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Interventions and controls to prevent emergency service vehicle incidents: A mixed methods review

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A R T I C L E I N F O

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A B S T R A C T

Background: Emergency service vehicle incidents (ESVI), including crashes, rollovers, and roadside struck-by-incidents, are a leading cause of occupational fatality and injury among firefighters and other emergency responders. Though there are numerous strategies and interventions to prevent ESVIs, the evidence base for these strategies is limited and dispersed. The goal of this study was to gather and present a review of evidence-based ESVI interventions.

Methods: We searched five academic databases for articles published within the last decade featuring interventions to reduce or prevent ESVIs. We interviewed key informants from fire departments serving major metropolitan areas for additional interventions. Interventions from both sources were summarized and data on intervention effectiveness were reported when available.

Results: Sixty-five articles were included in the final review and 17 key informant interviews were completed. Most articles focused on vehicle engineering interventions (38%), followed by policy and administration interventions (26%), environmental engineering interventions (19%) and education or training (17%). Most key informants reported policy (49%) and training interventions (29%). Enhanced drivers' training and risk management programs were associated with 19–50% and 19–58% reductions in ESVIs, respectively.

Conclusions: Only a limited number of interventions to address ESVIs had adequate outcome data. Based on the available data, training and risk management approaches may be particularly effective approaches to reducing ESVIs.

1. Introduction

Emergency service vehicle incidents (ESVIs) include crashes, rollovers, and roadside struck-by incidents. ESVIs are the leading cause of death among emergency medical services (EMS) personnel with 2.7 fatalities per 100,000 workers annually (Maguire et al., 2002), and are the second leading cause of occupational fatality among U.S. firefighters, accounting for 390 fatalities between 1994–2014 (United States Fire Administration, 2014). ESVIs also pose a serious threat to public road users given the vehicles' large size and high-speed operations. Between 1997 and 2006, 94 of 107 fatalities resulting from collisions involving a fire service vehicle during an emergency response were occupants of the other vehicle, pedestrians, or bicyclists (Fahy, 2008).

ESVI intervention effectiveness studies are sparse, and no systematic reviews of effective interventions to reduce ESVIs are available. While safety and regulatory agencies provide guidelines for the safe operations of emergency service vehicles (Federal Emergency Management Agency, 2012; United States Fire Administration, 2003) and best practices for roadside safety (Trench et al., 2014; International Association of Firefighters, 2010), these guidelines rarely cite evidence to support recommendations. Further, these guidelines are generally recommendations for safe practices (e.g., recommending lower vehicle speeds), as opposed to exogenous interventions that reinforce, enable,

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promote or strengthen safe practices (e.g., using in-cab devices to alert drivers to speeding). Though the evidence base for interventions targeting civilian crashes is robust, (Aeron-Thomas and Hess, 2005; Beyer Fiona and Ker, 2009; Bunn et al., 2003; Ker et al., 2003; Russell Kelly et al., 2011; Wilson et al., 2010) these interventions may not apply or be effective in occupational settings, especially in the emergency services where working conditions are highly variable and may be dangerous.

Synthesizing the evidence base for effective interventions will help inform policies and practices that may be implemented in emergency service departments by safety managers and will also provide information to help inform future research. The objective of this review is to collect and present potentially effective interventions used in the emergency services to reduce the risk of ESVIs and the severity of those incidents as measured by fatalities, injuries, and economic costs.

2. Materials and methods

We conducted a 'mixed methods review,' combining a systematic literature review with key informant interviews to identify interventions to reduce ESVIs (Grant and Booth, 2009). Studies involving emergency service workers, including: firefighters, ambulance crews, and emergency service technicians (i.e., first responders) operating emergency service vehicles in an occupational setting were eligible for inclusion. Articles describing or evaluating the effects of an intervention to reduce the frequency and/or severity of ESVIs were included for review. The types of interventions and vehicle incident types considered were broadly defined to capture all possibly effective interventions and three primary intervention domains were considered:

a) Education/Training: Interventions aimed at enhancing education and/or training of emergency vehicle workers (promotional behavior change campaigns, enhanced driver's training/licensure, etc.).
b) Policy/Administration: Administrative and policy approaches to creating safer vehicle operations, workflows and/or processes (introducing new laws, enforcement of existing policies, new standard operating procedures, and operational or procedural modifications such as changes to emergency response protocols, etc.).
c) Engineering: Interventions that modify or add technology to vehicles or the built environment to reduce the risk of ESVIs. Such interventions included modifications to the road environment (e.g., traffic light pre-emption) and additions to emergency vehicles (e.g., vehicle data recorders).

When available, outcome measures indicating the effectiveness of interventions were reported. We defined the outcomes of interest as 1) changes in the frequency or risk of vehicle incidents (incidence counts or rates, proportions, percentages, odds ratios or relative risks), and 2) changes in the severity of vehicle incidents (reductions in fatalities, injuries or economic costs). Unless otherwise noted, the term 'crash' in our review encompasses any type of ESVI including on-road collisions with other vehicles as well as striking fixed objects or structures.

2.1. Literature search methods

We conducted searches of PubMed, Embase, CINAHL, PsycInfo, and Web of Science databases using MeSH headings, Emtree terms, CINAHL descriptors and targeted keyword terms such as 'emergency vehicle.' 'ambulance.' 'first responder.' 'fire.' and 'crash prevention.' The timeframe of interest was restricted to 2006–2017 to capture the most current articles and interventions. An initial citation screening was conducted to remove duplicated or irrelevant citations such as those focusing on commercial trucking research.

After citation screening, two independent reviewers screened the remaining titles and abstracts and excluded articles that were unrelated to the emergency services or ESVIs. Next, the reviewers obtained the full texts of the remaining articles and independently assessed each article for inclusion eligibility. Articles were included for review if the article 1) was relevant to emergency services populations, and 2) assessed at least one intervention to reduce the incidence or severity of ESVIs. Articles were excluded if they only discussed general recommended guidelines. For example, articles that discussed or recommended reducing driving speed, but did not review exogenous mechanisms, tools or policies to promote, reinforce, or enable speed reduction, were excluded. Reviewers extracted data using a standardized data abstraction form collecting information on the study methods, participants, intervention description, and results and outcomes if reported. Disagreements in inclusion/exclusion criteria occurred in about a third of the articles reviewed, and were reconciled by a third reviewer (the lead author). Most disagreements occurred during abstract screening and were almost all on the classification of interventions.

2.2. Key informant interview methods

To supplement the literature review, we contacted key informants from a purposive sample of fire departments referenced in the reviewed articles to obtain updates on the interventions applied in their departments, attitudes and perceptions of effectiveness, and to request crash data to evaluate intervention effects. To expand the sample of key informants, we invited fire chiefs from the International Association of Fire Chiefs (IAFC) and National Fire Protection Association (NFPA) Metropolitan Fire Chiefs association to participate in the review. The Metropolitan Fire Chiefs include chiefs from fire departments with at least 350 full time career firefighters, serving large major metropolitan areas. Interviews were conducted between Fall 2016 and Spring 2017.

A semi-structured interview guide was created to gather information and data from each interviewee. Interviewers asked about policy, education and engineering interventions implemented and the perceived effectiveness of each intervention in terms of changes to crash frequency, severity and cost. Interviews were completed by the study's lead author and research assistants and lasted 30 to 60 min each. All interviews were completed via phone calls with follow-up conducted through emails. Interview results were recorded in guided interview forms. Frequencies and percentages were calculated for categorical response variables and key themes regarding intervention effectiveness, strengths and weaknesses were abstracted from the interview forms during data analysis. We requested outcome data from the fire department representatives to verify intervention effectiveness. When sufficient data were provided, we conducted interrupted time series analyses to quantify the impact of intervention on temporal changes in crash outcomes (i.e., changes to crash frequency, severity, or costs) before and after intervention (Linden, 2015).

