EVIDENCE-BASED OPTIMIZATION OF URBAN FIREFIGHTER FIRST RESPONSE TO EMERGENCY MEDICAL SERVICES 9-1-1 INCIDENTS

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ABSTRACT

Introduction. Many emergency medical services (EMS) systems dispatch nonparamedic firefighter first responders (FFRs) to selected EMS 9-1-1 calls, intending to deliver time-sensitive interventions such as defibrillation, cardiopulmonary resuscitation (CPR), and bag–mask ventilation prior to arrival of paramedics. Deciding when to send FFRs is complicated because critical cases are rare, paramedics often arrive before FFRs, and lights-and-siren responses by emergency vehicles are associated with the risk of en-route traffic collisions. **Objective.** To describe a methodology allowing EMS systems to optimize their own FFR programs using local data, and reflecting local medical oversight policy and local risk–benefit opinion. **Methods**. We constructed a generalized input–output model that retrospectively reviews EMS dispatch and electronic prehospital clinical records to identify a subset of Medical Priority Dispatch System (MPDS) call categories ("determinants") that maximize the opportunities for FFR interventions while minimizing unwarranted responses. Input parameters include local FFR interventions, the local FFR "first-on-scene" rate, and the locally acceptable ratio of risk to benefit. The model uses a receiver-operating characteristic (ROC) curve to identify the optimal mix of response specificity and sensitivity achieved by sending FFRs to progressively more categories of EMS calls while remaining within a defined risk–benefit ratio. The model was applied to a 16-month retrospective sample of 220,358 incidents from a large urban EMS system to compare the model's recommendations with the system's current practices. **Results.** The model predicts that FFR lights-and-siren responses in the sample could be reduced by 83%, from 93,058 to 16,091 incidents, by confining FFR responses to 27 of 509 MPDS dispatch determinants, representing 7.3% of incidents but 58.9% of all predicted FFR interventions. Of the 93,058 incidents, another 58,275 incidents could be downgraded to safer nonemergency FFR responses and 18,692 responses could be eliminated entirely, improving the specificity of FFR response from 57.8% to 93.0%. **Conclusions.** This model provides a robust generalized methodology allowing EMS systems to optimize FFR lights-and-siren responses to emergency medical calls. Further validation is warranted to assess the model's generality. **Key words:** emergency medical services communications systems; sudden cardiac arrest; cardiopulmonary resuscitation; firefighter first responders; dispatch policy; risk–benefit

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INTRODUCTION

Background

Many emergency medical services (EMS) systems dispatch conventional fire apparatus in addition to a paramedic ambulance to selected 9-1-1 EMS calls to speed the delivery of time-sensitive critical medical interventions such as chest compressions and bag–mask ventilation, control of exsanguinating peripheral bleeding, and, more recently, automated defibrillation.[1,2]

Nonparamedic firefighter first responder (FFR) intervention can be lifesaving in specific critical emergencies,[3–5] but ensuring that FFR programs are both effective (reaching patients who may benefit clinically) and efficient (minimizing unnecessary responses) can be remarkably complicated.

Identifying which EMS calls warrant lights-and-siren response by ambulances or other responding vehicles is a central principle in contemporary EMS dispatch practice, acknowledging the inherent risk to medical responders and to others during these responses.[6–9] Since FFRs respond in addition to the already responding paramedic ambulance, a number of factors make it difficult to design an FFR dispatch policy with simultaneously high sensitivity and specificity. First, truly critical cases are rare.[10] Second, in many communities, the paramedic ambulance arrives before fire apparatus in a significant proportion of cases, reducing opportunities for prior intervention by FFRs.[11,12] Finally, fire truck crashes, while fairly rare, can be catastrophic, largely because of the size and weight of fire apparatus. Therefore, optimizing FFR response will limit the inherent risks to those calls in which there is at least a minimal probability of true benefit.

