritized schools for receipt of EEW and where a radio-based EEW system has been available to the public since 1993, there is evidence that the technology can effectively warn the school community that a large earthquake is imminent [34,35]. During the Magnitude 7.3 Copala Earthquake in Mexico City in 1995, an alert was received by an estimated 1,970,000 students—97 % of the student population at the time. According to education officials, the alerted children were orderly and well-coordinated as they followed instructions. Today, all public schools in Mexico City receive alerts through multi-hazard radio receivers and the government broadcasts public alerts over thousands of loudspeakers installed throughout the city [35].

Studies in Japan also suggest that EEW can be successful at protecting school children if accompanied by regular drills [36,37]. For instance, Motosaka and Homma [37] found that students in four schools were able to follow alert guidance by ducking under their desks, covering their heads, and holding onto their desk legs moments before a M7.2 earthquake. They had practiced protecting themselves in this way during a drill just days earlier, so when the school broadcasting system sent the alert, they received a 21-s warning and were physically and mentally prepared to act in advance of shaking [37]. Similarly in Taiwan, there is evidence that EEW could be effective in schools when coupled with drills and actual earthquake experience. In a three-year EEW experiment in Taiwanese schools that had recently experienced one or more earthquakes, Wu and colleagues [38] found that most students followed the practiced evacuation procedures calmly when they received an EEW alert. These studies from other countries suggest that implementing ShakeAlert in schools in earthquake-prone regions of the United States can also provide valuable time for children, teachers, and staff to protect themselves by dropping, covering, and holding on or taking other appropriate protective actions [39].

More than 7 million children attend schools in the three U.S. states that currently have access to EEW. Specifically, an estimated 5.5 million children attended K-12 public schools in California in 2022, with an additional 1.1 million in Washington public schools and 582,000 in Oregon public schools [40]. There are 977 school districts in the California public school system, 306 in Washington, and 197 in Oregon, with these districts encompassing thousands of elementary, middle, and high schools across the three-state region [40]. Yet, as of early 2024, only one private school (in California) and four school districts—two in Washington, one in Oregon, and one in California—had adopted this potentially lifesaving technology [33]. While the diffusion of an innovation can take time [41], steps can be taken to accelerate more widespread adoption of ShakeAlert in schools. Research is the critical first step towards identifying approaches that will be the most fruitful at enabling many more schools to use the technology. Topics ripe for investigation include determining awareness levels among school leaders and what information school leaders need to make informed decisions about ShakeAlert. In terms of practical applications, such research can help with identifying opportunities for collaboration between USGS, its technical partners, and schools.

3. Methods

The University of Colorado Boulder-based members of the research team conducted a survey of public school superintendents in Alaska, California, Oregon, and Washington to assess gaps in knowledge about ShakeAlert in schools [42].³ Superintendents were the target sample population because their role involves managing budgets and identifying goals, policies, and procedures to implement across schools within their districts [43]. Further, one of their primary responsibilities is to ensure student safety and, as a result, most superintendents are familiar with school-based alert and warning systems for building fires, active shooters, and other hazards. School administrators are also aware of the complicated dynamics and costs associated with adopting additional alert and warning capabilities at the district level, even if they may not yet know about ShakeAlert [14,33].

The survey assessed superintendent awareness, perceptions, and preferences related to ShakeAlert, as well as potential opportunities and barriers to incorporating the system in schools. In addition to exploring these measures across the entire study sample, responses were compared across states, which differ in terms of drill mandates, funding, and risk of additional earthquake-related hazards (e.g., tsunami, liquefaction, landslides). Results from this survey can help to inform targeted strategies to increase ShakeAlert uptake and ultimately improve the safety of school children, teachers, and staff during earthquakes.

Every public school superintendent in Alaska ($n = 51$), California ($n = 987$), Oregon ($n = 176$), and Washington ($n = 303$) was invited to participate in a 15-min online survey about earthquake safety, drills, and warnings. The survey instrument included 35 questions, divided into three major sections. The first section included 11 questions asking superintendents about recent earthquakes in their districts and their schools' current emergency plans, drills, and warning systems. The second part of the survey, which consisted of 14 questions, was designed to determine what superintendents knew and thought about ShakeAlert, including their familiarity with the technology, current use of the system, and levels of adoption in the school district. Superintendents were also asked about potential funding for the system, perceived advantages and barriers to implementing it in their schools, preferences for alert messaging, and tolerance for false or missed alerts. The final 10 questions asked superintendents to describe their demographic background, professional experience, and their school district size, location, exposure to hazards, and whether it had a designated budget or personnel dedicated to emergency preparedness. Survey answers were not forced, so respondents could skip questions.

³ The University of Houston-based team member (Davies) helped co-lead the statistical analyses presented in this paper. The USGS-based research team members (McBride and de Groot) were involved in reviewing and contributing to the final manuscript; they did not take part in the distribution of the survey nor did they contribute to the collection or analysis of data.

The survey instrument was pilot tested in the spring of 2022 with academic researchers, school officials, and emergency managers familiar with ShakeAlert. The principal investigator for this study, Peek, provided a template and requested letters of support from state-level educational leadership in the four focal states. Alaska and Oregon submitted letters, which were included with the survey upon dissemination and follow-up to potential respondents in those states. California did not respond to the online request for a letter of support. While Washington was encouraging of the research, they declined to offer a letter of support. The final survey was distributed via email with a Qualtrics survey link on March 30, 2022. Respondents had until June 15, 2022, to respond, and three follow-up reminders were sent during the period when the survey was open. The final survey instrument, IRB protocol, and associated recruitment materials are published and publicly available for download [42].

The analyses in this paper are based upon a total of 225 survey responses (14.8 % response rate). Alaska had the highest overall response rate (29.4 %), followed by Oregon (25.6 %), Washington (16.5 %), and California (11.7 %). Although California had the lowest response rate, just over half of the respondents were from California (51.11 %) due to the high number of school districts there relative to the other states. The size of the school district represented by the superintendent varied, with small, medium, and large school districts included in the final sample (Table 1).

3.1. Statistical tests

Frequency distributions were calculated for each of the question responses across the entire dataset, then separately by state. Differences in the proportions of the responses across the four states were evaluated using chi-square tests. If the chi-square test assumptions were violated (i.e., 20 % of the cells did not have an expected count of five or more), a Fisher's exact test was used instead [44]. The Fisher's exact test measures the differences in proportions of the various outcomes in two nominal variables but does not compare the proportions to an ideal distribution. Instead, it assumes a fixed proportion and therefore is not subject to the assumption for the chi-square test [45]. If SPSS [46] was unable to calculate a Fisher's exact number within 5 min, a Monte Carlo simulation was used to check whether the difference in the proportions of responses were significant [47]. Each Monte Carlo test used 10,000 repetitions and a seed number to ensure replicability of the test.

3.2. Multiple response questions

Some of the survey questions allowed for multiple responses where the respondent could check one or more of the responses that were applicable. When a respondent selected any of the multiple response options, the individual responses were coded as 1 = Yes and the remaining responses were coded as 0 = No. As a result, the N in such questions may be greater than the number of respondents, as multiple selections could be chosen. Because questions were not forced and respondents could skip entire questions, individuals who did not select any response options were coded as Missing (= 99).