3. Results

3.1. Article results

The database search resulted in 7508 articles for screening. After preliminary citation screening, 416 articles remained for abstract screening (Fig. 1). After screening abstracts, 341 articles were excluded from full-text review because they did not cover an intervention to reduce ESVIs or were non-emergency related. Moreover, the excluded articles were predominantly opinion or editorial pieces on the hazards of crashes in emergency services or descriptive papers on crashes and safe driving (e.g., advice on safe driving). Seventy-five articles were deemed eligible for full-text review. An additional twelve articles (12/75, 16%) were removed after full-text review because they were descriptive articles on safe driving and/or did not review a specific intervention. We included one relevant report found by referral (Devlin, 2010) and one article found through review of citations within the final article set (Levick and Swanson, 2005).

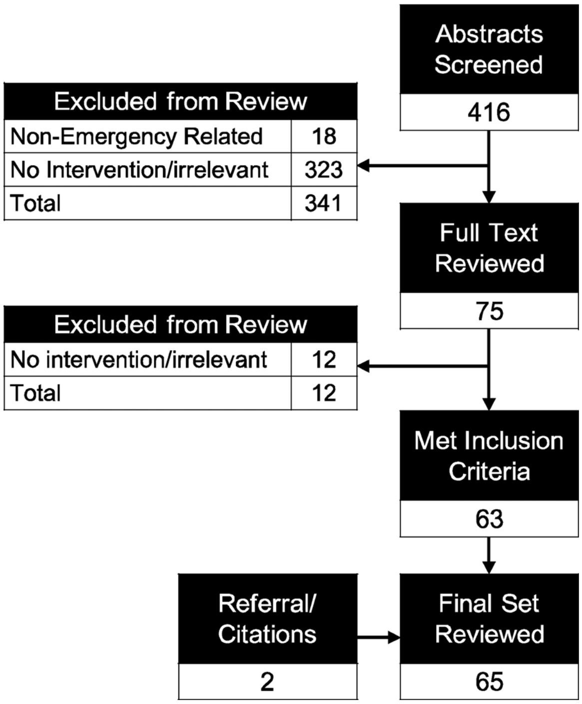

Fig. 1. Flowchart of screened and reviewed articles.

Table 1
Summary of articles included in final review.

	N	Col %
Total Articles, n (%)	65	100%
Primary Population, n (%)		
EMS/Ambulance	35	54%
Fire Service	22	34%
General First Responder	8	12%
Intervention Types[a], n (%)		
Engineering (Vehicle)	29	38%
Policy/Administration	20	26%
Engineering (Environment)	15	19%
Education/Training	13	17%
Outcomes Reported, n (%)		
Yes	31	48%
No	34	52%
Reported Outcome Types, n (%)		
Behavior Change	14	37%
Response/Travel Time	10	26%
Crash rate/risk	7	18%
Economic	5	13%
Injury Rate	2	5%
Article Type, n (%)		
Journal Article	54	83%
Conference Proceeding	9	14%
Published Thesis	1	2%
Report	1	2%

[a] Exceeds 67 because some articles review more than one intervention type.

Among the 65 articles in the final set, most reviewed interventions applied primarily in EMS, followed by the fire service and general first responders (Table 1). Over half of the articles did not report an evaluation outcome of interest. Studies without outcomes were usually descriptive and did not evaluate intervention efficacy nor provide supporting data to demonstrate intervention effect. Among reported outcome types, behavior change was most frequently reported and included changes in behaviors such as seatbelt use and reductions in unwanted driving behaviors. The second most frequently reported outcome was related to reductions in travel time due to enhanced vehicle routing, traffic signal pre-emption systems, or advanced warnings for civilian drivers, followed by crash rates or crash risk.

Table 2
Summary of interview participants and reported interventions.

Interviews, n (%)	17	100%
Informant Rank, n (%)		
Chief	11	65%
Captain	4	24%
Lieutenant	2	12%
Years w/ Department, mean (sd)	20.5	9.7
Department Location, n (%)		
South	8	47%
Northeast	3	18%
West	3	18%
Midwest	1	6%
International	2	12%
Intervention Type, n (%)[a]		
Policy/Administration	17	49%
Education/Training	10	29%
Engineering (Vehicle)	7	20%
Engineering (Environment)	1	3%
Provided Data for Analysis, n (%)	8	47%

[a] Exceeds 17 because key informants reported more than one intervention.

3.2. Interview results

A total of 17 key informant interviews were completed (Table 2). Most interviewees were chiefs (including Fire Chiefs, Battalion, Division and Assistant), followed by captains, and lieutenants. There were 35 interventions reported by the key informants, of which the most common types were Policy/Administration and Education/Training. Policy interventions included the issuance of new standard operating procedures (SOPs) for backing and spotting, Code 3 responses (i.e., using lights and sirens), seatbelt use and establishing crash review committees. The Education/Training-based interventions included strategies to enhance driver training. Only one department reported an Engineering (Environment) intervention, which was a traffic signal pre-emption system. Eight departments (47%) provided department crash rate data in time series format for analysis, but only five department datasets (29%) had sufficient records for analysis.

4. Intervention summaries

Among all interventions we reviewed, there were seven intervention types with reported crash reduction outcomes (Fig. 2). All interventions reviewed are summarized in Table 3 and described in greater detail by intervention type in the main text.

4.1. Summary of engineering interventions (vehicle focus)

4.1.1. DriveCam

DriveCam may be effective in reducing unwanted driving behaviors such as unsafe/careless maneuvers, inattentive/distracted driving and seatbelt non-compliance (Devlin, 2010; Myers et al., 2012; Lindstrom, 2006; Erich, 2007a,b). We were not able to find data to confirm that DriveCam reduced the risk of ESVIs, but may reduce associated costs. Baltimore City Fire Department found that crash reports remained flat since inception of their DriveCam program in 2014, despite reductions in unwanted driving behaviors, but the total cost of their liability claims and worker's compensation reduced from \$1.5 million in 2014 to \$812,000 in 2015 (Personal communication, April 10, 2017). Orange County Fire and Rescue showed there was a 6.7% per year increase in their overall crash rate (IRR = 1.067, P = 0.001) during the DriveCam deployment period, but there were significant reductions in large