Beyond calls in which urgent FFR interventions occur, fire crews also provide valuable on-scene assistance to the transporting paramedic crew, particularly in scene management, removing patients from the call location to the ambulance, and in marshaling

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equipment. Because this assistance is provided largely as paramedics conclude their on-scene evaluation and treatments, it would be useful to determine which EMS calls are likely to be serious enough to warrant this assistance, but in which the crash risk could be reduced by having the added fire apparatus respond without the use of lights and sirens.

No comprehensive methodology for optimizing firefighter first response has been described in the literature. Simply introducing a structured call triage process has been shown to permit the selective response of FFRs instead of sending them on all EMS calls.[13] Related literature includes an observational study of FFR interventions in one city[14] and another study that found limited need for FFR response to facilities with on-site medical staff.[15] Others have described EMS dispatch categories producing the most advanced life support interventions by paramedics[16–18] and those most likely to produce cardiac arrests[19,20] versus those that could safely receive a low-priority response.[21–23] We describe here a generic methodology allowing EMS systems to optimize their own FFR programs using local data, and reflecting local medical oversight policy and local risk–benefit opinion.

METHODS

Study Design

We constructed a generalized input–output model that considers several key factors governing opportunities for FFRs to deliver specific critical medical interventions at EMS 9-1-1 calls prior to the arrival of paramedics. When applied to an EMS system's dispatch and clinical data, the model's outputs include a recommended subset of EMS dispatch categories ("determinants") that maximize the opportunities for FFR interventions while simultaneously minimizing needless FFR responses.

We then applied the model to a retrospective data set from a large urban EMS system, comparing the model's recommendations with the system's current practices.

Ethics approval was obtained from the Sunnybrook Health Sciences Centre Research Ethics Board, which waived a requirement for individual patient consent.

Setting

The study site was the Toronto (Canada) EMS system, in which a two-tiered (advanced life support and basic life support) "third-service" EMS agency provides all EMS care to 2.6 million residents in a 250-square-mile homogeneously dense urban environment.

Toronto EMS dispatch call takers interviewed 9-1-1 callers requesting medical aid using the Medical Priority Dispatch System (MPDS) Version 10.2 (Priority Dispatch Corporation, Salt Lake City, UT). This scripted interrogation algorithm ensures that EMS calls are consistently classified into one of 509 MPDS determinants within the EMS Computer-Aided Dispatch (CAD) system based on the nature and apparent acuity of the call. The EMS response to each of these determinants was predetermined, including which should receive firefighter first response. All FFR responses were undertaken on a lights-and-siren basis by a single paid municipal fire department, Toronto Fire Services, whose FFR interventions include first aid, cardiopulmonary resuscitation (CPR), and automated external defibrillation. Where firefighter response was to occur, the fire dispatch center was electronically notified via a CAD-to-CAD data link.

Study Population

The study population included all Toronto EMS 9-1-1 emergency calls from July 1, 2003, to October 31, 2004.

Design of the Predictive Model

The purpose of the model is to identify the MPDS determinants most likely to require FFR intervention (as locally defined) and then to decide which of these determinants should receive an FFR response while remaining within a locally defined risk–benefit framework.

The model has four input parameters whose values can be set by the user to reflect local medical opinion and risk tolerance:

1. *FFR trigger interventions:* A locally defined list of prehospital interventions or circumstances that define a call record as having warranted lights-and-siren FFR response.
   While the model permits the use of any locally defined list of interventions, in our example, the authors defined a patient as warranting FFR response:
   a. If any rescuer performed:
      - CPR
      - Defibrillation
      - Automated external defibrillator (AED) rhythm analysis

   b. Or if the patient was classified by the treating EMS paramedics as "CTAS-1–resuscitation" under the Canadian Triage and Acuity Scale (CTAS).[24]

   In Toronto, CTAS-1 patients represent the 1.2% most critically ill or injured EMS patients; they were included in the study to identify a broad range of incidents that might also benefit from FFR intervention. A CTAS score is assigned to all EMS-transported patients and to all emergency department patients in Ontario.