3.3. Likert scale questions

Seven survey questions used a Likert scale [48]. Specifically, two questions asked respondents to rank on a scale from (1) Strongly Disagree to (5) Strongly Agree whether they felt that ShakeAlert had the potential to provide their students, staff, and teachers with lifesaving warnings to drop, cover, and hold on, to mentally prepare for shaking, to evacuate, or to take other protective actions in the event of an earthquake. Another Likert scale question asked superintendents to rank whether certain items were barriers to implementing ShakeAlert in their schools on a scale of (1) Not a Barrier to (5) Major Barrier. Superintendent preferences for alert messaging and their tolerance for false alerts were assessed with statements on a scale from (1) Not at All Important to (5) Extremely Important. Finally, two questions explored concerns surrounding false or missed alerts with statements ranging from (1) No Impact to (5) Major Impact.

To assess the average response from superintendents on these questions, we created a weighted average using the following formula:

Table 1
Respondent location and school district size.

Variable	Number of Respondents	Percentage of Sample
Respondents by State		
Alaska	15	6.67
California	115	51.11
Oregon	45	20.00
Washington	50	22.22
Total	225	100.00
District Size (number of students)		
Less than 300	54	24.00
300 to 599	29	12.89
600 to 999	22	9.78
1000 to 2499	21	9.33
2500 to 4999	27	12.00
5000 to 9999	26	11.56
Missing	46	20.44
Total	225	100.00

$$\bar{x} = \sum_{i=1}^n w_i x_i / n$$

Where: w is the value for the Likert response (1 through 5), $x = 1$ (response) or $x = 0$ (no response) and n captures the number of observations.

4. Results

4.1. Participant characteristics

Most of the respondent sample identified as male (57.33 %), white (61.33 %), middle-aged (mean age = 54.91 years), and held a master's or professional degree or higher (72.89 %). The average length of reported time in the position was 5.96 years, indicating a similar tenure to the national average for superintendents [49] (Table 2).

4.2. Awareness of ShakeAlert

In the survey, ShakeAlert was introduced as follows: "ShakeAlert is a U.S. Geological Survey operated earthquake early warning system that detects significant earthquakes quickly so that alerts can reach many people before shaking arrives. It may also trigger automated system shutdowns in some cases. ShakeAlert is currently operational in California, Oregon, and Washington. Before taking this survey, had you previously heard of ShakeAlert?"

When asked about their knowledge of ShakeAlert, only 38 % of respondents had previously heard of it. However, as Fig. 1 depicts, there were significant differences in levels of awareness about the system between states (Fisher's exact test, $p = 0.027$). Awareness was lowest among superintendents in Alaska (13 %), where the system is not operational. About one third of respondents were aware of the system in Washington (30 %) and California (37 %). In Oregon, over half of respondents (56 %) had heard of ShakeAlert. Of those superintendents who had sought information about the system, they had most frequently consulted local emergency management agencies (63 %) followed by USGS (28 %).

Table 2
Participant characteristics.

Variable	Number of Respondents	Percentage of Sample
Gender		
Man	129	57.33
Woman	39	17.33
Transgender/Gender Variant/Non-Conforming	0	0.00
Prefer not to answer	10	4.44
Did not answer	47	20.89
Total	225	100.00
Highest Level of Education		
Some College	2	0.89
Associate's Degree	2	0.89
Bachelor's Degree	9	4.00
Master's/Professional Degree	126	56.00
Doctoral Degree	38	16.89
Prefer not to answer	2	0.89
Did not answer	46	20.44
Total	225	100.00
Race and Ethnicity		
African American/Black	2	0.89
Asian American/East Asian/South Asian/Southeast Asian	3	1.33
Hispanic/Latinx	15	6.67
Indigenous/Native American/Alaska Native	4	1.78
White	138	61.33
Prefer not to answer	17	7.56
Did not answer	46	20.44
Total	225	100.00
Age		
X: 54.91, SD: 7.728	153	68.00
Did not answer	72	32.00
Total	225	100.00
Length of Time in Position		
X: 5.96, SD: 6.228	176	78.22
Did not answer	49	21.78
Total	225	100.00

X = Mean.

SD = Standard Deviation.

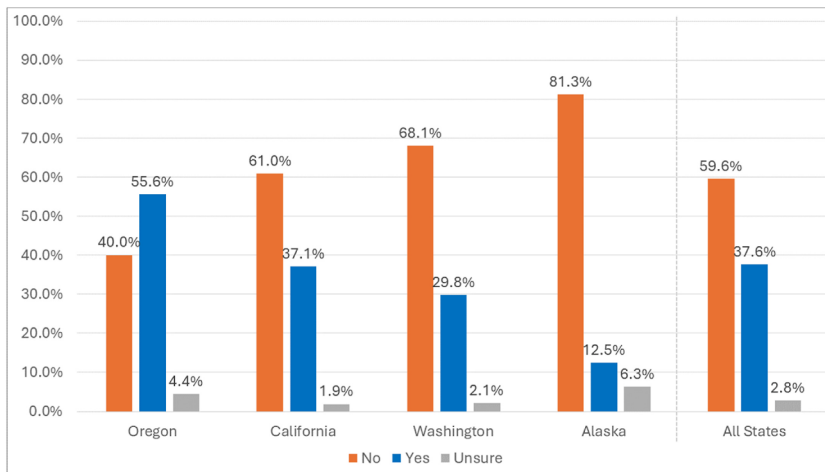


Fig. 1. Superintendent Awareness of ShakeAlert by State. Note. $n = 213$. The figure displays how respondents answered the question, “Before taking this survey, had you heard of ShakeAlert?”

Additional analyses were conducted to understand what factors might be driving these differing levels of awareness among superintendents. First, we evaluated whether superintendent demographic characteristics and professional experience (i.e., age, education, gender identification, racial and ethnic identity, time in position) were associated with awareness of ShakeAlert. Our Chi square statistical tests indicated, however, that none of these characteristics were significantly associated with awareness. Next, we assessed whether characteristics of the school district—such as its size, emergency preparedness budget, types of emergency plans and drills—were associated with superintendents’ awareness of the system; these variables, too, however, were mostly nonsignificant (see Tables A.1 and A.2 in the appendix).

Only two factors in these additional analyses proved to be significantly associated with superintendents’ awareness of ShakeAlert. The first factor was related to their risk perceptions; those superintendents who perceived earthquakes as a risk in their school districts were more likely to have heard about the technology. The second factor concerned superintendents’ experience with other school-based hazard alert systems; superintendents whose districts had extreme weather alert systems installed in their schools were also slightly more likely to be aware of ShakeAlert. These results are reported in Table 3 along with the findings for state-level differences. The effect sizes for these variables were small to medium, which implies that factors beyond those assessed in the survey may be driving awareness.

4.3. Adoption of ShakeAlert

Most of the respondents indicated that the superintendent was the decision-maker regarding potential adoption of a new alert system such as ShakeAlert, with at least 75 % of respondents in every state indicating that superintendents had this administrative responsibility. The Fisher’s exact test indicated that there was no statistically significant difference by state for this response ($p = 0.501$). When the subset of respondents ($n = 80$) who had previously heard of ShakeAlert were asked whether they had consid-

Table 3
Significant factors associated with Superintendent awareness of ShakeAlert.