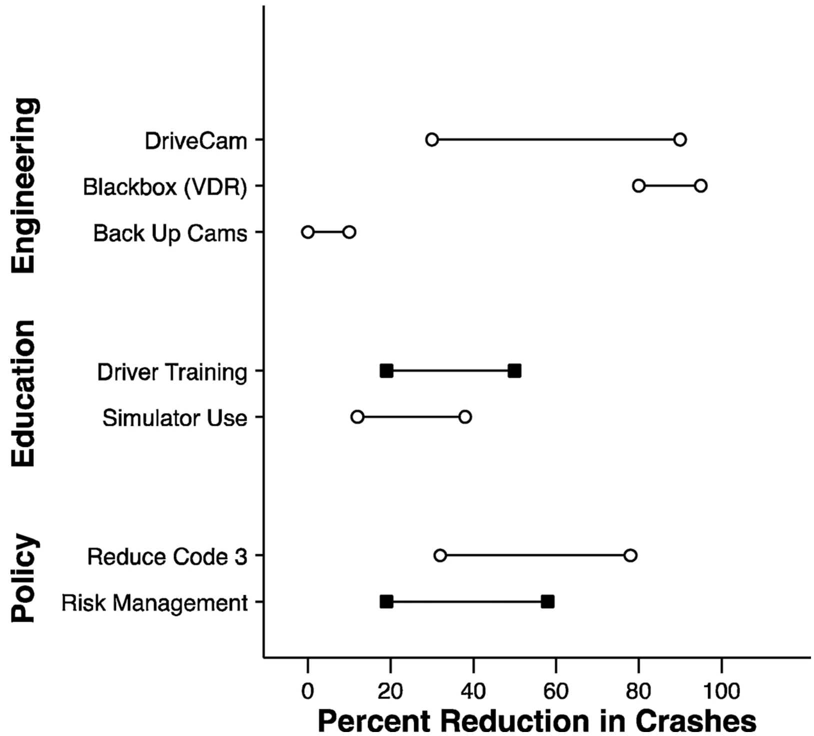

Fig. 2. The reported ranges of percent reduction in ESVIs by interventions identified in literature review and interviews. The ranges with white circle markers are from reports without supporting data; the ranges with black square markers are from reports with supporting data.

liability claims. The number of their large liability claims approximately halved from an average of 52 claims during 2008–2011 to 27 claims during 2011-2016 (Fig. 3). We estimated a $1037 reduction in annual large claim payouts per DriveCam unit installed. The DriveCam parent company has claimed to reduce vehicle incident costs by 30–90% in commercial and government fleets (Lindstrom, 2006).

4.1.2. Black boxes and in-cab audio feedback

The use of vehicle data recorders (VDRs) supplemented with in-cab audio alerts has been documented in Metro EMS of Little Rock, AR (Levick and Swanson, 2005; Barishansky and O'Connor, 2007; Erich, 2009; Swanson and Levick, 2005; Nordberg, 2010). The department reported that seatbelt violations, speeding, and harsh braking events were reduced by 90% or more (Levick and Swanson, 2005; Barishansky and O'Connor, 2007; Erich, 2009; Swanson and Levick, 2005; Nordberg, 2010). Similar results were reported in at least one other department also using an in-cab feedback alert system (Erich, 2009). Metro EMS reported just one collision during the evaluation period of 18 months and 1.9 million service miles. Using a similar VDR system, Sunstar EMS of Pinellas County, FL reportedly experienced a 95% reduction in vehicle incidents (from 19 incidents to one) over a one year period. Ferno's ACETECH and ZOLL's Road Safety are two VDR systems commonly used in emergency vehicles and particularly in ambulance or medical support vehicles to monitor unwanted driving behaviors that occur in the field (Harden, 2012; McGowan, 2014; McRoy and Lawrence, 2014). ZOLL has estimated a 30% reduction in crash related repairs attributable to their systems (Harden, 2012). One department using ZOLL's Road Safety System reported an 80% reduction in preventable incidents and considerable (but undisclosed) reductions in maintenance and repair costs (McRoy and Lawrence, 2014; Robyn, 2006).

4.1.3. Civilian in-vehicle advanced warning alerts

In a small simulation study (N = 22), drivers using Advanced Warning Devices (AWD) compared to controls, reduced their driving speed earlier, used more controlled braking pressure (i.e., more controlled yielding) and tended to change lanes earlier to allow ESVs to pass (Lenné et al., 2008). Another pilot simulation study (N = 85) found drivers using AWDs significantly increased safety margins (distance between civilian driver and ESV when ESV entered cross-traffic intersection), reduced civilian reaction time to ESV lights and sirens, and had significantly better braking control than drivers not using AWDs (Drucker, 2014). The study's simulation experiments found the odds of crash were between 60% (OR = 0.4, 95% CI = 0.2-0.8) and 90% (OR = 0.1, 95%CI = 0.0–0.2) lower among the drivers using AWDs compared to controls not using AWDs (Drucker, 2014).

4.1.4. Emergency service vehicle design

The reports prioritized designs that permitted and encouraged providers to remain seated and restrained during patient care (Slattery and Silver, 2009; change, 2013). Measures were taken to reduce equipment/projectile related injury (Bellace, 2012; Forgues, 2014; Slattery and Silver, 2009; Nicol, 2016). Integrated LED lighting and cameras were recommended to allow drivers to view the patient care team in the rear compartment (Bellace, 2012; Vanderlooven and Isaacs, 2008). Using illuminated arrows, reflective markings, box side floodlights, high intensity lights, 360° revolving lights, high visibility striping and high visibility vests were recommended as methods to increase on-scene visibility (Bellace, 2012; Vanderlooven and Isaacs, 2008; Heightman, 2009).

4.1.5. Enhancing efficacy of lights and sirens

One study assessed the effect of various light bar frequencies and flash patterns on civilian drivers using video simulations (Turner et al., 2014). Higher flash rates (4 Hz vs 1 Hz) reduced the risk of civilian vehicle pull out in single pulse patterns. Although no significant differences were found between single flash or triple flash patterns, a 4 Hz flash rate with single pulse combination was found to be the safest. Another study used acoustic measurements and ambulance transit times to evaluate the effectiveness of two siren types: 1) a standard "wail and yelp" sound pattern siren installed under the wheel arch, and 2) an experimental system with a two-stage localizable warning featuring a

Table 3
Summary of interventions reviewed.