2. *FFR first-on-scene rate:* The percentage of calls where local FFRs are expected to arrive before paramedics.
   In the Toronto example, this was set at 50% based on evidence in the local cardiac arrest database.[25]
3. ***FFR nonemergency response cutoff point:*** The point at which further firefighter nonemergency response to provide on-scene assistance to paramedics is considered unwarranted, expressed as a minimum probability that a call will require one of the FFR interventions.
   In the Toronto example, this was set at one chance of FFR intervention in 250 or fewer responses by author consensus.
4. ***Risk–benefit ratio:*** The ratio of tolerance for the risk of a major fire apparatus crash during a medical response relative to the societal benefit of FFR intervention in critical cases.
   In our example, this was set at 1.0 (1:1) as a conceptual representation of the authors' equipoise regarding the overall balance of societal risks (low frequency and high societal consequence) and benefits (higher frequency but lower societal impact) of FFR response in the Toronto demonstration setting.

This model consists of software written in Microsoft Visual Basic 6.3, with Microsoft Excel 2002 (Microsoft Corp., Redmond, WA) used for certain statistical processes and to produce graphical output.

The software analyzes a large sample of local EMS electronic patient care records and CAD data to retrospectively identify and classify opportunities for FFR intervention and conducts the following:

1. Reviews each patient record to identify its MPDS dispatch determinant and to establish which patients met at least one of the descriptors listed under "FFR trigger interventions."
2. Tallies the total number of calls arising from each MPDS determinant, and the total number of cases in each determinant where FFR trigger interventions were performed.
3. Calculates the proportion of calls in each MPDS determinant producing the opportunity to perform specific FFR interventions.
   a. For example, if 13 of 100 cases in MPDS determinant "10-D-1" required at least one of CPR, AED application, or defibrillation, or produced a CTAS-1 patient, the "FFR-warranted rate" for "10-D-1" would be 0.13.
4. For each MPDS determinant, predicts the number of opportunities for FFRs to intervene prior to arrival of EMS paramedics by prorating the number of cases requiring FFR trigger interventions by the "FFR first-on-scene rate" parameter.
   a. In the example above, if the FFR first-on-scene rate is 50%, then MPDS determinant 10-D-1 will yield 6.5 opportunities for FFR intervention prior to paramedic arrival for every 100 cases (13 / 100 $\times$ 50%).
5. Ranks all MPDS determinants from the determinant with the highest proportion of calls producing an opportunity for FFR intervention to the determinant least likely to do so.
6. Tallies the total predicted opportunities for FFR intervention in the entire sample as well as the total number of EMS responses from which they arise.

The model considers MPDS to be a quantitative diagnostic test, for which a range of possible cutoff points for FFR lights-and-siren response exists, each point representing a progressively larger group of MPDS call determinants designated for FFR response.

The model creates each of these cutoff points by progressively adding one more MPDS determinant to the set proposed for FFR response in descending order of the determinant's proportion of FFR-warranted calls until all determinants with any FFR-warranted calls are represented. For each cutoff point, the model recalculates the total predicted opportunities for FFR intervention and the total FFR lights-and-siren responses required to reach them.

The model calculates the true-positive fraction (sensitivity) and false-positive fraction (1–specificity) for FFR response at each possible cutoff, and plots these to create a receiver-operating characteristic (ROC) curve. The model then plots a risk–benefit isocost line with a slope equaling the risk–benefit ratio defined in the inputs such that it intersects the arc of the ROC curve at a single point.

This single point of intersection between the ROC curve and the risk–benefit isocost line identifies the optimal cutoff point for FFR lights-and-siren response. If FFRs respond with lights and sirens to only the selection of MPDS determinants identified by this cutoff point, the optimal mix of sensitivity and specificity of FFR response will be achieved while remaining within the defined risk–benefit ratio.