Factor	Had you previously heard of ShakeAlert?				Chi Square Test of Independence
Superintendent state	No/Unsure		Yes		
	<i>n</i>	%	<i>n</i>	%	
Alaska	14	6.57	2	0.94	$\chi^2(4) = 11.72, p = 0.01$ $\varphi = .24, n = 213$
California	66	30.99	39	18.30	
Oregon	20	9.39	25	11.74	
Washington	33	15.49	14	6.57	
Superintendent perceives earthquakes as risk in district	No/Unsure		Yes		Chi Square Test of Independence
	<i>n</i>	%	<i>n</i>	%	
No	30	16.95	4	2.26	$\chi^2(1) = 13.12, p = 0.00031$ $\varphi = 0.27, n = 177$
Yes	78	44.07	65	36.72	
School district has extreme weather warning system installed	No/Unsure		Yes		Chi Square Test of Independence
	<i>n</i>	%	<i>n</i>	%	
No	76	45.24	41	24.40	$\chi^2(1) = 3.76, p = 0.05$ $\varphi = 0.15, n = 168$
Yes	25	14.88	26	15.48	

Note. The table displays those factors associated with superintendent awareness of ShakeAlert that had significant Chi Square tests of independence. Full results of nonsignificant factors are reported in Tables A.1 and A.2 in the appendix.

ered incorporating it as part of their emergency or operation plans, 49 % had not yet considered incorporating it, while 35 % had considered incorporating it, and 9 % were taking steps to do so. Only 5 % reported that they had already incorporated ShakeAlert and 3 % responded “Other.” A Fisher’s exact test indicated that there was no statistically significant difference in responses by state ($p = 0.095$) (Table 4).

4.4. Potential advantages of incorporating ShakeAlert in schools

When activated, EEW can provide seconds to tens of seconds of advance warning that can prompt people to take protective actions and automatically shut down gas, water, and other systems to protect life and property. Given the range of warning time that people may receive depending on their distance from the epicenter of an earthquake—with those who are closer to the epicenter receiving no or much less warning time—10 s or less of warning time was used on the survey.

Superintendents were asked about their level of agreement with statements regarding the protective actions students, teachers, and staff in their school districts would be able to take with 10 s of warning time, with 1 indicating that they strongly disagreed with a statement and 5 indicating that they strongly agreed. Survey results showed that superintendents across all four states mostly agreed or strongly agreed that the alert would give students more time to drop, cover, and hold on. In addition to asking about the recommended protective action, respondents were also asked whether the alert would allow students to mentally prepare for shaking or to evacuate the building—the latter being an action that may be necessary if there was a tsunami warning or if a building were to become unsafe. Respondents generally agreed that an alert could allow students to mentally prepare. The results for evacuation were more mixed, with a Fisher’s exact test yielding a significant difference in proportion of responses across states. In California, Washington, and Oregon, most superintendents felt that a 10-s or less alert would not provide students with enough time to evacuate. Alaska respondents, however, were mostly neutral (54 %) about the possibility (Fig. 2).

Regarding teachers and other school staff, most superintendents reiterated what they had said about the benefits of ShakeAlert for students and strongly agreed that the technology would also give teachers and staff more time to drop, cover, and hold on. In addition, as shown in Fig. 3, superintendents felt that the 10-s warning would allow teachers and staff to help their students take the ap-

Table 4
Superintendent interest in incorporating ShakeAlert into district emergency operations.

Have you considered incorporating ShakeAlert into the district's emergency preparedness or other operations plans?										
State	No		Yes, but have not done so		Yes, taking steps to do so		Yes, already incorporated		Total	
	N	%	n	%	n	%	n	%	n	%
Alaska	1	50	1	50	0	0	0	0	2	100
California	23	59	10	26	4	10	0	0	39 ^a	100
Oregon	11	44	9	36	1	4	4	16 ^b	25	100
Washington	4	29	8	57	2	14	0	0	14	100
All 4 States	39	49	28	35	7	9	4	5	80	100

Note. $n = 80$. Analysis was restricted to the subset of 80 superintendents with prior knowledge of ShakeAlert. Fisher’s Exact Test $p = 0.095$.
^a Two respondents from California selected “Other,” which is not shown in the table. These two responses represented 5 % of California’s total and 3 % of all responses. Their written responses to explain their selection of “Other” said that their school districts may have already adopted ShakeAlert, but that they were unsure.
^b Although four superintendents indicated that their school district had already incorporated ShakeAlert, our collaborators at USGS confirmed that only one school district in Oregon had adopted the technology as of the spring of 2024. This discrepancy may be due to a lack of knowledge of the system or understanding of what steps are needed to incorporate it at the school district level.

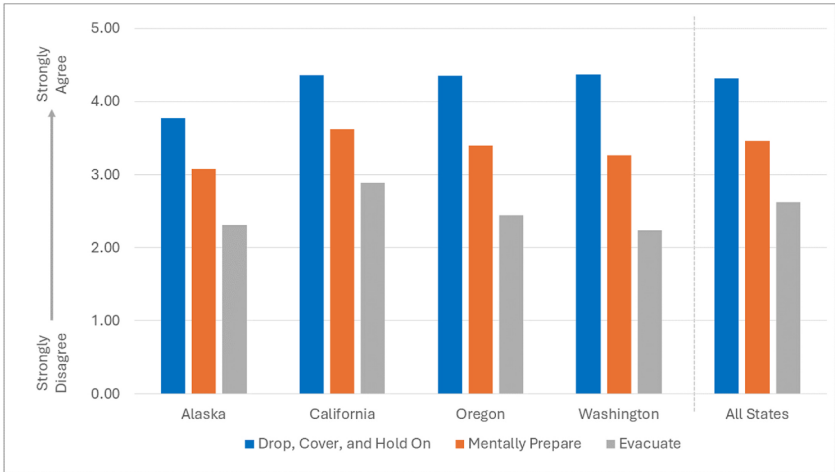


Fig. 2. Superintendent Agreement that an Alert of 10 Seconds or Less Could Enable Students to Take Specific Protective Actions. Note. $n = 188$.

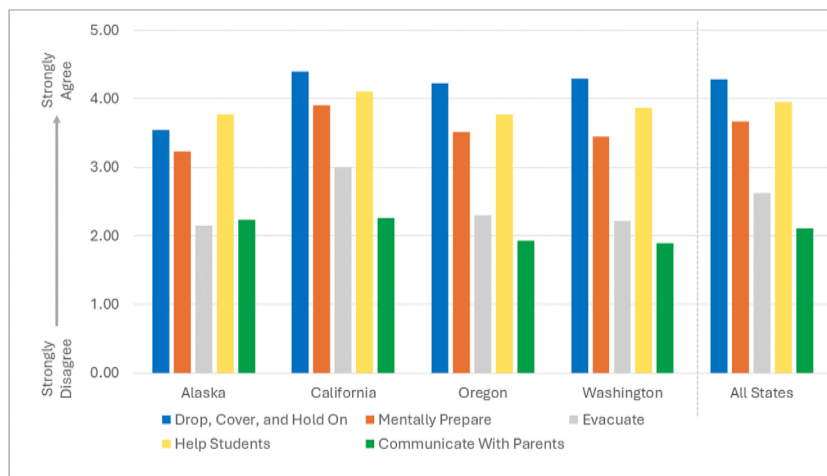


Fig. 3. Superintendent agreement that an alert of 10 seconds or less could enable teachers and staff to take specific protective actions. Note. $n = 187$.

appropriate protective actions. They did not, however, feel it would enable teachers or staff to communicate with parents. Superintendents also did not feel the 10-s warning would allow teachers and staff to evacuate, if such an action was necessary, which was consistent with their opinions on student evacuation.

4.5. Financial costs and barriers to implementing ShakeAlert in schools

Because there is no clear, set cost for implementing ShakeAlert in schools, the survey introduced the topic in the following way: “Adding an earthquake early warning system to the school district will likely require paying for both the initial installation of hardware required to activate the earthquake early warning system and an annual subscription fee to maintain alert delivery service in schools in your district. Please indicate who you think should pay for these two expenses.”