Type	Intervention	Description	Effectiveness	Citing Articles[a]
Engineering (Vehicle)	DriveCam	DriveCam is an on-board event recording system which has been implemented in ambulances in several departments. The DriveCam system captures 12 second video clips of the inner vehicle cabin and forward street view when there is a sudden and significant change in longitudinal or latitudinal g-force (e.g., hard braking, hard acceleration, hard cornering or collision). Video clips are reviewed by trained analysts for driving issues.	No articles reviewed report that DriveCam is effective in reducing ESVIs. Several articles, suggest DriveCam may reduce vehicle incident costs (repairs and claims). Most studies report changes to driver behaviors (e.g. rate of breaking defined driving rules) documented by the DriveCam system. Data from departments revealed that DriveCam reduced the amount of ESVI legal claim payouts; however, no reduction in overall crash rates was observed. Lytx, the DriveCam parent company, has reported crash reductions between 30-90%.	Devlin, (2010), Myers et al. (2012), Lindstrom (2006), Erich (2007a,b, EMS Union wary as FDNY starts DriveCam Pilot Program, 2005),D[a]
	Vehicle Data Recorders (VDRs)/ Black Boxes/ In-cab Driver Alerts	These systems track vehicle movement and engine data, but do not have a video or audio recording component. Some have audible in-cab alerts to alert drivers to speeding or harsh braking. The most basic systems simply track driving data that can be reviewed by safety managers. Some systems are designed to include metrics for monitoring vehicle issues and scheduling regular maintenance and repairs. VDRs are required for heavy fire service vehicles to meet the NFPA 1901 Standard.	Black box devices with audible in-cab alerts had significant reductions in unwanted driving behaviors (e.g. speeding) and reduced ESVIs among EMS drivers. Most studies reported behavioral outcomes related to significant reductions in unwanted driving behaviors. Vendors of certain systems reported significant annual cost savings due to vehicle repair and crash costs. Two articles reported reductions between 80-95% in ESVIs attributable to these systems.	Levick and Swanson (2005), Barishansky and O'Connor (2007), Erich (2009), Swanson and Levick, (2005), Nordberg (2010), Harden (2012), McGowan (2014), McRoy and Lawrence (2014), Robyn (2006)
	Advanced Warning Devices (in-cab civilian alerts)	These systems focus on increasing the time to saliency (noticeability) of emergency service vehicles operating with lights and sirens among civilian drivers. Studies included simulations of advanced warnings to identify optimal timing of alerts and one study was a pilot demonstration.	All studies reported significant reductions in time-to-saliency, increased distance at point of saliency, and improved driver braking (as opposed to slamming on brakes). In one simulation study, the risk of collision with an ESV was significantly lower by 60% in the advanced warning group compared to controls.	Lenné et al. (2008), Drucker (2014), Finucane (2010)
	Emergency Service Vehicle Design	Articles discuss design elements to reduce the risk of injury during a crash. Ambulance redesigns were based on expert consensus to reduce in-cab projectile injury risk, reduce hard surfaces in the patient care area, increase seatbelt compliance during patient care, and increase vehicle visibility and conspicuity.	None of the articles we reviewed evaluated or reported reductions in crash incidence or risk, injury incidence or risks, or any cost savings. Most design decisions were based on expert consensus and implemented designs reported in the articles were not evaluated in the field.	Bellace (2012), Vanderlooven and Isaacs (2008), Forgues (2014), Nordberg (2007), Slattery and Silver (2009), Anon. (2013), Nordberg (2006a,b), Sagarra (2015), Heightman (2009, 2006),
	Enhancing Efficacy of Lights and Sirens	One study evaluated various light bar configurations (frequency and flash patterns) to identify optimal settings for vehicle conspicuity and saliency. One study evaluated siren frequencies to identify optimal frequencies.	4 Hz frequencies were rated more urgent than 1 Hz. The siren study reported significant reductions in transportation times when using the experimental siren.	Turner et al. (2014), Catchpole and McKeown (2007)
	Five Point Harness Seatbelts	Five-point harness seat restraints have been used in apparatuses and ambulances to improve mobility while seated and increase vehicle restraint use.	Articles reviewed did not evaluate usage or other outcomes, but noted enthusiasm and high acceptability among emergency services personnel.	Bellace (2012), Nordberg (2006a,b)
	Spotter-to-Driver Headsets	The use of both wired and wireless headsets for spotter-to-driver communication is often recommended.	No evaluations or outcomes found.	Wilbur (2010)
	Backup Cameras	Cameras are mounted to the rear (and in some cases to the side) of vehicles to aid in visual clearance of surroundings while executing backing and other turning maneuvers.	Departments estimated a < 10% reduction in backing incidents after installing backup cameras in department vehicles.	D
Engineering (Environment)	Emergency Service Vehicle Signal Pre-emption	Pre-emption systems utilize on-vehicle signal emitters that trigger receivers built into traffic signals to switch the traffic light in the direction of travel to green while switching opposing and cross-traffic lights red, permitting priority passage of the emergency vehicle and stopping cross traffic.	Studies reported small, but significant reductions in response times and traffic flow. However, no study we reviewed, evaluated, or reported reductions in crash incidence or crash risk. Our analysis of secondary data showed no significant changes to intersection crash risk after adoption of pre-emption.	McGowan (2014), Wang et al. (2013), Yun et al. (2011), Shankar et al. (2015), Tonguz and Viriyasitavat (2016), Vemuri and Mande (2014), Afdhal (2015), Tokuda and Ohmori (2011), Eltayeb et al. (2013), Pei-Hsuan and Tsung-Chuan (2014), D
	Connected Vehicle Technology			Lu et al. (2014), Chung-Ming et al. (2009), Venkatesh et al. (2012), Jae Bong et al. (2010)

(*continued on next page*)

Table 3 (*continued*)

Type	Intervention	Description	Effectiveness	Citing Articles[a]
		Connected vehicle technology uses wireless short-range communication technology to enable vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) data exchange. Such technology permits vehicles to exchange driving data such as position, speed and heading, which can lead to improved situational awareness, improved crash avoidance systems, and enhanced vehicle routing to reduce congestion.	Studies were mainly pilot and/or demonstration studies that evaluated the ability of connected vehicle technology to intelligently route emergency vehicles and reduce transit times. No evaluation of crash reduction was found. Currently, research and development of connected vehicle technology for emergency service applications is limited.	
Education/Training	Enhanced Training/ Refresher Training	Enhanced training and refresher training programs were cited in several articles and interviews. These are typically training program overhauls that increase the amount of hands-on field training and vehicle specific operation training and closed course evolutions and scenarios.	No articles reported evaluations or outcomes of driver training programs. Our analysis of secondary data showed significant effects of formal driver training on reducing crash incidence. Departments interviewed reduced their crash rates by 19-50%. One department reported an average of $3-4 million of annual cost savings.	McRoy and Lawrence (2014), Dow (2007), Erich (2007a,b), D
	Driver Mentoring Program	One department used a driver mentoring program whereby experienced and trained driver mentors were assigned to new recruits during a probationary period to oversee their driving. The mentor conducted field observations and was responsible for evaluations and on-the-job driver training.	No program evaluations were reported, however the department reported changes in driving behaviors and habits and increased situational awareness.	D
	Graduated Driving Privileges/ Responsibilities	One department reported restricting new recruits from any driving duties during the first year of employment. After one year, recruits received formal driver training.	The department interviewed did not provide data nor do a formal evaluation of their program. However, they reported seeing a 50% reduction in ESVIs and a < 10% reduction in crash costs.	D
	Internet-based Education and Training	The United States Fire Administration in collaboration with The National Volunteer Fire Council created the Emergency Vehicle Safe Operations for Volunteer and Small Combination Emergency Service Organizations online educational program.	No evaluations or outcomes found.	Nordberg (2006a,b
	Driving Simulator Training	Departments have purchased driving simulators as supplemental training tools. Simulators allow trainees to experience driving in various conditions (e.g. snow, rain) and navigate various scenarios (e.g., bicyclists and traffic) without collision risk.	One department reported reductions in overall collisions (12%) and intersection collisions (38%) attributable to the use of driving simulator training. Another paper reported improved novice trainee skill acquisition using simulators.	Lindsey and Barron (2008)
	Safety Stand Down	The Safety Stand Down had a thematic focus on preventing ESVIs and provided policies, vehicle safety drills, guides and articles for use in all US and Canadian fire departments.	No evaluations or outcomes found.	Goldfeder (2006)
Policy/Administration	Reducing Use of Lights and Sirens	Several articles and departments reported the use of policies to modify Code 3 response protocols to reduce the use of unnecessary emergency lights and sirens when crash risk is generally elevated. One study reported the development of an algorithm using field indicators to determine if a lights and siren dispatch was warranted for vehicle crash incidents.	A modified Code 3 SOP at FDNY resulted in a reported 32% reduction in crashes. Similar results were found in other departments, with between 10-78% reductions in crashes reported. The dispatch algorithm was 97% sensitive and 33% specific in identifying incidents where patients required prompt trauma care.	Trench et al. (2014), Anon. (2013), Lindstrom (2011), Isenberg et al. (2012), Wilbur (2011), D
	Increasing Accountability/ Liability	Several articles cited lack of accountability and discipline for driving SOP violations as contributing to lax safety cultures and recommended strict enforcement of disciplinary policies as a countermeasure. Some articles recommended holding both driver and officer accountable for all vehicle incidents with discipline including suspension, remedial training, termination or fines. One key informant implemented a seatbelt policy with clearly defined disciplinary measures for non-compliance.	No evidence was found that increased discipline and accountability reduced crash risks. The one department that implemented a seatbelt policy with discipline reported (but did not provide data) an over 50% increase in seatbelt usage.	Erich (2007a,b), Sanddal et al. (2008), Fontenot (2011a,b), D
	Crash Review Boards		No formal evaluation data were provided.	D