MPDS determinants with a probability of FFR intervention below the optimal lights-and-siren response cutoff point but still above the FFR nonemergency response cutoff point were considered to warrant a nonemergency FFR response to back up paramedics on scene. Determinants with a probability of FFR intervention below the FFR nonemergency response cutoff point were considered not to warrant FFR response at all.

A before-and-after Bayesian 2 $\times$ 2 analysis was conducted comparing the statistical performance of the model's optimized FFR scheme for the study community with that of its current FFR practices.

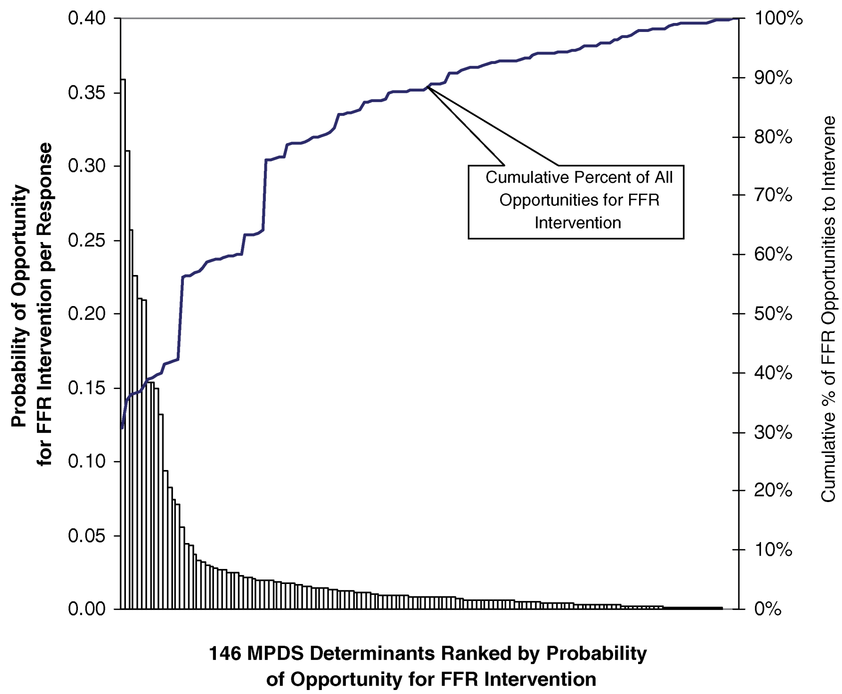

FIGURE 1. Pareto distribution of Medical Priority Dispatch System (MPDS) determinants ranked by probability of opportunity for firefighter first responder (FFR) intervention. This distribution demonstrates that opportunities for FFR intervention are tightly clustered in a very small number of MPDS dispatch determinants at the left of the chart. The cumulative percentage curve demonstrates that response to these most productive dispatch determinants rapidly captures nearly all opportunities to intervene. Considered together, these curves mean that very large numbers of additional firefighter responses are required to reach even very small numbers of additional FFR patients beyond some optimum point.

RESULTS

To demonstrate the model, a total of 267,761 EMS 9-1-1 emergency calls from a 16-month period were reviewed for inclusion in the study. We eliminated 16,237 because their CAD record lacked an MPDS determinant, and another 17,507 were excluded because an electronic patient record could not be located, leaving 234,017 incidents in the final data set.

MPDS determinants with fewer than 30 patient records or no FFR-warranted cases at all were eliminated, producing a final input sample of 220,358 incidents and 156,138 patients in 146 MPDS determinants. Imposing this sample size constraint eliminated 242 determinants from consideration but retained 3,067 (98.2%) of the 3,122 total cases warranting FFR intervention.

To establish the probability that MPDS would correctly discriminate between calls providing the opportunity for FFR intervention and those that do not, a run of the model was conducted with the first-on-scene rate and the risk–benefit features excluded. The area under the resulting ROC curve (AUC) was calculated using the trapezoidal method as 0.92, defining MPDS as an "excellent" (AUC > 0.90) diagnostic test for making this discrimination.

