Early detection of disease outbreaks is essential for authorities to initiate and conduct an appropriate response. A need for an outbreak detection that monitored data predating laboratory confirmations was identified, which prompted the establishment of a novel symptom surveillance system.

The surveillance system monitors approximately 80% of the Danish population by applying an outbreak detection algorithm to ambulance dispatch data. The system also monitors both regional and national activity and has a built-in, switch-on capacity for implementing symptom surveillance reporting in case of an alert.

In an evaluation with outbreak scenarios it was found that decreasing the outbreak detection sensitivity from a prediction limit of 95% to one of 99% moderately reduced the time to detection, but considerably diminished the number of false alerts. The system was able to detect an increased activity of influenza-like illness in December 2003 in a timely fashion. The system has now been implemented in the national disease surveillance programme.

**Key words:** Ambulance, bioterrorism, outbreak surveillance, statistical data analysis.

---

**Original Articles**

**Surveillance of Ambulance Dispatch Data as a Tool for Early Warning**

**KH Bork**, BM Klein, K Mølbak, S Trautner, UB Pedersen, E Heegaard

Early detection of disease outbreaks is essential for authorities to initiate and conduct an appropriate response. A need for an outbreak detection that monitored data predating laboratory confirmations was identified, which prompted the establishment of a novel symptom surveillance system.

The surveillance system monitors approximately 80% of the Danish population by applying an outbreak detection algorithm to ambulance dispatch data. The system also monitors both regional and national activity and has a built-in, switch-on capacity for implementing symptom surveillance reporting in case of an alert.

In an evaluation with outbreak scenarios it was found that decreasing the outbreak detection sensitivity from a prediction limit of 95% to one of 99% moderately reduced the time to detection, but considerably diminished the number of false alerts. The system was able to detect an increased activity of influenza-like illness in December 2003 in a timely fashion. The system has now been implemented in the national disease surveillance programme.

**Key words:** Ambulance, bioterrorism, outbreak surveillance, statistical data analysis.
or attack, thereby reducing the median outbreak detection time (MOD-Time) and allowing authorities sufficient time to start outbreak investigation and implement medical countermeasures such as quarantine, mass vaccination or administration of antibiotics. Specifically, the goal was to detect outbreaks of severe illness at an earlier stage than is possible when using traditional sources of information such as clinical reports and laboratory results. Ambulance transport data has previously been found to be useful as an early indicator of increased disease activity unrelated to origin [1], but a thorough testing with scenarios had not been done. The present paper reports results from validation and implementation of the system, which has been termed Bioalarm.

**Material and methods**

In brief, the surveillance system monitored the activity of ambulance dispatch data by daily applications of an outbreak detection algorithm (Level I). In case of an alert due to an increase in the demand for ambulance transport, a built-in reporting system could be activated (Level II). The second level served as a switch-on capacity for online recording of epidemiological data (selected patient symptoms, geographical data and onset of symptoms) in order to collect information for a preliminary case definition before patients arrived at the hospital.

**Level 1**

*Ambulance dispatch data*

In Denmark, ambulance transport data has been recorded for more than a decade. We collected data on dispatch for emergency medical conditions from January 2000 to August 2005 from six regions in Denmark and evaluated regional as well as national activity simultaneously. Data was recorded at a central registration unit operated by a primary ambulance transport contractor (Falck A/S). This dataset covered more than 80% of the total Danish population of approximately 5.4 million people. The data demonstrated significant variation and included a period with several minor and one major influenza epidemic.

**Incidence data from outbreaks**

Three scenarios were developed to test and optimise the outbreak detection algorithm. The amplitude (new cases/day) of some of the scenarios was scaled to fit the regional background transport level of the region where the scenarios were applied. The epidemiological profiles of the outbreaks were unaffected.

**Scenario I:** Outbreak of tularaemia with 100 persons displaying symptoms due to Francisella tularensis. The incidence curve resulted from standardised epidemiological calculations [2]. Scenario II: From the Sverdlovsk outbreak of anthrax in 1979 [3,4] incidence data was collected and the amplitude of the outbreak was up scaled to a total number of 420 persons contracting the disease. Scenario III: Incidence data from Madrid in 1981 concerning an outbreak of symptoms later revealed to be due to the illegal sale of toxin-laced cooking oil causing toxic oil syndrome (TOS) [5]. The amplitude of the extensive outbreak was downscaled to a total number of 448 displaying symptoms [FIGURES 1, 2].

**Statistical methods**

We developed a model in which previous observations were primarily used to determine the variations, while deviations from the baseline were evaluated based upon the observations of the most recent day. The model predicted short term level of transport frequencies one day ahead and calculated prediction intervals with 95% and 99% limits. The upper limits were the focus for analysis and defined the alert thresholds. Whenever transport frequencies increased to above the threshold level of either 95% or 99%, an automatic notification was generated. The statistical engine consisted of a state space dynamic model with local level combined with a Kalman smoother [6,7]. The model was calibrated to fit regional transport frequencies in each region. A user-friendly interface was designed for day-to-day operation and graphic presentation of events.