As shown in Fig. 4, superintendents across all four states predominantly said that the state government should bear the initial costs of adopting ShakeAlert. Their second preference was for the federal government to cover this expense. Alaska was the only state where a substantial minority of superintendents indicated that local government (33 %) or families (7 %) should pay the initial installation; however, most Alaskan superintendents still preferred the costs be covered by the state or federal government.

Regarding paying annual subscription fees to maintain ShakeAlert, most superintendents again indicated that they preferred that the state or federal government cover these costs, with 74 % saying that state government should do so and 37 % choosing the federal government. Nearly one third of superintendents said that their school districts could contribute to paying these annual subscription and maintenance costs, but their financial contribution would be limited. When asked how much their school district could contribute annually, 37 % of superintendents said less than \$100 and an additional 40 % said no more than \$1500 per year.

As depicted in Fig. 5, three-quarters of respondents said that the financial costs of the technology would be a moderate or major barrier to adoption. A Fisher's exact test found no significant association between states and financial barriers to implementation

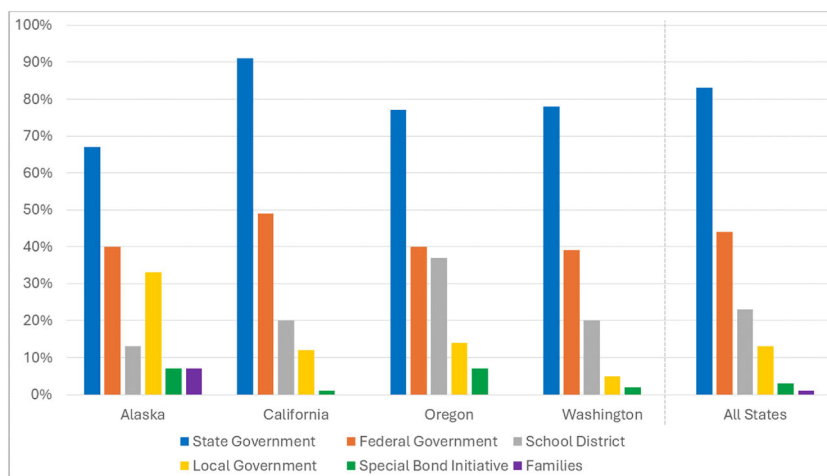


Fig. 4. How Superintendents Prefer to Fund Initial Installation of ShakeAlert. Note. $n = 196$. Respondents were allowed to choose more than one response.

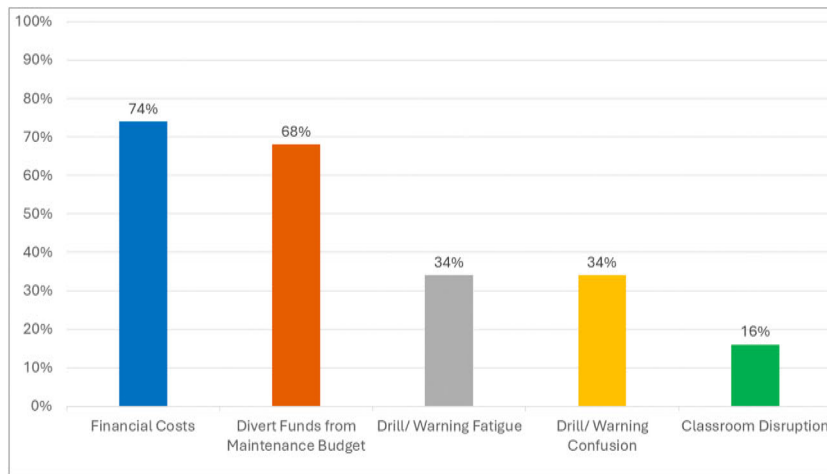


Fig. 5. Perceived barriers to implementing ShakeAlert in schools.

Note. $n = 184$. Respondents were allowed to choose more than one response.

($p = 0.767$), indicating that respondents in each state had similar concerns surrounding the costs of the system. They also expressed concern that adopting the technology could divert funds away from building maintenance and other mitigation projects. More than two-thirds of respondents indicated financial diversion was a moderate or major barrier. A Monte Carlo simulation determined that there was no statistically significant relationship between the proportion of responses across states ($p = 0.360$, 99 % confidence p lies between 0.348 and 0.373), again indicating that this was a relevant concern among respondents across all four regions.

As indicated in Fig. 5, superintendents perceived other non-financial issues as less of a barrier to adoption. For example, when asked whether they thought disruption of the classroom environment—such as through false alerts or too frequent alerts—would be a barrier to implementing ShakeAlert in schools, only 16 % of superintendents said it was a concern. The responses about the potential for ShakeAlert to lead to drill fatigue—here referring to a sense of overwhelm among students and staff about the number and frequency of different drills for different hazard types that schools must enact—were more mixed. However, on average the superintendents who responded to the survey were less concerned about drill fatigue (34 %) or drill confusion (34 %) as barriers to implementing ShakeAlert. There was no statistically significant difference in responses by state.

4.6. Preferences for alert delivery pathways and messaging

As part of the survey, superintendents were asked about how they would want their students, teachers, and staff to receive alerts if the district were to adopt ShakeAlert. The question allowed them to make multiple selections among the following options: SMS/text messaging, smartphone app, computer alert, siren/public address system within a school building, a specific device designed to receive a ShakeAlert-powered alert, or other (Fig. 6). Most superintendents across each of the states indicated that they preferred their school community to receive alerts through multiple mechanisms. SMS/text messaging, for example, was chosen by nearly 80 % of superintendents as the preferred way to provide alerts. There was no statistically significant difference in responses by state. Superin-

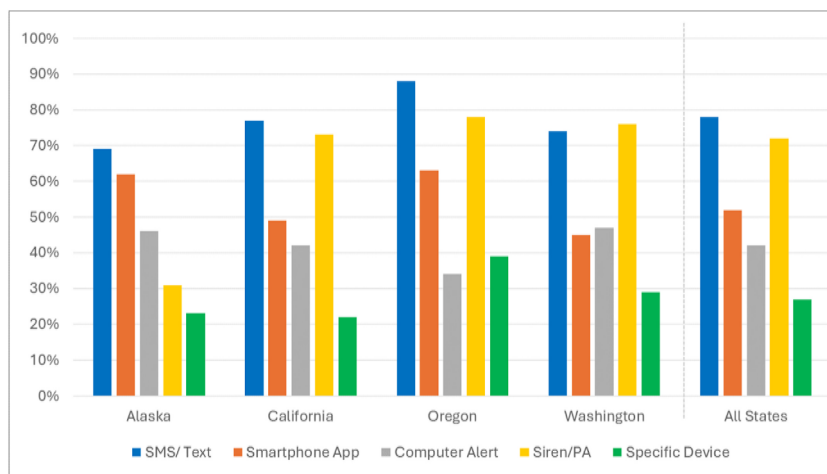


Fig. 6. Preferences for Alert Method. Note. $n = 183$. Respondents were allowed to choose more than one response.

tendents in California (73 %), Washington (76 %), and Oregon (78 %) also strongly preferred having siren/public address systems that could alert their students and staff. Respondents in Alaska (31 %), however, were less interested in this option. Across the four states, fewer superintendents indicated wanting a specific ShakeAlert device than the other options, although superintendents in Oregon (39 %) were slightly more interested in this option than those in Washington (29 %), Alaska (23 %), and California (22 %). There were no significant differences in responses across the other methods of receiving alerts.