Firefighter first response was warranted in 3,067 (1.4%) of the 220,358 incidents, defined as having at least one of the study's FFR trigger criteria (CPR, defibrillation, AED analysis, or a patient rated by the treating paramedics as requiring "CTAS-1 resuscitation").

Figure 1 shows a Pareto distribution chart with MPDS determinants ranked by the descending probability of opportunity for FFR intervention. Calls warranting FFR intervention were found to be heavily clustered in a small number of determinants. For instance, 41% of all cases warranting FFR intervention could be reached by responding only to the 12 top-ranked MPDS determinants representing 2.0% of all EMS calls.

In our example, the optimal lights-and-siren cutoff point (Fig. 2) prescribes FFR response to 27 of the 146 MPDS determinants (Table 1), sending FFRs to a total of 16,091 (7.3%) of the 220,358 incidents in the 16-month sample. This selection of MPDS determinants would deliver an FFR to 1,837 (58.9%) of all 3,067 opportunities for FFR intervention. However, in 50% of these 1,837 possible opportunities, paramedics are predicted to arrive before FFRs, reducing actual FFR intervention opportunities to 919 cases, or about one opportunity for every 17 responses (Table 2).

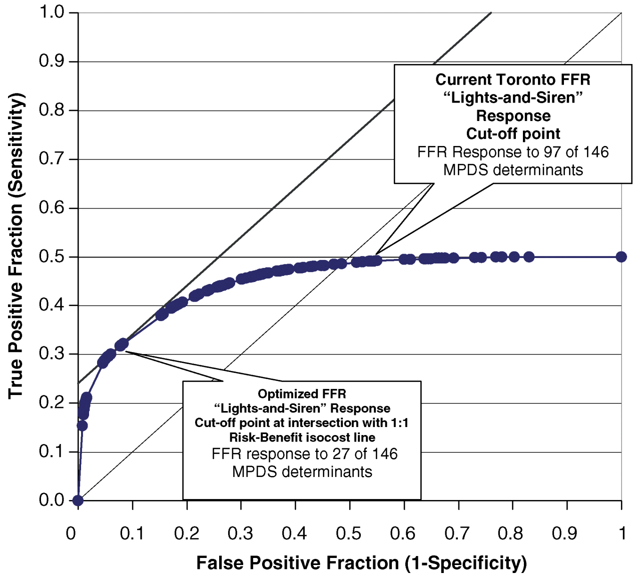

FIGURE 2. Receiver-operating characteristic (ROC) curve for Toronto optimization: firefighters first on scene in 50% of responses (risk–benefit ratio set at 1.0). FFR = firefighter first responder; MPDS = Medical Priority Dispatch System.

Compared with current FFR dispatch practices in the study community, this optimization would reduce lights-and-siren responses by 76,967 (–82.7%) at the expense of forgoing 473 opportunities to intervene. Of these 76,967 incidents, 58,275 were recommended for conversion to nonemergency response to provide on-scene assistance to paramedics, and 18,692 current responses were recommended to no longer receive an FFR response at all.

Of the 220,358 incidents in the sample, 145,992 incidents (including the 18,692 mentioned above) would produce a rate of less than one patient warranting FFR interventions per 250 responses and were designated as falling below the nonemergency response cut-off point, thus not warranting FFR response.

The optimization produced a 3.8-fold improvement in the dispatch process's positive predictive value from 0.015 (95 confidence interval [CI] 0.014–0.016) to 0.057 (95% CI 0.054–0.060) and improving its specificity to 93% (95% CI 93%–93%) from 57.8% (95% CI 57.8%–57.8%), but at a cost of a decrease in sensitivity from 45.4% (95% CI 43.6%–42.4%) to 30% (95% CI 28.4%–31.6%).

