Detecting Influenza Outbreaks Based on Spatiotemporal Information from Urban Systems

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Abstract This paper explores the application of real-time spatial information from urban transport systems to understand the outbreak, severity and spread of seasonal and pandemic influenza outbreaks from a spatiotemporal perspective. We believe that combining travel data with epidemiological data is the first step to develop a tool to predict future epidemics and better understand the effects that these outbreaks have on societal functions over time. Real-time data-streams provide a powerful, yet underutilised tool when it comes to monitoring and detecting changes to the daily behaviour of inhabitants. Historical datasets from public transport and road traffic serves as an initial indication of whether changes in daily transport patterns corresponds to seasonal influenza data. It is expected that changes in daily transportation habits corresponds to swings in daily and weekly influenza activity and that these differences can be measured through geostatistical analysis. Conceptually one could be able to monitor changes in human behaviour and activity in nearly true time by using indicators derived from outside the clinical

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health services. This type of more up-to-date and geographically precise information could contribute to earlier detection of influenza outbreaks and serve as background for implementing tailor-made emergency response measures over the course of the outbreaks.

1 Introduction

Influenza is one of few diseases that have a major impact on public health and cause regular epidemics, re-occurring every winter in the Northern hemisphere. Influenza is also the only disease that have caused several pandemics. An estimate based on the 1998–2006 period in Norway show that the direct cost of seasonal influenza totalled US$22 million annually. Loss of working days resulting in an estimated productivity loss of US$231 million. Self-reported sick leave accounted for approximately one-third of the total indirect cost. During a pandemic, the total cost could rise to over US$800 million (Xue et al. 2010). Worldwide, influenza outbreaks carry an enormous societal cost in human and monetary terms, and are one of the few crises with a global reach and sub-yearly temporal frequencies. The seasonal variants see significant loss of life, with the Norwegian Institute for Public Health (NIPH) estimating the 2016/2017 epidemic to have caused an excess of 1700 deaths (NIPH 2017c). This is mirrored at the global scale, with the World Health Organization (WHO) estimating 5–15% of the world's population being infected with the seasonal influenza each year (WHO 2013), resulting in 300,000 to 650,000 deaths per year (Iuliano et al. 2017). The Spanish flu in 1918–1919 presents a dire example of the human costs of major influenza outbreaks, with 20–50 million deaths, equal to 3–5% of the world's population at the time (Guan et al. 2010). While recent outbreaks have not seen the same impact, the risk for severe epidemic or pandemic influenza outbreaks remain, pandemic influenza is rated as one of the top 10 threats to global health in 2018 by the WHO.

The societal ability to respond to major influenza outbreaks is heavily dependent on successful interactions between a wide series of participants, components, and processes (Wolf 2017). Essential components are early detection and monitoring of the influenza outbreak, reporting to responsible health authorities and to the general public, public health action by increased awareness, proper vaccination and general public personal protective measures such as improved personal hygiene and increased social distancing (i.e. avoiding mass gatherings and public transporting). Accomplishing this requires a major emphasis on having robust technological and organisational tools and methods available to manage information flow and decision support between stakeholders at all levels of the hierarchy (WHO 2018). Urban societies present a series of complex and dynamic systems, with many interacting subsystems and processes that change fluidly depending on time of day, societal trends, and a host of other influencing factors. Efficient preventive measures and management procedures is reliant on contextual knowledge of societal functions, as spread of influenza within a population is strongly driven by human social patterns at the individual and societal levels. Surveillance systems are used to acquire and maintain situational awareness of ongoing and emerging trends which is fundamental for all stages of the influenza management process.

The emergence of urban information initiatives has vastly increased the access to data streams that measure the use and integrity of critical societal systems. Real-time use metrics is increasingly feasible and integrated across a variety of societal systems. Transportation systems, critical infrastructure and distribution networks collects statistics in near real-time, allowing for a continuous understanding of how these systems are used in spatial and temporal contexts within an urban area. Conceptually one could be able to monitor changes in human behaviour and activity in close to real-time by using indicators derived from outside the clinical health services. Combining the spatial components of existing data streams with GIS-based data from additional sources adds to the spatial and temporal quality of produced information, and can be a significant addition to the public health surveillance and early detection of disease by geographic understanding of the evolving risk picture.

This article describes the design of an initiative that seeks to examine the viability of monitoring real-time data from urban systems to improve the public health surveillance by earlier detection and monitoring of influenza outbreaks in urban societies. This type of more up-to-date and geographically precise information could be a helping tool in the day-to-day planning and management of the public health services related to outbreaks. The earlier detection and a better geographic overview of areas with influenza spread could make public health action more efficient by for instance relocation of staffing and scarce resources related to medical equipment as e.g. respirators and equipment for extracorporeal membrane oxygenation.