**Testing**

The system was first tested in a dry run on background data alone, defining the baseline number of alerts and overall stability. Subsequently, background data for one region with approximately 640,000 inhabitants were spiked with incidence data from outbreaks. This process created a simulated data-material that was used to estimate the response times of the system. The starting point (Day 0)
Early warning and response

of the epidemiological profiles in the three scenarios were added to the background data, beginning with the first day of January 2004, then the second day of January 2004 and so forth until the end of July 2004 (three scenarios on 182 days, the equivalent of 546 runs) (FIGURE 2). The average, median and maximum outbreak detection time in days were then recorded after each new starting point for all three scenarios.

Level II
For eight days in March 2006, epidemiological data from patients with emergency medical illnesses in one region with approximately 640,000 inhabitants were collected online, following a command from the Danish National Centre for Biological Defence (NCBD) (National Center for Biologisk Beredskab) Data contained selected patient symptoms, patient characteristics and geographical information, [TABLE 1]. Paramedics recorded the data on forms prepared for this purpose and forms were sent by fax to the NCBD for estimation of baseline values (incidences of symptoms, geographical distribution, etc.). Subsequently, the data was spiked with epidemiological symptom data before analysis, in order to simulate a geographically located, symptom-specific disease outbreak.

Results

Ambulance dispatch data:
The data was collected from six regional dispatch centres which had median dispatches ranging from 45 to 130 per day. There were no significant simultaneous seasonal variations on the six dispatch centrals. At a 95% detection limit, we expected 109.5 alerts per year, while a 99% limit resulted in an expected number of 21.9 alerts per year (95%: 5 alerts every 100 days per region or 18.25 alerts per year per region, 18.25 _ 6 = 109.5 alerts/year), (99%: 1 alert every 100 days per region or 3.65 alerts per year per region, 3.65 _ 6 = 21.9 alerts/year).

During an influenza epidemic in 2003 the ambulance reporting system issued 13 alerts at the 99% level. Immediately prior to this, one alert had been issued at the 99% level detection limit. During the period when the observed numbers of influenza cases were below the National Influenza Sentinel Registration’s threshold level, the system

### Figure 2
Addition of scenario (toxic oil syndrome) to background data

![Graph showing observed and expected number of calls and prediction limits with MOD-Time after toxic oil addition: 14 days](image)

Note
The smoothed activity of alerts before and after addition of data from the toxic oil syndrome scenario, Madrid 1981. The dotted vertical lines on the lower illustration denote time from the sale of toxic oil to system alert. The MOD-Time of the 99% detection limit was 14 days. The blue dots mark the calculated daily dispatch intensities above the 99% threshold limit.

### Table 2
Scenario outbreak detection time (day)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Delay</th>
<th>95% Limit</th>
<th>99% Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Mean</td>
<td>2.36</td>
<td>2.70</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>II</td>
<td>Mean</td>
<td>3.08</td>
<td>4.80</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>8.00</td>
<td>8.00</td>
</tr>
<tr>
<td>III</td>
<td>Mean</td>
<td>12.68</td>
<td>14.23</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>16.00</td>
<td>16.00</td>
</tr>
</tbody>
</table>
issued two alerts. Ambulance dispatch activity, compared with the Sentinel Registration, is illustrated in Figure 3.

**Scenario detection**

When the ambulance dispatch data were spiked with data on the outbreak scenarios, we were able to detect all outbreaks both at a 95% and 99% detection limit [FIGURE 1]. Based on daily applications of the algorithm, a change from a 95% to a 99% detection limit increased the MOD-Time by 1 (scenario I) or 2 days (scenario II and III) [TABLE 2].

**Operational issues**

One minor system breakdown occurred during the period of automatic prospective ambulance transport frequency monitoring, but overall, the system was operative above 99% of the time. The system updated automatically once every 24 hours. Running costs were limited; the operating officer checked the status of the system and the transport level daily and the procedure required no special skills or training. There was good compliance by operating officers.

**Collection of early epidemiological data, Level II**

During eight days a total of 553 patients were transported as critically ill medical patients in the selected region. During the same period 243 patients were registered at the NCBD by online faxing of completed ambulance forms which indicated underreporting (243/553 = 44%). Of the 243 patients, 186 were uniquely identifiable in the ambulance statistics. The remaining 57 patients had erroneous or missing patient identification numbers.