Ten additional runs of the model were made using the study community's data to demonstrate the model's sensitivity to variation in two of its key parameters. Five runs were conducted varying FFR first-on-scene rates from 20% to 90% while holding the risk–benefit ratio at 1.0 (Table 3), and another five runs were conducted varying the risk–benefit ratio from 0.5 (risk considered to be half as important as benefit) to 1.5 (risk considered to be 1.5 times as important as benefit) while holding the FFR first-on-scene rate constant at 50% (Table 4).

DISCUSSION

We have developed a generalized model that optimizes the balance between opportunities for FFR critical intervention in EMS 9-1-1 calls and the number of lights-and-siren FFR responses within a risk–benefit framework. It fills an important need in public safety systems since many communities (including the study city) dispatch a lights-and-siren FFR response to a large proportion of their total EMS call volume without an objective comprehensive mechanism for evaluating any of these factors. Conversely, the model may assist communities with few FFR responses to identify additional opportunities for FFR intervention.

Important public policy issues are posed by the small but real rate of catastrophic fire apparatus crashes. In 1999, a U.S. national study found large fire apparatuses (over 26,000-lb gross vehicle weight) were annually involved in nearly 2,500 accidents, which killed an average of six firefighters and 15 civilians per year, and injured more than 1,000 others. Civilians were 2.5 times as likely to be killed and four times as likely to be injured as the responding firefighters.[26]

Risk to civilians is ethically important because it is imposed without informed consent on individuals who do not stand to directly benefit from a particular emergency response. Widely accepted practices such as the doctrine of "tolerability of risk" require aggressive mitigation of such risks,[27–30] although doing so is rarely, if ever, explicitly addressed in the design of FFR systems.

Tolerability of risk theory defines this form of risk to be particularly important because its magnitude is nonzero but uncertain (because of a lack of definitive data specific to FFR-related crashes), yet possesses potentially grave consequences including death and serious injury, as demonstrated by sentinel examples. In the literature, the inability to obtain authentic informed consent from the public for their share of community risk (such as accidental radiation releases from nuclear power plants) generally requires that this risk be attenuated to one order of magnitude below the level of risk tolerated by a group who can provide such consent, in this case, firefighters themselves.

Establishing firefighters' tolerance for this risk is complex. For instance, one might ask firefighters "How many civilian lives would have to be saved by FFR before you would accept the death of (or grave injury to) a firefighter in return?" In a city where FFR was believed to save 10 lives per year and local firefighters said that they would accept a firefighter's death (or severe disability) for every 500 civilians saved, this would require that the crash risk to firefighters be reduced to one death/grave injury per 50 years. Applying the criteria of tolerability of risk, the risk of civilian death arising from FFR would therefore need to be attenuated by one $\log_{10}$ to 1 per 500 years.

TABLE 1. Optimal 27 Medical Priority Dispatch System Determinants Selected for Firefighter "Hot" Response