In terms of the message provided in an alert, on average superintendents favored actionable guidance, followed by a reminder to stay calm, a countdown to shaking, and more information about the earthquake (e.g., epicenter location, magnitude). There were no significant differences in preferences for these alert messages across states. For messaging after shaking would have stopped, most respondents favored a message about next steps, information about additional hazards, a reassuring note, and further information about the earthquake. There was a significant difference in how the states rated having a post-earthquake message that provides information about next steps. Most Oregon respondents thought this was extremely important (73 %) whereas superintendents in the other three states tended to think this was only moderately important. For reference, Fig. 7 presents an example of an alert and of post-alert information currently delivered by ShakeAlert LtO technical partners [16,22].

4.7. Tolerance for false and missed alerts

The survey asked superintendents how they felt false alerts—referring to ShakeAlert issuing a warning when no earthquake was recorded—would affect their school district. On average, most participants thought false alerts could negatively impact teacher and parent confidence in ShakeAlert. They also thought that false alerts could moderately impact student confidence, drill fatigue, and classroom instruction time. There was a significant difference in how respondents rated the impact of false alerts on classroom instruction across states. Superintendents in Alaska were more likely to say that false alerts would have a major impact (42 %) than respondents in the other three states. Superintendents in Oregon were more likely to say this would have a moderate impact (60 %) than superintendents in California (38 %), Washington (17 %), and Alaska (17 %). Superintendents had similar levels of concern about missed alerts, which refer to instances where ShakeAlert fails to issue a warning during a recorded earthquake.

5. Discussion

The survey data examining ShakeAlert awareness, perceptions, and preferences among superintendents generated several findings that can provide a foundation for building the social science evidence base concerning EEW and schools in the U.S. Further, these

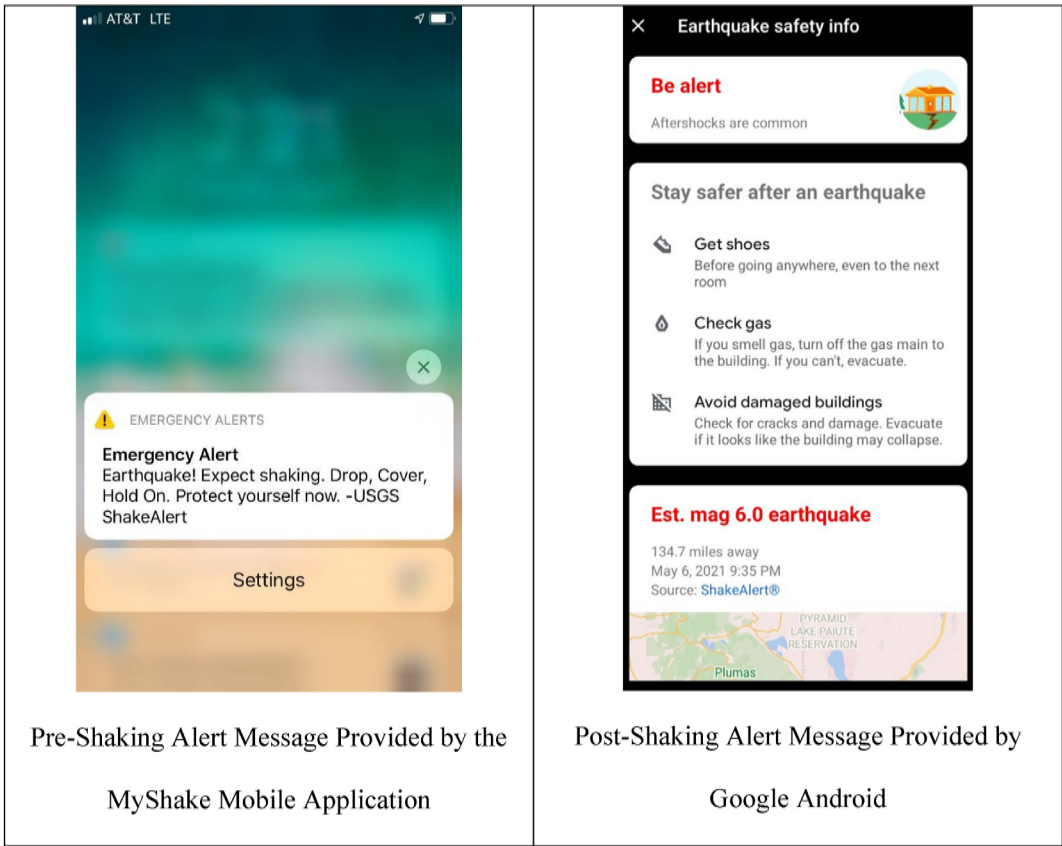


Fig. 7. Examples of pre- and post-shaking alerts issued by ShakeAlert licensed operators.

findings can be used to enhance ShakeAlert's uptake and usefulness in schools in earthquake-prone regions of the U.S. The key findings are summarized below, and their implications for policy and practice are emphasized.

5.1. Outreach needed to raise awareness of ShakeAlert among superintendents and school leaders

The survey results showed that superintendents strongly agree that ShakeAlert can provide valuable, lifesaving warnings to their students, teachers, and staff. Yet, it also revealed that superintendents have low awareness of the technology. While understandable that system awareness might be low in Alaska (13 %), where ShakeAlert is not operational, only 37 % of respondents in California (where the system had been operational for more than two years at the time of the survey release) and 30 % in Washington (where the system had been operational for several months prior to the release of the survey) were aware of ShakeAlert. Although more than half of superintendents in Oregon (56 %) reported they were aware of the technology—perhaps because there has been contention in that state concerning earthquake early warning and the best recommended protective actions in an earthquake-tsunami event [50,51]—44 % still responded that they had not heard of ShakeAlert.

Because awareness is obviously a first step toward adoption, additional analyses were conducted to understand what factors might be driving these differing levels of awareness among superintendents. The analyses revealed that demographic characteristics, years of professional experience, and characteristics of the school district itself were *not* associated with higher levels of awareness. Only two factors—superintendents' earthquake risk perception and their experience with other school-based hazard alert systems—proved to be significantly associated with superintendents' awareness of ShakeAlert. Because the effect sizes for these variables were small to medium, it is likely that factors beyond those assessed in the survey may be driving awareness.

These findings concerning awareness suggest that outreach and promotion specifically targeting superintendents as well as school board members, school emergency managers, principals, teachers, and others who may have a say—and certainly have a stake—in the adoption of this potentially life-saving technology would likely improve awareness [33]. Further, in light of Oregon's relatively high awareness levels when compared to the other states, an examination of the impact of media coverage of the system and local- and state-level dissemination tactics would be worthwhile to understand the best outlets and communication strategies to reach school district leadership. Similarly, those superintendents with high levels of risk perception and knowledge of alert systems might be poised to serve as mitigation champions for the early adoption of ShakeAlert [52]. Their voices and stories could be spotlighted in messaging campaigns, as fellow superintendents may be more likely to listen to and respond to their colleagues' appeals for action in adopting this technological innovation [41]. For the participants who indicated that they had sought out information about ShakeAlert, the most common sources were local emergency management agencies and USGS. This highlights the importance of government agencies and local to federal partnerships in disseminating information to school leaders about ShakeAlert. However, because schools are complex institutional environments with diverse constituencies and unique funding and regulatory environments, approaches to outreach and collaboration will need to take various forms [3].