1.1 Impact of the Seasonal and Pandemic Influenza

The Pandemic Influenza Severity Assessment (PISA) initiative (WHO 2017) describes the following key metrics to assess influenza severity: *Transmissibility, Seriousness of disease, Impact*. These metrics describes the spread of influenza within a population, the virus effect on the individual person, as well as the effect of the epidemic and pandemic on health-care services and societal systems. It can be used as a tool for global and national risk assessment of influenza outbreaks. Recent outbreaks provide an avenue to understand the impact and societal effects of influenza outbreaks. The 2009 A(H1N1) pandemic was notable as the first pandemic since the Hong Kong influenza in 1968. The saw the mobilisation of major cross-sectoral epidemic efforts (WHO 2013). The global mortality has been estimated between 201,200 (Simonsen et al. 2013), to 284,000 (Dawood et al. 2012). In Norway, the 2016–2017 seasonal influenza outbreak was estimated to have caused 1,700 deaths (NIPH 2017c).

The Norwegian Directorate for Civil Protection (DSB) claims the effects of a severe influenza outbreak to be severe, implying a large to very large impact on the Norwegian society (DSB 2015). The National Risk Analysis (NRA) from the quantifies the costs of a major pandemic in Norway, based on the influenza metrics developed by the NIPH and the WHO. The likelihood is estimated to be high, based on historical pandemics such as the 1918 Spanish influenza, the 1957 Asian influenza, the 1968 Hong Kong influenza, and the 2009 Swine influenza (Guan et al. 2010). The direct impact on life and health is estimated to 1.2 million people infected (25% of the Norwegian population), with a mortality rate of 0.5% (6,125), and 3% (35,000) requiring hospitalization. The socioeconomic effects primarily stem from disruptions to production, with large numbers of the work force out at any given time over the course of the outbreak. The knock-on effect caused by the disruption to societal functions and health services in the event of a pandemic outbreak is expected to lead to an increase in mortality, resulting in an overall death toll of around 8,000 persons.

The NRA case is exploratory, and has as such not explored the societal effects of a pandemic outbreak in detail. The limited scope of the assessments must be taken into consideration, and we believe that further analyses should be initiated. The epidemic and pandemic risk assessments are limited by a lack of mechanisms to acquire updated information on societal functions and integrity over the course of an outbreak. Without a way to assess the impact of influenza outbreaks on society, these calculations will remain coarse. Our proposed framework and research methodology must be seen as a contribution to better understanding of factors and mechanisms in influenza patterns. Hence, it would present a way to map and monitor the societal effects of influenza outbreaks at earlier stages, where knowledge is scarce. We think this could significantly improve the quality of information used in risk assessments of epidemic and pandemic influenza. Mapping the effects of societal systems over time will provide valuable information on how societal behaviour changes during outbreaks, and may improve the understanding of the societal impact of influenza outbreaks, and to give us quantifiable indicators of the societal cost of these outbreaks.

1.2 *Influenza Management and the Norwegian Health Sector*

The 2014 national pandemic influenza preparedness plan (Ministry of Health and Care Services 2014) outlines the roles and responsibilities of the various components of the Norwegian health management structure, as well as the contributions of auxiliary parts of the national emergency management domain. A recent examination of the risk and vulnerability within the Norwegian health sector (Norwegian Directorate of Health 2017) outlines the main challenges facing the public health emergency management domain in Norway. Seasonal and pandemic influenza are the main concerns, with major accidents and disasters as the secondary and tertiary focus areas. An emphasis is placed on issues relating to information security and systems integrity, with comparatively little focus placed on management of information. Issues arising from the lack of clear routines and responsibilities relating to flow of information in major health-related disasters is only briefly mentioned.

One of the main future challenges of the Norwegian health sector is to manage the impact of influenza outbreaks, both of seasonal and non-seasonal variants. A influenza pandemic is stated to be one of the main societal threats facing the Norwegian society (DSB 2015), while the seasonal influenza each year affects the entire society during the winter months. Rapid response to influenza outbreaks requires a major mobilisation of societal resources and depends on the activation of large parts of the national and international disease management structures. The NIPH publishes annual risk assessments of seasonal influenza at the beginning of each influenza season (NIPH 2017b). NIPH also produce weekly influenza reports during the Norwegian influenza season (NIPH 2017d), as well as end-of-season summaries (Bragstad et al. 2018; Norwegian Institute of Public Health 2017b) and reports to guide WHO in vaccine composition meetings (National Influenza Centre 2018). To manage seasonal influenza outbreaks, virologists, public health officials and epidemiologists use information compiled from the national surveillance system for influenza. The Norwegian Syndromic Surveillance System (NorSySS) is one of the data sources used in this system. NorSySS collects diagnosis data from general practitioners (GPs) and out-of-hours primary care facilities. A network of GPs and national microbiological laboratories contribute to the surveillance program with clinical samples and reports weekly lab confirmed influenza cases with denominator. In addition, surveillance of severe influenza is carried out at hospitals and intensive care facilities.