(*continued on next page*)

Table 3 (*continued*)

Type	Intervention	Description	Effectiveness	Citing Articles[a]
		Several departments have reported using crash review boards as a component of their safety programs. The review board members generally use sessions to identify causes of crashes and make recommendations for remedial training or discipline.		
	Seatbelt Pledge	Several articles discussed the use of seatbelt pledges to increase seatbelt compliance in the fire service.	No formal evaluations or outcomes found. None of the articles reviewed reported any changes to seatbelt compliance or use.	Fontenot (2011a,b), Ludwig (2008)
	Crew Resource Management (CRM)	CRM was developed in the 1970s by NASA to reduce human error and increase safety during flight operations. One of the core tenets of the system is redundant and multi-person verification of critical actions to catch and reduce the risk of errors. This can be applied in emergency vehicle operations by having both driver and officer verbally verify intersection cross traffic is clear or not.	Though not formally evaluated, there are near miss case reports demonstrating the use of CRM in preventing imminent collisions in fire apparatuses.	McRoy and Lawrence (2014), Slattery and Silver (2009), Ellis (2006), Tippett (2011)
Policy/Administration	Proactive Risk Management/ Risk Assessment	Proactive risk management utilizes a formalized procedure of identifying, evaluating and ranking risks, and implementing controls. This has been implemented in various industries to prevent and reduce occupational risks and hazards. Some departments also use formal and informal risk assessment to identify root causes of collisions.	Articles we reviewed reported a 58% reduction in ESVIs, 54% reduction in related costs and 36% reduction in crash related injuries. Data provided by one department we interviewed revealed a 19% reduction in overall crash rates.	McRoy and Lawrence (2014), Mund (2010), Shiring (2007), Ludwig (2013), D
	On Scene Blocking	Various policies and procedures have been outlined for effective on scene blocking to reduce on-scene roadside collisions. Examples of policies include always dispatching two vehicles and using one for blocking, assigning spotters to watch and direct oncoming traffic, and deploying roadside flares.	No evaluations or outcomes found.	Salka (2010)
	Crashworthiness Testing	One article discussed the need to establish crashworthiness standards for ESVs. The Society of Automotive Engineers International (SAE International) released guidelines and standards for crashworthiness testing of ambulances. Such standards may improve survival and reduce the severity of crash related injuries.	No evaluations or outcomes found.	Kahn (2006)
	Reducing Driver Fatigue	One department where EMTs previously drove for 24 hour shifts implemented a policy called 12-12 for EMTs. The new policy mandated EMTs switch off driving every 12 hours during a 24-hour shift to reduce fatigue-related incidents and risks.	No data were provided for evaluation of policy effects; however, the department reported (unspecified) reductions in repair costs and insurance claims against the department.	D

Engineering (Vehicle): interventions involving modifications, redesign, or technological additions to emergency service vehicles.
Engineering (Environment): interventions involving modifications to the traffic environment.
Education/Training: interventions with aim to improve driver behavior, skills, and safe driving knowledge.
Administration/Policy: interventions involving policy or procedural changes.

[a] D indicates department interviews as a source.

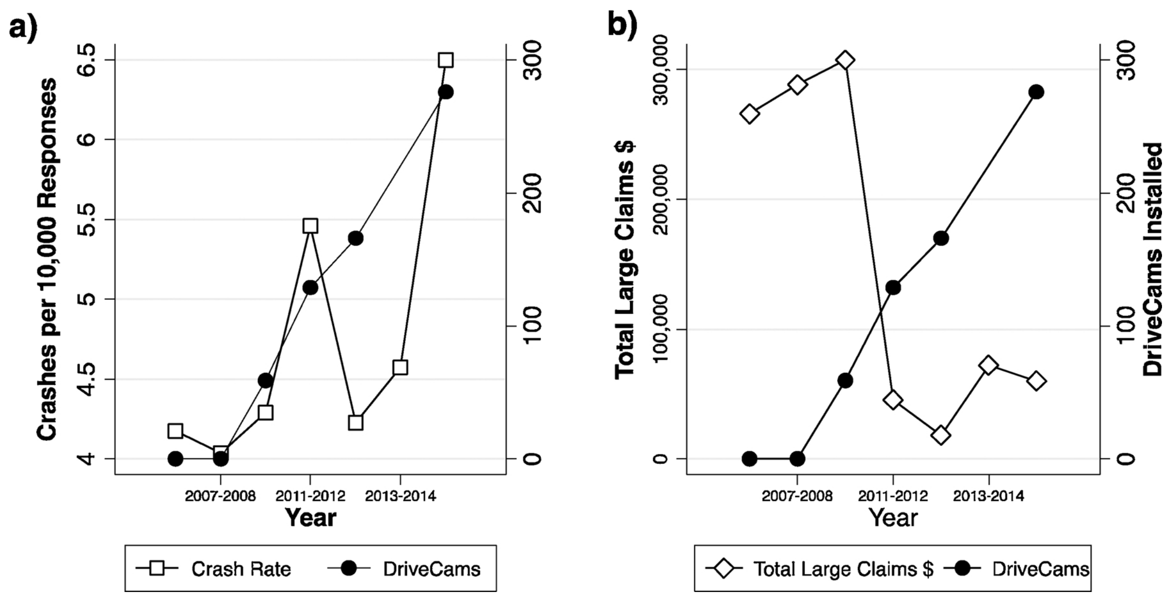

Fig. 3. Plots of total DriveCams installed at Orange County Fire Department (FL) compared to a) crash rate and b) total dollar amounts paid in large claims.

55-cycle per minute rate and sound patterns with frequencies up to 11,000 Hz installed behind the radiator grill. The experimental system provided better civilian vehicle penetration while reducing in-cab noise exposure (Catchpole and McKeown, 2007).

4.1.6. Five point harness

Several departments have implemented five-point harnesses, a safety belt configuration with five harnesses mounted to the vehicle frame, in ambulances to restrain paramedics while providing in transit care (Bellace, 2012; Nordberg, 2006a,b). The departments noted enthusiasm and high acceptability of the harness system (Nordberg, 2006a,b), although no formal evaluation was completed to assess compliance or changes in injury rates attributable to the system.

4.1.7. Spotter-to-driver communication headsets

Wired headset systems use receptacles located in the rear of vehicles, which require spotters to physically move to the correct spotting positions and plug into the vehicle during backing operations to communicate directly with drivers (Wilbur, 2010). Wireless headsets provide similar benefits, but with the advantage of allowing spotters to position themselves further away from the apparatus (Wilbur, 2010). No data were found regarding their effect on backing-related incident rates.

4.1.8. Backup cameras

Virginia Beach Fire and Rescue reported a possible reduction in backing incidents by < 10% attributed to the adoption of backing cameras (Personal communication, February 8, 2017), but outcome data were not available for review.

4.2. Summary of engineering interventions (environment focus)

4.2.1. Emergency vehicle traffic signal pre-emption

None of the studies reviewed evaluated the use of signal pre-emption for reducing ESVIs. The studies found focused on presenting novel signal pre-emption systems (Eltayeb et al., 2013; Pei-Hsuan and Tsung-Chuan, 2014) that improved traffic flow (Yun et al., 2011; Shankar et al., 2015; Tonguz and Viriyasitavat, 2016; Vemuri and Mande, 2014) and/or reduced response times (Wang et al., 2013; Tonguz and Viriyasitavat, 2016; Afdhal, 2015; Eltayeb et al., 2013). One noted limitation is that pre-emption systems may be operated independently by multiple ESVs, creating the potential for intersection conflicts between responders. One key informant noted that despite using a signal pre-emption system, all department vehicles were still required to reduce speeds at intersections because other responding vehicles may approach from other directions and receive conflicting preemption signals (Personal communication, November 21, 2016).