5.2. Superintendents perceive financial costs of installing and maintaining ShakeAlert as a major barrier to adoption

Superintendents across all four states perceived the financial costs of ShakeAlert as a major barrier to installing it in their schools. They also predominantly said that the initial costs of adopting ShakeAlert should largely be financed by the state government, followed by the federal government. This finding is perhaps not surprising, as funding and financial management are challenging for school districts across the United States, and therefore many leaders turn to state or federal sources of funding to support new interventions. The most recent School Superintendents Association survey, for example, indicated that finance was the most time-consuming issue superintendents face [53]. Given that public schools—and especially those that serve communities of color, rural areas, and low-income populations—have limited resources and many pressing demands [54], there is a need for clarity concerning the implementation and maintenance costs of ShakeAlert. Outreach materials that plainly describe the potential financial commitments and associated benefits of such investments could aid decisions—and perhaps alleviate some concerns—regarding the use of ShakeAlert.

The findings from this research also strongly suggest that including a guide that assists superintendents and other school leaders in accessing available state and federal grant programs that support hazard alert and warning systems could be part of a successful outreach strategy [6]. For example, when the Stanwood-Camano School District in Washington added alerting capability to all 13 of its buildings through an upgraded, centralized public address system, they were able to pay most of the costs through grants [25]. Developing additional case studies and lists of available funding mechanisms could help further ease superintendent concerns and ensure that the implementation of ShakeAlert does not hinder other important investments in school infrastructure and safety.

While superintendents indicated that financial costs could impede adoption of ShakeAlert, results indicated that they were not as worried about other non-financial issues. Most respondents, for example, did not consider the potential for ShakeAlert to cause classroom disruptions to be a barrier to adopting the alert system. Similarly, most superintendents in these same states did not feel that drill fatigue or confusion would be major barriers. Responses in Alaska were more split, which may relate to their recent experience with the 2018 Anchorage earthquake and the subsequent disruption caused, as well as their other concerns with drill fatigue across different hazard types [14,33]. Despite this finding, there were no significant differences in responses by state. Together these results suggest that while there may be some apprehension among school leaders for adopting a new system, overall, the respondents recognized the importance of regular drills and alerts for maintaining preparedness and safety in the event of an earthquake.

5.3. Superintendents were concerned about maintaining confidence in the ShakeAlert System

While the survey revealed that superintendents did not perceive the false or missed alerts to be barriers to adopting ShakeAlert, they did believe such errors could erode confidence in the system among students, parents, and teachers. This contrasts with the sur-

vey findings reported by Bostrom et al. [28], where there was a much higher reported tolerance for false alerts among the general public. The findings presented in this paper therefore suggest a heightened sensitivity to the proper use of alert systems in school settings—a sensitivity that is perhaps driven by the fact that schools carry out so many drills for so many different hazard types throughout the year [3,33].

Effective communication strategies that both explain the possibility of false alerts, as well as the ongoing efforts to mitigate these issues through regular testing and quality control, are therefore needed to maintain trust in the ShakeAlert System. Past research emphasizes the importance of quickly sending follow-up messages after false alerts that clearly explain that recipients are safe and can return to normal functioning [16,28,55]. In a study by Sutton et al. [55], for example, a post-alert message was sent after a false earthquake alert in Ridgecrest, California. That research found that the most critical information that respondents wanted was to know if they were safe, not what happened or what to do next time. In regions where an alert may trigger other concerns, such as worries about building safety or the potential for a tsunami, tailored post-alert messaging could potentially provide additional reassurance. This is true in both the case of false alerts—when recipients need to be reassured of their safety to return to classroom instruction—as well as during actual events—when details about next steps are critical for ensuring safety and security. Taking these steps to maintain confidence in ShakeAlert among students, teachers, and parents will ensure that false or missed alerts do not become barriers to use after the system is installed.

5.4. Superintendents prefer alerts be delivered through multiple channels

Superintendents indicated a preference for alerting their students, teachers, and staff through multiple channels. Results from the survey revealed that the most selected method among superintendents across all states was receiving alerts via SMS/text messaging. This indicates a clear preference for mobile communication as the most convenient and widely accessible method for disseminating alerts to relevant school employees.

Given the respondents' preference for receiving mobile alerts, one possible implementation strategy would be to have school districts require that all classrooms have at least one mobile phone capable of receiving WEAs via SMS/text messaging, which all cell phones receive by default unless a user opts out. Some superintendents may be concerned about this approach, however, because many schools have enacted "no cell phone" policies for both teachers and students that could impede the receipt of alerts delivered only via mobile devices [33]. As an alternative possibility, research in Costa Rica has shown that installing protective boxes around cell phones and then mounting them in classrooms, hallways, gyms, and multipurpose rooms is an effective way to install an EEW system—and could perhaps be integrated into EEW alerts in the future [56]. Specifically, Brooks and colleagues (2021) showed that this solution was also cost effective as an end-to-end system, which suggests such an approach could alleviate some financial concerns concerning alerts as well. As more schools adopt EEW, it could be useful to study this and other available international approaches to assess which strategies are most desirable and feasible in the U.S.

As noted, however, relying solely on cell phone alerts may not work well as a school-wide alerting strategy in all districts. Superintendents appeared to be aware of the potential limitations of a mobile phone-based system and therefore preferred pairing additional alerting channels. More than 75 % of superintendents in Washington, Oregon, and California, for example, preferred to have a siren/public address system provide alerts as well. Across all four states, more than 50 % expressed interest in a computer-based alert system. Future research could evaluate how pairing mobile phones with other alerting systems may provide additional benefits, such as serving as a backup in case one system malfunctions or providing coverage across the school campus, rather than within each classroom. Developing outreach materials that inform school districts about the menu of alert channel options, their anticipated costs, and their advantages and disadvantages can inform superintendents and other school leaders who are deciding which approach best fits their needs and financial capacities.

Regarding alert message content, respondents highly favored actionable guidance, followed by reminders to stay calm, countdowns to shaking, and more information about the earthquake. These preferences indicate a need for clear and concise instructions that can enable individuals to take appropriate steps for their safety. For messaging after the shaking stops, respondents favored messages about next steps, information about additional hazards, reassuring notes, and further information about the earthquake. Interestingly, there was a significant difference in how the states rated having information about next steps, with most Oregon superintendents ranking this as extremely important. This is perhaps related to coupled earthquake-tsunami risk, which is a major threat to Oregon's coastal communities. School leaders in such coastal areas may want official guidance on whether to keep children and staff in place or to encourage them to rapidly evacuate. Because school buildings are generally older and used for longer periods of time than other structures in the United States [6], it will be important for post-alert messaging for schools to consider the age and type of building stock as well as other potential co-occurring hazards.

As outreach to schools continues, the nuances of how, when, and where children and those who educate them can receive these alerts will need to be kept at the forefront of all dissemination strategies. Schools would then need to regularly practice earthquake drills that integrate mobile alerts to fully leverage the power of this technology.

5.5. Limitations

There are limitations to this research that need to be acknowledged. First, though a census sampling approach was used, the response rate could be considered low at 14.8 %. This response rate, however, may be typical for superintendents. The American School District Panel Survey, for example, received only 150 responses from superintendents, which represented a 13.6 % completion rate [57].

Despite repeated follow-ups and other efforts to increase response rates, the findings presented here are not generalizable to all superintendents or school districts in the four-state region. The lack of a representative sample, geographical clustering by state, and

lack of linear relationship between key variables and ShakeAlert awareness meant the data did not lend themselves to regression analysis. We were therefore limited to generating univariate and bivariate statistics. Furthermore, there may have been selection bias because this was an opt-in survey. It is possible that those already aware of ShakeAlert, or those with positive perceptions related to the technology were more likely to respond. The findings may therefore be skewed. About one-fifth of the respondents declined to answer demographic questions, and therefore the demographic results should be read accordingly. Furthermore, to respect the respondents' anonymity, the survey asked about hazard experience but did not collect geographic location information. Therefore, survey data could not be overlaid with geospatial hazard exposure data.