MPDS Determinant	MPDS Determinant Clinical Description (As Reported by 9-1-1 Caller)	Total Incidents	Cumulative Firefighter "Hot" Responses	Patients Warranting Firefighter Intervention	Cumulative Incidents Warranting Firefighter Intervention	Opportunities for Firefighter Intervention at 50% "First on Scene"	Cumulative Opportunities to Intervene at 50% "First on Scene"
09E01	Cardiac or Respiratory Arrest/ Death—Not breathing at all	2,618	2,618	939	939	470	470
09E02	Cardiac or Respiratory Arrest/ Death—Breathing uncertain (agonal)	468	3,086	145	1,084	73	542
11E01	Choking—Choking verified	105	3,191	27	1,111	14	556
09E03	Cardiac or Respiratory Arrest/ Death—Hanging	62	3,253	14	1,125	7	563
09O01	Cardiac or Respiratory Arrest/ Death—Expected death (unquestionable)	38	3,291	8	1,133	4	567
31E01	Unconscious/Fainting—Ineffective breathing	91	3,382	19	1,152	10	576
09D01	Cardiac or Respiratory Arrest/ Death—Ineffective breathing	286	3,668	44	1,196	22	598
12D01	Convulsions/Seizures—Not breathing (after key questions)	39	3,707	6	1,202	3	601
11D01	Choking— Not alert	114	3,821	17	1,219	9	610
27D01	Stabbing/Gunshot/ Penetrating Trauma—Unconscious or arrest	53	3,874	7	1,226	4	613
06E01	Breathing Problems—Ineffective breathing	467	4,341	44	1,270	22	635
06E00	Breathing Problems—EMD upgrade from Delta	85	4,426	7	1,277	4	639
09B01	Cardiac or Respiratory Arrest/ Death—Obvious death (unquestionable)	202	4,628	15	1,292	8	646
24D06	Pregnancy/Childbirth/ Miscarriage—Baby born	42	4,670	3	1,295	2	648
31D01	Unconscious/Fainting—Unconscious (at end of interrogation)	7,809	12,479	432	1,727	216	864
27D03S	Stabbing—Central wounds	113	12,592	5	1,732	3	866
06E01A	Breathing Problems—Ineffective breathing	46	12,638	2	1,734	1	867
23D01	Overdose/Poisoning—Unconscious	268	12,906	10	1,744	5	872
10D02	Chest Pain—Not alert	369	13,275	12	1,756	6	878
32D00	Unknown Problem—EMD upgrade from Charlie	471	13,746	15	1,771	8	886
17D03	Falls—Not alert	999	14,745	30	1,801	15	901
29D05	Traffic/Transportation Accidents—Not alert	308	15,053	9	1,810	5	905
27B04	Stabbing/Gunshot/Penetrating Trauma—Unknown status (3rd-party caller)	181	15,234	5	1,815	3	908
27D03	Stabbing/Gunshot/Penetrating Trauma—Central wounds	224	15,458	6	1,821	3	911
27D01S	Stabbing—Unconscious or arrest	76	15,534	2	1,823	1	912
11D02	Choking— Abnormal breathing (partial obstruction)	476	16,010	12	1,835	6	918
12D00	Convulsions/Seizures—EMD upgrade from Charlie	81	16,091	2	1,837	1	919

EMD = emergency medical dispatch; MPDS = Medical Priority Dispatch System.

Further, it may be difficult to demonstrate that the underlying justification for FFR and its risks—a survival benefit in critical patients—arises exclusively from, or was achievable only by, FFR intervention. Our methodology permits the inclusion of precise values about such clinical benefit, should later research provide them.

Optimization of FFR response may reduce opportunities for FFR intervention, compared with existing practices. The data do suggest that adding FFR responses beyond the optimum (7.3% of EMS calls in our example) should be undertaken cautiously, as the rate of FFR opportunities to actually intervene falls off sharply beyond the optimum.

TABLE 2. Optimized Response Model Compared with Current Toronto Firefighter First Responder Dispatch Practice

	Current FFR Dispatch Practice		Optimized FFR Response Model		Optimization Impact	
	Incidents 16-Month Sample	Percent of Total EMS Call Sample	Incidents 16-Month Sample	Percent of Total EMS Call Sample	Change 16-Month Sample	Percent Change
Calls receiving lights-and-siren FFR response	93,058	42.2%	16,091	7.3%	–76,967	–82.7%
Calls receiving nonemergency FFR response	NA	0.0%	58,275	26.5%	58,275	NA
Calls not receiving any FFR response	127,300	57.8%	145,992	66.3%	18,692	14.7%
Total	220,358		220,358			
FFR opportunities to intervene	1,392	0.6%	919	0.4%		
MPDS determinants receiving FFR response	97		27		–70	

EMS = emergency medical services; FFR = firefighter first responder; MPDS = Medical Priority Dispatch System; NA = not applicable.

However, the sensitivity analysis demonstrates that improving FFR first-on-scene rates produces rapid increases in the absolute number of FFR intervention opportunities while remaining within any particular risk–benefit balance (Table 3). Use of established performance improvement techniques such as optimizing notification times,[31] shortening the time to leave the station after receiving the call, and using real-time geographic resource redeployment would likely improve FFR first-on-scene rates in most systems. Moreover, other issues such as increased acceptance by firefighters of a role in medical first response[32,33] and expeditious application of the AED to the patient by FFRs upon arrival[34] would maximize these opportunities.