4.2.2. Connected vehicle technology

Current pilot applications of Connected Vehicle technology in the emergency services focus on both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication (Chung-Ming et al., 2009; Venkatesh et al., 2012; Jae Bong et al., 2010). These systems utilize infrastructure sensors for real time monitoring of traffic conditions to intelligently route ESVs through low traffic areas with the goal of reducing response times. More comprehensive systems provide early warning alerts directly to civilian vehicles along the path of the oncoming ESV (Chung-Ming et al., 2009; Jae Bong et al., 2010). No studies evaluated the effects of these technologies on ESVIs.

4.3. Summary of training and education interventions

4.3.1. Enhanced training and refresher training

The Seattle Fire Department began providing a comprehensive driver training program in 2008. The training program consists of a combination of classroom instruction and intensive hands-on vehicle ‘rodeo’ training where drivers are required to navigate various cone courses and scenarios on a closed course. Prior to 2008, the mean crash rate was 15.9 per 10,000 calls. After 2008, the mean crash rate decreased to 12.9 per 10,000 calls ($P < 0.001$) for a reduction of nearly 19% (Fig. 4). Since 2008, Seattle Fire Department’s crash rate has declined about 0.18 per 10,000 calls per year (i.e., 1.3% per year). Notably, no statistically significant changes to their non-preventable crash incidents during this timeframe were observed, showing the effects of training were isolated to preventable crash types only, as expected.

The Sacramento Fire Department’s comprehensive emergency vehicle operator course has reportedly saved the city an average of $3-4 million dollars annually from avoided vehicle collisions (Personal communication, May 3, 2017). Their training program features 4 h of lectures and 20 h of hands on training during the regular fire academy. Firefighters are required to complete an additional 28 h of drivers training prior to the end of their probationary period (2 h in class and 26 hands on) and 8 annual hours of refresher training.

Their training curriculum includes high speed maneuvers to

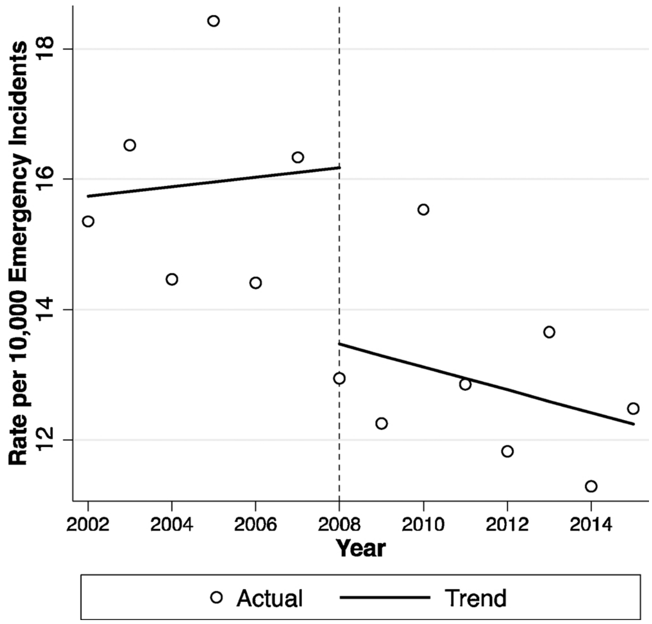

Fig. 4. Change in crash rate at Seattle Fire Department, WA between 2002 and 2014. The vertical hashed line indicates when the training program was implemented (between 2007 and 2008).

accustom drivers to g-forces and vehicle handling. A variety of exercises are used to drill accident avoidance maneuvers, high speed braking, and vehicle placement. There was an immediate 26% drop in their crash rate one year after the training program formally began in 1998 ($P = 0.04$). Since the training program has been in place, there has been a 2.8% per year reduction in their annual crash rates ($P < 0.01$) compared to a relatively flat trend prior to 2009 ($P = 0.29$), resulting in an overall 50% reduction in crashes (from 25.1 to 11.9 per million miles) (Fig. 5).

4.3.2. Driver mentoring programs and graduated driving responsibilities

Colorado Springs has been using a driver mentoring program since 2009 (Personal communication, December 13, 2016). Senior drivers mentor new drivers and sign off on completed necessary skills and minimum Code 3 responses (30 on engines and 20 on aerials). No program evaluation was formally completed; however, the department observed changes in driving behaviors, including increased situational awareness. Charlotte Fire Department instituted a policy restricting new recruits from driving during the first year of employment. After the first year, firefighters participate in a one-week driver course. While impact was not directly measured, the department estimated a 50% reduction in overall incidents and a < 10% decrease in cost associated with collisions (Personal communication, February 7, 2017).

4.3.3. Internet-based education and training

The Emergency Vehicle Safe Operations for Volunteer and Small Combination Emergency Service Organizations online educational program (Nordberg, 2006a,b), created in 2006, provides resources such as self-assessment tools and example standard operating guidelines to reduce ESVIs covering: collision investigations, driver qualifications, drug/alcohol policies, emergency driver training, highway safety, vehicle maintenance, and seatbelt policies (Nordberg, 2006a,b). No crash reduction evaluations or outcomes were found.

4.3.4. Simulator training

The Fire Department of the City of New York reported a 12% single year reduction in EMS collisions and a 38% reduction in intersection collisions attributable to simulator training as part of an EMS Emergency Vehicle Operators Course (EVOC) training program (Raheb and Vehicle ops, 2005). In another study, trainees were given traditional in-class training, but a subset received supplemental simulator training (Lindsey and Barron, 2008). Drivers receiving additional simulator training completed a competency cone course faster, received fewer penalty points, and required fewer attempts to complete the competency course compared to the control group.

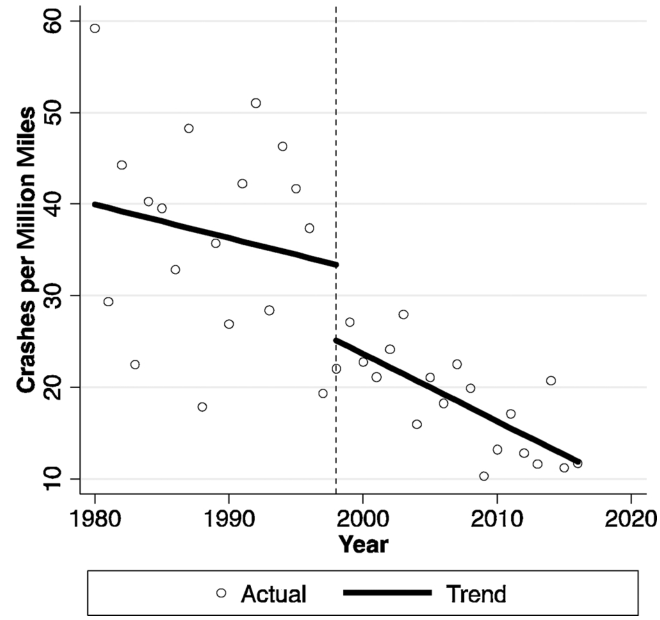

Fig. 5. Sacramento Fire Department annual crash rates. Vertical dashed line (1998) indicates the start of their formal driver training program.