With these limitations in mind, the analyses of the survey data presented in this paper yielded new findings that are specific to the school context. Because schools have been understudied in relation to EEW, this research provides an important early look into some of the possible concerns and opportunities as the system continues to be more widely adopted across the West Coast of the United States.

6. Conclusion

Millions of children attend schools across high-risk, earthquake-prone regions in the United States, and schools have a special responsibility to ensure the health and welfare of children [3,58]. Therefore, these institutions need to be aware of potentially lifesaving EEW systems such as ShakeAlert. Research in other nations, such as Mexico, Japan, Taiwan, and Costa Rica has demonstrated that drills and properly installed EEW systems can help prepare students for earthquake events and encourage them to take protective actions. This study, which is the first to focus systematically on EEW and school districts in Alaska, California, Oregon, and Washington, indicates that there is still much progress to be made in terms of raising awareness, lowering perceived barriers to adoption, encouraging implementation, and enhancing the long-term sustainability of the system. As ShakeAlert has become operational and widely available to the public, important gaps in knowledge remain about how to implement this technology in core social institutions such as schools. Because differences exist in terms of size, drill mandates, funding, and risk of additional earthquake-related hazards such as tsunamis and landslides, a one-size-fits-all approach is not likely to work for schools across different states. Therefore, it is important to keep schools and their diversity in focus while also collaborating directly with school officials to move forward with future research and implementation.

Disclaimers: Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. ShakeAlert® is a registered trademark of the U.S. Geological Survey and is used with permission.

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CRediT authorship contribution statement

Rachel M. Adams: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Holly Davies:** Writing – review & editing, Writing – original draft, Formal analysis. **Lori Peek:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Meghan Mordy:** Writing – review & editing, Methodology, Investigation. **Jennifer Tobin:** Writing – review & editing, Project administration, Methodology, Investigation. **Jolie Breeden:** Writing – review & editing, Methodology, Investigation. **Sara K. McBride:** Writing – review & editing, Methodology, Investigation. **Robert M. de Groot:** Writing – review & editing, Methodology, Investigation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Lori Peek reports financial support was provided by National Science Foundation, Award #1635593. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

Appendix

Table A.1
Nonsignificant Tests of Association Between Superintendent Characteristics and Their Awareness of ShakeAlert

Factor	Had you previously heard of ShakeAlert?				Chi Square Test of Independence
Superintendent age by birth decade	No/Unsure		Yes		
	<i>n</i>	%	<i>N</i>	%	
1940s	2	1.31	2	1.31	FFH Exact ^a (4) = 4.87, <i>p</i> = 0.30 <i>φ</i> = .18, <i>n</i> = 153
1950s	8	5.23	11	7.19	
1960s	43	28.10	32	20.92	
1970s	27	17.65	17	11.11	
1980s	9	5.88	2	1.31	
Educational level	No/Unsure		Yes		Chi Square Test of Independence
	<i>n</i>	%	<i>n</i>	%	
Less than high school	0	0.00	0	0.00	FFH Exact ^a (5) = 3.83, <i>p</i> = 0.613 <i>φ</i> = .15, <i>n</i> = 179
High school or GED	0	0.00	0	0.00	
Some college no degree	2	1.12	0	0.00	
Associate's degree	1	0.56	1	0.56	
Bachelor's degree	5	2.79	4	2.23	
Master's degree	80	44.69	46	25.70	
Doctoral degree	20	11.17	18	10.06	
Prefer not to answer	2	1.12	0	0.00	
Gender identity	No/Unsure		Yes		Chi Square Test of Independence
	<i>n</i>	%	<i>n</i>	%	
Woman	22	12.36	17	9.55	<i>χ</i> ² (2) = 0.66, <i>p</i> = 0.72 <i>φ</i> = 0.06, <i>n</i> = 178
Man	82	46.07	47	26.40	
Transgender	0	0.00	0	0.00	
Gender variant/non-conforming	0	0.00	0	0.00	
Prefer not to answer	6	3.37	4	2.25	
Racial and ethnic identity	No/Unsure		Yes		Chi Square Test of Independence
	<i>n</i>	%	<i>n</i>	%	
African American/Black	1	0.56	1	0.56	FFH Exact ^a (5) = 1.96, <i>p</i> = 0.91 <i>φ</i> = 0.10, <i>n</i> = 179
Asian American/East Asian/South Asian/Southeast Asian	2	1.12	1	0.56	
Hispanic/Latinx	11	6.15	4	2.23	
Indigenous/Native American/Alaska Native	3	1.68	1	0.56	
Middle Eastern/Arab American	0	0.00	0	0.00	
Native Hawaiian/Pacific Islander	0	0.00	0	0.00	
White	82	45.81	56	31.28	
Other	0	0.00	0	0.00	
Prefer not to answer	11	6.15	6	3.35	
Time in job by months	No/Unsure		Yes		Chi Square Test of Independence
	<i>n</i>	%	<i>n</i>	%	
0–12	20	14.08	8	5.63	FFH Exact ^a (9) = 12.30, <i>p</i> = 0.165 <i>φ</i> = 0.31, <i>n</i> = 142
13–24	15	10.56	4	2.82	
25–36	12	8.45	14	9.86	
37–48	16	11.27	9	6.34	
49–60	9	6.34	5	3.52	
61–72	8	5.63	4	2.82	
73–84	6	4.23	2	1.41	
85–96	2	1.41	4	2.82	
97–108	0	0.00	2	1.41	
109–120	2	1.41	0	0.00	
Perception of district's risk for natural hazards	No/Unsure		Yes		Chi Square Test of Independence
	<i>n</i>	%	<i>n</i>	%	
<u>Extreme heat</u>					<i>χ</i> ² (1) = 1.22, <i>p</i> = 0.34 <i>φ</i> = 0.08, <i>n</i> = 177
No	70	39.55	39	22.03	
Yes	38	21.47	30	16.95	
<u>Extreme cold</u>					<i>χ</i> ² (1) = 0.35, <i>p</i> = 0.69 <i>φ</i> = -0.04, <i>n</i> = 177
No	87	49.15	58	32.77	
Yes	21	11.86	11	6.21	
<u>Flood</u>					<i>χ</i> ² (1) = 1.69, <i>p</i> = 0.20 <i>φ</i> = 0.10, <i>n</i> = 177
No	73	41.24	40	22.6	
Yes	35	19.77	29	16.38	
<u>Hurricane</u>					Fisher's exact ^b (1), <i>p</i> = 1.00 <i>φ</i> = -0.06, <i>n</i> = 177
No	107	60.45	69	38.98	
Yes	1	0.56	0	0.00	

(continued on next page)

Table A.1 (continued)

Factor	Had you previously heard of ShakeAlert?				Chi Square Test of Independence
Superintendent age by birth decade	No/Unsure		Yes		
	<i>n</i>	%	<i>N</i>	%	
<u>Landslide</u>					$\chi^2(1) = 1.13, p = 0.86$
No	82	46.33	54	30.51	$\phi = -0.03, n = 177$
Yes	25	14.69	15	8.47	
<u>Severe storms</u>					$\chi^2(1) = 2.82, p = 0.09$
No	73	41.24	38	21.47	$\phi = 0.13, n = 177$
Yes	35	19.77	31	17.51	
<u>Tornado</u>					$\chi^2(1) = 2.23, p = 0.14$
No	107	60.45	66	37.29	$\phi = 0.11, n = 177$
Yes	1	0.57	3	1.70	
<u>Tsunami</u>					$\chi^2(1) = 1.84, p = 0.18$
No	93	52.24	54	30.51	$\phi = 0.10, n = 177$
Yes	15	8.48	15	8.48	
<u>Volcano</u>					$\chi^2(1) = 0.60, p = 0.44$
No	91	51.41	61	34.46	$\phi = -0.06, n = 177$
Yes	17	9.61	8	4.52	
<u>Wildfire</u>					$\chi^2(1) = 0.26, p = 0.61$
No	32	18.08	18	10.17	$\phi = .04, n = 177$
Yes	76	42.94	51	28.81	
<u>Winter Storms</u>					$\chi^2(1) = 3.58, p = 0.06$
No	50	28.25	42	23.73	$\phi = 0.14, n = 177$
Yes	58	32.77	27	15.25	
<u>Other</u>					Fisher's exact ^b (1), $p = 0.75$
No	102	57.63	64	36.16	$\phi = -0.06, n = 177$
Yes	6	3.39	5	2.83	

^a Fisher-Freeman-Halton exact test is used where expected cell count assumption is violated in greater than 2x2 tables.