**Discussion**

Data to monitor early increased disease activity can be obtained from several sources, including work/school absenteeism and ‘over the counter’ pharmaceutical sales. We chose to develop a symptom surveillance system that used ambulance transport data and operated on two levels. One advantage was that we could make use of existing high-quality ambulance transport data for achieving a reduction in MOD-Time. The need for an early unspecified alert in case of abnormal ambulance transport frequency was accomplished with this model. Our requirements for operational success were few false alerts, high sensitivity and the ability to adapt in case of minor regional changes over time. An increased number of patients, for whatever reason, will, to a variable degree, influence transport statistics as well as other parameters, such as physician calls and emergency centre statistics. With increased severity of an outbreak, the degree of patients requiring ambulance transport will invariably be high, thereby increasing the likelihood of a system alert. However, the system has limitations in case of a larger mild disease outbreak where only a smaller fraction of patients require transport by ambulance. Overall, the system responds rapidly to differences in epidemiological profiles for instance as a result of a massive patient influx or geo-clusters.

**Level I**

The results from initial testing indicated that the system had a low degree of false alerts. On two consecutive days in December 2003 the system reported increased activity. This episode heralded the beginning of a subsequently well-documented influenza epidemic in Denmark [8]. This suggests that the system was able to trace and report this outbreak from an early stage, in a timely fashion compared with existing monitoring systems which rely on manual reporting and compiling of results. By adding scenarios to background transport activity we were able to determine the MOD-Time of the system from a precise event. Balancing sensitivity and number of false alerts was a key issue. By the use of a 99% detection limit we achieved sensitivity almost as high as with the 95% detection limit, but significantly reduced the number of false alerts. This was essential for the performance and acceptability of the system. The scaling of some scenarios influenced only the amplitude of the outbreak, but maintained the unique epidemiological profile of the outbreak curve which best simulated a real event. The system responded rapidly.

---

**Figure 3**

Ambulance dispatch activity compared to National influenza Surveillance Reporting Systems, Denmark, October 2003 – May 2004

- **Standardised intensity**
- **Smoothed intensity for the 5% centiles**
- **Influenza surveillance (sentinel)**
- **% of influenza consultations on total number of consultations**
- **Observed**
- **Expected**
- **Threshold**

* In order to compare the data from the centrals the intensities have been scaled by dividing with the average number of transports for each central during the period 1 January 2002 to 31 March 2006.

The vertical lines indicate the period where the observed number of influenza cases exceeded the threshold, i.e. the Sentinel system indicated an influenza epidemic.
in all cases and would, with regards to scenario III, have notified authorities at an earlier stage than documented by the historical facts. The prospective testing of the system demonstrated reliability, few false alerts and good compliance with operating officers.

The Kalman filter is a recursive estimator. This means that the only estimated state from the previous time step and the current measurement are needed to compute the estimate for the current state. Thus, the chosen method was robust against ‘noise’ generated from previous spikes of ambulance dispatches and changes in the baseline by, for example, organisational changes or other artefacts. On the other hand, the system would not respond to a slow increase in the number of ambulances. Hence, the system may have limited sensitivity to detect an outbreak from a continuous source or an outbreak of a disease with a long and variable incubation time.

**Level II**

In case of an alert at level I, the responsible officer at the regional ambulance dispatch centre has to determine the credibility and severity of the alert and to a certain degree what caused it. In most cases the alert is easily explained by known events and local conditions leading to an increased demand, but ultimately the duty officer might choose to upgrade monitoring to second level preliminary epidemiological investigation after consulting with the NCBD, epidemiologists and public health officials. In case further investigation is needed, the completed ambulance reporting forms containing information such as patient data, patient symptoms and pickup time/place, will be the object of a further centrally guided investigational process and cluster analysis. Reporting of symptoms by faxed forms during testing supplied the basis for further investigation. However, this proved to be a bottleneck, since forms were not completed for a large proportion of patients transported on the days of the exercise, while other forms were difficult to match with actual patients in the database of the ambulance contractor. This illustrates the need for the automatic collection of epidemiologically relevant data and the development of a standardised data collection procedure for further improvement of the system. Testing of automatic online distribution and transferral of patient data, such as temperature and ECG from ambulances to emergency wards, is being conducted by the ambulance contractor.

Small outbreaks with a limited number of exposed persons over a number of weeks, such as the American anthrax outbreak in 2001, would be difficult to detect with ambulance dispatch surveillance. However, medium to large sized outbreaks with a disease with or without potential epidemic can be difficult to recognise in the very early stages unless statistical real time evaluation is available, as demonstrated by an outbreak of salmonellosis in Oregon in 1984 [9]. The outbreak detection system presented in this study serves as a tool for reducing the essential MOD-Time, through limited investments, using existing databases and the implementation of specific reporting procedures.

**Acknowledgements**

The authors would like to thank the European Union Directorate General for Health and Consumer Affairs (DG SANCO) for financial support.

**References**

8. Sentinel surveillance of the influenza activity, Epidemiological Department SSI. EPI-NEWS. 2004(9).