4.3.5. Safety stand down

During the Safety Stand Down, fire departments are encouraged to dedicate non-emergency operation time to health and safety training and promotion using online resources available on the Safety Stand Down website. In 2006, the Safety Stand Down had a thematic focus on preventing ESVIs and provided policies, vehicle safety drills, guides and articles for use in all U.S. and Canadian fire departments (Goldfeder, 2006). The key areas of focus were: seatbelt compliance, driving and backing, and vehicle checkout and operation. No program evaluations were found.

4.4. Summary of policy and administration interventions

4.4.1. Reducing use of lights and sirens

The Fire Department of the City of New York uses a protocol which divides incidents into eight tiers of prioritization with the lowest priority incident types prompting no lights and sirens during response (Wilbur, 2011). The department estimated a 32% reduction in crashes during their test period and similar results were reported by other departments with reported reductions in crash rates as high as 78% (Lindstrom, 2011). Colorado Springs estimated a 10–20% reduction in Code 3 driving after restricting lights and siren use on second and third due apparatus to automatic fire alarms and giving officers discretion for downgrading/upgrading response modes based on updated information about the incident severity (Personal communication, December 13, 2016). Algorithms have been developed to aid dispatchers to triage and identify cases where lights and sirens may or may not be necessary to reduce the use of lights and sirens (Isenberg et al., 2012).

4.4.2. Increased accountability and discipline

Baltimore County Fire Department introduced a policy to fine both driver and spotter 10 h of pay per backing incident if SOPs were not followed, but data were not available to verify if backing incidents decreased (Personal communication, December 1, 2016). Memphis Fire Department instituted a disciplinary policy mandating four hours of suspension and remedial driver training for backing incidents where spotters were not used, but did not measure the impact of the new disciplinary policy (Personal communication, March 9, 2017). We did not find any published data demonstrating an association between increased accountability or discipline and a reduction in ESVIs.

4.4.3. Crash review boards

Seminole County Fire Department established a crash review board nearly 20 years ago and reported a reduction in repeat crash offenders and risky behaviors (Personal communication, December 15, 2016). Oklahoma City began a crash review board in 2005 with a defined discipline policy based on severity of the incident (Personal communication, January 20, 2017), but no outcome data were available.

4.4.4. Seatbelt pledge

The NVFC encourages members to sign the International First Responder Seat Belt Pledge (Fontenot, 2011a,b). There are no published data evaluating whether signing the pledge has increased seatbelt compliance, although the pledge may increase awareness about seatbelt safety and encourage peer accountability around seatbelt compliance (Ludwig, 2008).

4.4.5. Crew Resource management

There are near miss case reports demonstrating the effective use of informal crew resource management to prevent ESVIs (McRoy and Lawrence, 2014; Slattery and Silver, 2009; Ellis, 2006; Tippett, 2011). In one instance, an engine driver pulled forward into an intersection after being given the green light signal, but stopped when a crew member yelled “stop” to observe a police vehicle cross their path in code 3 at a very high speed (Tippett, 2011). Another near miss report described an instance where an engine driver was initiating a right turn at a pre-emption controlled intersection when a crewmember in the backseat yelled “stop” as a vehicle in the second lane was approaching out of the driver’s blind spot at 50mph (Tippett, 2011).

4.4.6. Proactive risk management

Rockland Paramedic Services has reported a 58% reduction in crashes (12 crashes in 2008 to 5 in 2009), a 54% reduction in collision costs (from $39k to $18k), and a 36% reduction in crash-related injuries (from 33 in 2008 to 21 in 2009) after implementing a formal risk management program (Mund, 2010). In 2008, the London Fire Brigade implemented a risk management program for mitigating high levels of ESVIs (Personal communication, June 13, 2017). The department had a steady reduction in their crash rates in 2009 of about -0.30 crashes per 1000 incidents or 1.5% per quarter ($P < 0.01$) until 2012. Since 2012, the crash rate has remained flat ($P = 0.99$) (Fig. 6).

The Human Factor Analysis Classification System (HFACS), a model used in aviation to identify human factors involved in plane crashes, has been applied to ESVIs in some departments (Ludwig, 2013). The Richmond Ambulance Authority uses “After Action Review/Root Cause Analysis” after every vehicle contact or incident to identify causes of the incident which may be modifiable to prevent future incidents, and similar practices are done in other departments (McRoy and Lawrence, 2014).

4.4.7. On scene blocking

Policies to reduce on scene incidents included dispatching two vehicles to every highway incident and utilizing one vehicle primarily for blocking, assigning a spotter to watch for oncoming traffic and ensure people are yielding and slowing down, and increasing on scene visibility with flares, safety cones and flashing lights (Salka, 2010). However, no studies evaluating the effectiveness of these policies to prevent ESVIs were found.

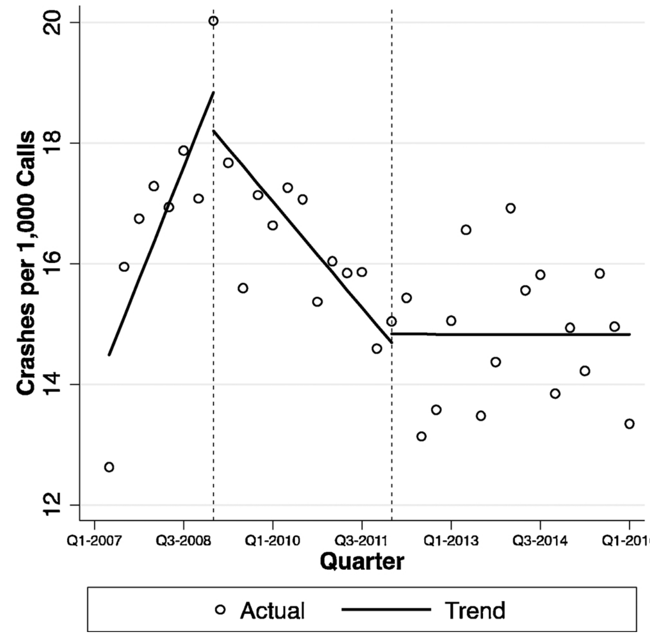

Fig. 6. Quarterly crash rates at London Fire Brigade, UK. Vertical dashed lines indicate a) when risk management interventions began (Q1–2009) and b) when crash rate leveled off (Q1–2012).

4.4.8. Crashworthiness testing

Legislation requiring crashworthiness testing and minimum safety ratings for ambulance and other emergency services vehicles may lead to reductions in crash injuries and fatalities similar to those seen in civilian passenger vehicles due to improvements in crashworthiness (Kahn, 2006).

4.4.9. Reducing driver fatigue

Memphis Fire Department has implemented a “12-12” policy for EMTs, requiring EMTs to switch off driving every 12 h during a 24-hour shift. Collisions were reportedly reduced along with repair costs and claims against the department (Personal communication, March 9, 2017).

5. Discussion

First responders have made great progress in addressing ESVIs and personnel safety through the introduction and improvement of standards, best practices, education and apparatus design. For example, line of duty deaths in the fire service continue to trend downward from a high of 174 in 1978 to 69 in 2016, and injuries resulting from ESVIs are declining (Fahy et al., 2017; Haynes and Molis, 2016). Despite these improvements, ESVIs remain a key cause of firefighter and first responder fatalities (Fahy, 2008) and the frequency of ESVIs have remained unchanged over the last 20 + years (Haynes and Molis, 2016).