^b Fisher's exact test is used where expected cell count assumption is violated for 2x2 tables.

Table A.2

Nonsignificant Tests of Associations Between School District Characteristics and Superintendent Awareness of ShakeAlert

Factor	Had you previously heard of ShakeAlert?				Chi Square Test of Independence
School district experienced earthquake(s) in past two decades	No/Unsure		Yes		
	<i>n</i>	%	<i>n</i>	%	
No	63	29.72	31	14.62	$\chi^2 = 1.33, p = 0.25$
Yes	31	33.02	48	22.64	$\phi = .079, n = 212$
Types of school district emergency plans	No/Unsure		Yes		Chi Square Test of Independence
	<i>n</i>	%	<i>n</i>	%	
<u>Emergency Preparedness</u>					Fisher's exact ^a (1), $p = 1.00$
No	8	3.77	4	1.89	$\phi = 0.02, n = 212$
Yes	124	58.49	76	35.85	
<u>Emergency Operations</u>					χ^2 (1) = 0.28, $p = 0.60$
No	51	24.06	28	13.21	$\phi = 0.04, n = 212$
Yes	81	62.26	52	65.00	
<u>Continuity of Operations</u>					χ^2 (1) = 0.58, $p = 0.45$
No	94	44.34	53	25.00	$\phi = 0.05, n = 212$
Yes	38	17.92	27	12.74	
<u>Other</u>					Fisher's exact ^a (1), $p = 0.30$
No	128	60.38	75	35.38	$\phi = 0.08, n = 212$
Yes	4	1.89	5	2.36	
Type(s) of school district emergency drills	No/Unsure		Yes		Chi Square Test of Independence
	<i>n</i>	%	<i>n</i>	%	
<u>Earthquake</u>					Fisher's exact ^a (1), $p = 0.75$
No	7	3.29	3	1.41	$\phi = 0.04, n = 213$
Yes	126	59.15	77	36.15	
<u>Tsunami</u>					χ^2 (1) = 2.72, $p = 0.10$
No	125	58.69	70	32.86	$\phi = 0.11, n = 213$
Yes	8	3.76	10	4.69	
<u>Active shooter/lockdown</u>					Fisher's exact ^a (1), $p = 0.77$
					$\phi = -0.02, n = 213$

(continued on next page)

Table A.2 (continued)

Factor	Had you previously heard of ShakeAlert?				Chi Square Test of Independence
School district experienced earthquake(s) in past two decades	No/Unsure		Yes		
	n	%	n	%	
No	7	3.29	5	2.35	Fisher's exact ^a (1), $p=1.00$ $\phi=0.01$, $n=213$
Yes	126	59.15	80	37.56	
<u>Fire</u>					χ^2 (1) = 2.13, $p=0.15$ $\phi=0.10$, $n=213$
No	2	0.94	1	0.47	
Yes	131	61.50	79	37.09	Chi Square Test of Independence
<u>Other</u>					
No	119	55.87	66	30.99	χ^2 (4) = 1.33, $p=0.25$ $\phi=.079$, $n=212$
Yes	14	6.57	14	6.57	
Annual earthquake drills	No/Unsure		Yes		Chi Square Test of Independence
	n	% ^b	n	%	
0	5	2.35	3	1.41	χ^2 (1) = 1.35, $p=0.25$ $\phi=0.09$, $n=168$
1–3	107	50.23	66	30.99	
4–6	21	9.86	8	3.76	χ^2 (1) = 0.07, $p=0.80$ $\phi=0.09$, $n=168$
7–9	39	18.31	27	12.68	
10+	58	27.23	36	16.90	Chi Square Test of Independence
Annual emergency drills	No/Unsure		Yes		
	n	% ^b	n	%	χ^2 (1) = 1.23, $p=0.27$ $\phi=-0.09$, $n=168$
0	1	0.47	0	0.00	
1–3	14	6.57	9	4.23	χ^2 (1) = 0.28, $p=0.60$ $\phi=0.04$, $n=168$
4–6	21	9.86	8	3.76	
7–9	39	18.31	27	12.68	Chi Square Test of Independence
10+	58	27.23	36	16.90	
Hazard warning systems in district	No/Unsure		Yes		FFH Exact ^c (4) = 4.40, $p=0.34$ $\phi=0.15$, $n=198$
	n	%	n	%	
<u>Tsunami</u>					Chi Square Test of Independence
No	93	55.36	58	34.52	
Yes	8	4.76	9	5.36	χ^2 (5) = 2.21, $p=0.83$ $\phi=0.11$, $n=179$
<u>Fire</u>					
No	15	8.93	9	5.36	Chi Square Test of Independence
Yes	86	51.19	58	34.52	
<u>Active shooter</u>					Chi Square Test of Independence
No	41	24.40	33	19.64	
Yes	60	35.71	34	20.24	Chi Square Test of Independence
<u>Other</u>					
No	86	51.19	55	32.74	Chi Square Test of Independence
Yes	15	8.93	12	7.14	
ShakeAlert adoption decision maker ^c	No/Unsure		Yes		Chi Square Test of Independence
	n	%	n	%	
Superintendent	97	48.99	62	31.31	Chi Square Test of Independence
District emergency manager	5	2.53	7	3.54	
School board	12	6.06	4	2.02	Chi Square Test of Independence
Other	3	1.52	4	2.02	
Already adopted	0	0.00	0	0.00	Chi Square Test of Independence
Unsure	3	1.52	1	0.51	
District student population	No/Unsure		Yes		Chi Square Test of Independence
	n	%	n	%	
< 300	36	20.11	18	10.06	Chi Square Test of Independence
300–599	17	9.50	12	6.70	
600–999	14	7.82	8	4.47	Chi Square Test of Independence
1000–2499	14	7.82	7	3.91	
2500–4999	14	7.82	13	7.26	Chi Square Test of Independence
5000–9999	15	8.38	11	6.15	
10,000–24,999	0	0.00	0	0.00	Chi Square Test of Independence
≥25,000	0	0.00	0	0.00	
Emergency preparedness budget	No/Unsure		Yes		Chi Square Test of Independence
	n	%	n	%	
No	71	39.66	51	28.49	Chi Square Test of Independence
Yes	26	14.53	13	7.26	
Unsure	13	7.26	5	2.79	

^a Fisher's exact test is used where expected cell count assumption is violated for 2x2 tables.^b Percentage of total for question or sub-question.^c Fisher-Freeman-Halton Exact Test is used where expected cell count assumption is violated in greater than 2x2 tables.

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