LIMITATIONS AND FUTURE RESEARCH

As a derived clinical prediction tool, this model has inherent limitations and requires validation. The results presented may be specific to Toronto's EMS call profile and patient population, and to the input parameters used. Validation should include repetition of the analysis using a data set from the study community from another time period, and comparison of these results with those obtained from multiple data sets from other communities.

Some of the software written for this model is inherently specific to the study community's database. However, the methodology is not, and other researchers can easily apply steps of the model to their local data sets.

The model does not evaluate the medical effectiveness of FFR programs, instead estimating only "the opportunity to intervene" before paramedic arrival. Further research should be undertaken to correlate these opportunities with actual interventions and to quantify any survival advantage these programs convey to patients.

Probabilistic risk analysis, community and/or provider risk tolerance assessment, or other techniques would enhance the precision of our risk–benefit estimates. However, the 1.0 risk–benefit ratio used in the optimization properly models the authors' equipoise about risk and benefit. A wide spectrum of opinion may exist about the most appropriate balance between benefit and tolerance for risk, and any ratio reflecting local opinion can be used in this methodology.

The precision of the model would be improved by fire dispatch data containing sufficient detail to establish the actual rate of firefighter "first arrival" in each different MPDS determinant. In the study community, using cardiac arrest calls alone likely overstates the actual rate of first arrival when all types of FFR calls are considered. However, actual fire dispatch data were not available to the investigators.

Selection bias may have been introduced by the exclusion of calls missing an MPDS determinant

TABLE 3. Analysis of the Model's Sensitivity to Changes in the Firefighter First-on-Scene Rate

Firefighter First-on-Scene Rate	Optimized "Hot" FFR Responses within 1.0 Risk–Benefit Ratio (16-Month Sample)	Percent of Total EMS Calls Receiving FFR Response	Predicted Opportunities for Firefighter Intervention before EMS Arrival
20%	4,670	2.1%	259
30%	12,592	5.7%	520
40%	15,053	6.8%	735
50%	16,091	7.3%	919
60%	22,434	10.2%	1,102
70%	45,704	20.7%	1,286
80%	46,782	21.2%	1,945
90%	51,385	23.3%	2,245

EMS = emergency medical services; FFR = firefighter first responder.

Table 4. Analysis of the Model's Sensitivity to Changes in the Risk–Benefit Ratio

Ratio of Risk to Benefit	Optimized "Hot" FFR Responses Where a Firefighter Was First on Scene in 50% of Calls (16-Month Sample)	Percent of Total EMS Calls Receiving FFR Response	Predicted Opportunities for Firefighter Intervention before EMS Arrival
1.50	12,874	5.8%	872
1.00	16,091	7.3%	919
0.75	45,645	20.7%	1,208
0.50	58,159	26.3%	1,291

EMS = emergency medical services; FFR = firefighter first responder.

(6.0%) and of calls without an available patient record (6.5%).

The use of the CTAS-1 score as a surrogate for calls warranting lights-and-siren FFR response is particular to the EMS system in Ontario. However, the model permits systems not using CTAS to substitute any desired list of critical interventions.

The results presented for the study community in Table 1 are specific to MPDS Version 10.2. However, the methodology remains general as it inherently reflects whatever version of MPDS was used in the CAD data it analyzes.

Finally, the model does not evaluate other supportive care measures that FFRs may provide when critical interventions are not required. Whether these measures warrant a lights-and-siren FFR response or whether they would be as medically effective if delivered after a slower "cold" response remains an open question.

Conclusions

This model provides a robust generalized methodology allowing EMS systems to optimize FFR lights-and-siren responses to emergency medical calls. Further validation is warranted to assess the model's generality.

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