To our knowledge, there are no other published systematic reviews of interventions to prevent or reduce ESVIs. There are systematic reviews on interventions to reduce motor vehicle crashes in general and in specific populations, including adolescents (Buckley et al., 2014; Small, 2008), older drivers (Desapriya et al., 2014) and alcohol-impaired drivers (Shults et al., 2001), and there are meta-analyses of single interventions like speed enforcement detection devices (Wilson et al., 2006, 2010), red light cameras (Aeron-Thomas and Hess, 2005), vision screening (Desapriya et al., 2014), traffic calming (Bunn et al., 2003), motorcycle helmets (Liu et al., 2008), and police patrols to reduce vehicle speeds (Goss et al., 2008). We chose to use a mixed methods review because, based on our prior experience, we expected to find little published data on the effectiveness of interventions to prevent

ESVIs. Incorporating key-informant interviews with departments allowed us to identify interventions currently in use that had not previously been published and that were effective based on reported or documented reductions in department crash rates.

Most published articles found in this review focused on vehicle engineering and policy-related intervention types, while our sample of key informants focused predominantly on policy and training related interventions. Limited outcome data were provided. Furthermore, articles that claimed reductions in injuries and ESVIs rarely provided supporting data or evidence to suggest the reductions were sustained or persistent. Even when outcomes were reported, outcomes of actual consequence (e.g., crash and injury) were infrequently reported. Only seven intervention types had reported crash reduction outcomes and even then, only two of the seven had sufficient data (which were obtained through key informant interviews) to support claims (Fig. 2). Our review does not cover the contributing factors and recommendations found in NIOSH Fire Fighter Fatality Investigation and Prevention Program fatality case reports (Anon., 2017The National Institute for Occupational Safety and Health (NIOSH)). While these reports are a comprehensive source of information on fatal ESVIs, the recommendations provided through these reports do not include evaluation of interventions and so were outside the scope of this review. Similarly, our review does not include review or presentation of NFPA Standards. While the NFPA Standards are excellent sources of information (particularly, 1901 and 1500) on how apparatus and vehicles are designed, built and should be operated, they do not provide information on the effectiveness or efficacy of interventions or recommendations to prevent or reduce ESVIs.

Both vehicle and environmental engineering interventions were commonly reported. The vehicle engineering interventions reviewed included monitoring devices such as DriveCam, VDRs and advanced civilian warning systems. Engineering interventions focused on environmental modifications were limited to traffic signal pre-emption systems and connected V2I technology. While other benefits were reported, we did not find empirical data from articles or key informants that demonstrated that these technologies effectively reduced the incidence of ESVIs. There is a lack of data regarding the effects of pre-emption systems on intersection safety. Moreover, the risk for responder-to-responder vehicle conflicts and crashes at controlled intersections is a noted limitation of traditional signal pre-emption systems.

Connected vehicle technology is not yet widespread; however, the ability to intelligently route emergency services vehicles around high traffic areas and to alert road users may reduce the risk of collisions. Current pilot studies focus largely on reducing response times, but future evaluations of public safety and crash prevention benefits are needed. The U.S. Department of Transportation is currently engaged in a series of studies to evaluate the use of V2V technology and estimates the technology will potentially address up to 80% of all crash types and crash scenarios. Research efforts are concentrated on refining V2V applications to aid light passenger vehicle drivers with emergency stop warnings, forward collision warnings, intersection safety, blind spot warnings, do not pass warnings, and control loss warnings (National Highway Traffic Safety Administration, 2011). Connected vehicle research in heavy trucks and commercial vehicles is also currently underway with preliminary results in simulation studies indicating V2V technology may prevent up to 50% of all heavy truck crashes (Chang, 2016).

Driver training and education were shown to be effective in several departments that we interviewed. These driver training programs focused largely on one-on-one instruction with ample hands-on training. Among all intervention types we reviewed, the driver training and education programs provided the most robust supporting data to demonstrate their effectiveness. This conflicts with the evidence-base on civilian driver training programs which have been found to be inconclusive or ineffective. For example, meta-analyses of pre-licensure rider training programs for motorcyclists have been found to be inconclusive (Kardamanidis et al., 2010). In a meta-analysis of randomized controlled trials, Ker et al. found post-licensure driver education to be ineffective in reducing crash risk among general driver populations (Ker et al., 2005). The difference in outcomes may be due in part to the comprehensive and hands-on nature of the training programs provided by Seattle Fire Department and Sacramento Fire Department. Moreover, these driver training programs are designed to teach drivers to operate large specialized apparatus, whereas general driver licensing education may focus more on driving laws and avoiding traffic offences rather than safe vehicle operation (Ker et al., 2005). Supporting this hands-on approach to training, the Network of Employers for Transportation Safety released a best practice reports for employers and drivers in occupational settings highlighting the importance of comprehensive driver training programs with training elements (e.g., hands-on driving and teach back) similar to the Seattle and Sacramento driver training programs (Network of Employers for Traffic Safety, 2016).

Policy-related interventions we reviewed focused on creating or modifying SOPs to reduce the use of lights and sirens, increasing driver accountability, or adopting risk management practices. We found multiple reports and articles that suggested reductions in Code 3 responses may lead to reductions in ESVIs. However, detailed data from such articles were rarely presented and well-designed causal studies were lacking.

Several articles and key informants reported, with supporting data, significant reductions in ESVIs after the introduction of risk management, suggesting the process may be an effective approach to reducing ESVIs. This is consistent with prior studies demonstrating that the use of risk management was associated with significant cost savings and reductions in occupational injuries in other fire department settings (Griffin et al., 2016; Poplin et al., 2015). Moreover, risk management has been successfully applied in other industries to reduce occupational injuries and fatalities. For example, proactive risk management implementation in the Australian coal mining industry was associated with up to 72% reductions in industry-wide injury rates compared to more compliance-based mining operations in the U.S. (Burgess et al., 2014; Poplin et al., 2008). The effectiveness of risk management may be due to the nature of the intervention as an ongoing and iterative cycle that identifies, assesses and prioritizes risks for mitigation that are specific to departments (International Organization for Standardization, 2009). The data driven nature of risk management ensures that resources can be concentrated on choosing a suite of interventions that directly target and address high frequency and high severity ESVI types. In addition, the continuous nature of interventions associated with risk management in departments like London Fire Brigade may lead to sustained declines in incidents through 'culture change' whereby drivers develop a greater focus on safety.

Our study has a number of limitations. Over half of the articles reviewed did not provide supporting outcome data. Additionally, many of the cited articles and studies reported surrogate outcomes not directly related to outcomes of consequence such as crash. For example, studies of driving simulator interventions rarely reported crash rates among simulator trained drivers and opted instead to report improvements in cone course scores (Lindsey and Barron, 2008). ESVs vary widely in design and operate differently; however, the articles reviewed did not report, discuss or indicate heterogeneity of effects for interventions. Some articles focused exclusively on one vehicle type (e.g., ambulances only) while other articles focused on interventions applicable to all ESV types (e.g., risk management). Apparatus such as pumpers, aerials and tillers are larger and heavier than ambulances and require further stopping distances and have wider turning and pivoting radii (United States Fire Administration, 2003; Trench et al., 2014). These significant differences in large apparatus may have important mediating or moderating effects on interventions that are designed specifically for smaller apparatus or ambulance type vehicles. Further research is needed to determine if certain vehicle types are more responsive to certain interventions. Finally, it should be noted that the effectiveness analyses we conducted were limited to time-series data and we could not control for confounding or exogenous factors. Therefore, causal inference and reported effectiveness should be interpreted with appropriate caution.

6. Conclusions

Though numerous interventions are available to reduce ESVIs, the evidence base for these interventions is limited. Based on our results and available data, comprehensive driver training and risk management may be effective approaches to mitigating ESVIs and related injuries. Additional studies are necessary to identify data-supported interventions that may be effective for preventing crashes involving ESVIs.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.aap.2018.01.006.

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