2 Connecting Influenza to Societal Behaviour

Spread of infections within a societal system cannot be assumed to be static or uniform but is rather a continuously changing process based on local factors, such as time of day, occupation, access to services and information patterns. The dynamic nature of these types of events makes rapid intelligence capabilities a necessity, as situational awareness is highly dependent on information with a high temporal resolution (Yan et al. 2017). Analyses based on a single point of time will rapidly be outdated, given the rapid changes in number of afflicted and their effect on the integrity and functions of the key societal systems (Gao et al. 2018; Wang and Ye 2018). Behavioral changes caused by influenza outbreaks have been observable in how people interact with societal functions, such as how they move throughout a cityscape or make use of urban medical services. Symptomatic individuals see an increase in societal contact patterns at home, while the average number and duration of social contacts drops drastically for travel, work and leisure while symptomatic (Van Kerckhove et al. 2013). Some measures of population self-control can also be expected to be applied for asymptomatic individuals (Durham et al. 2012; Kleczkowski et al. 2015). Furthermore, the gradual spread of disease throughout a society acts as a catalyst for further behavioural changes, as people adapt their behaviour because of infection, or through adopting preventative measures to avoid illness (Aleman et al. 2009; Fierro and Liccardo 2013).

2.1 Influenza Spread Within an Urban System

To accurately model the spread of disease in urban areas, it is necessary to understand the structure and dynamics within these societies. Urban systems are composed through interactions of numerous networks and processes, which are driven by the behaviour of inhabitants at the individual and group levels (Batty 2009). Cities exists at various states of a dynamic scale, with subsystems that continuously react and adapt to ongoing events and trends (Batty 2012; Kitchin 2014). Sudden or gradual changes to inhabitant behaviour causes changes in the dynamic subsystems that builds up urban societies (Kitchin et al. 2015). Time of day, occupation, and access to services are strong influencing factors of human mobility patterns, while access to information, socioeconomic background and age are examples of factors that influence population behaviour. The complex and dynamic nature of these factors means that the spread of infections within a societal system cannot be assumed to be static or uniform but should rather be viewed as a continuously changing process based on a variety of local factors.

The spread of infectious diseases within an urban area can be predicted and modelled by the use of epidemiological tools. There have been multiple examinations that draw the link between human mobility and spread of diseases (Timpka et al. 2009), with development of complex models to account for urban and rural population patterns (Aleman et al. 2009; Poletto et al. 2013). The link between environment and health has been debated by multiple authors (Robertson 2017), demonstrating importance of modelling spatial environmental factors to accurately assess the spread of infectious diseases. Lal et al. (2018) presents a case for real-time surveillance of non-clinical indicators to map the societal factors that directs the spread of influenza. Yang et al. (2017) propose a framework to model the spatiotemporal characteristics of an outbreak, showcasing an approach to infer a dynamic social contact structure based on demographic data, heterogeneous surveillance data and epidemiological models. Yao et al. (2017) shows an application of multi-source geospatial data for modelling population distributions. Lewis and White (2017) demonstrates an approach that integrates multi-source surveillance information based on spatial components to model the incidence and prevalence rates of Chlamydia within a local population.

3 Influenza Surveillance

Public health surveillance is defined as “The ongoing systematic collection, analysis, interpretation and dissemination of data regarding a health-related event for use in public health action to reduce morbidity and mortality and to improve health” (German et al. 2001). The public health surveillance traditionally only included infectious diseases, but later also other public health issues were includes such as poisonings, disabilities, risk factors and health practices (Thacker and Berkelman 1988). One of the important public health surveillance functions is detection of outbreaks such as the start of the influenza season. This is identified by an increase of cases above the baseline value. Most European countries have an influenza surveillance system in place and are reporting to the infectious disease indicator-based surveillance system at the European level (TESSy) (ECDC 2014) or at WHO. The surveillance systems can include only one or several data sources, and as automated electronic tools are getting broadly available, the systems tend to be more complex. Traditionally, influenza surveillance has been accomplished through clinical indicator-based surveillance systems. These methods are based on collection and aggregation of patient diagnosis data of influenza-like illness (ILI) from physicians and laboratories. In addition, laboratory confirmed influenza reported from laboratories and through the sentinel system of GPs ensures all year-round reporting of influenza viruses and virus characterisation data. The high reliability, broad sampling and relatively high temporal accuracy provides a powerful dataset that describes the spread of influenza in the society with a time delay ranging from 0–28 days, depending on the characteristics of the national systems (Dailey et al. 2007).

The last decade has seen further development of the clinically-based surveillance approaches, often coupled with the development of other indicator-based approaches, where they make use of non-clinical indicators such as pharmaceutical sales, absenteeism reports and website access to trace the spread of influenza throughout a society. One of the focal points of this research has been to make use of web-based indicators, and a series of approaches has been developed to integrate the wealth of data found in online search patterns and social media behaviour. Google Flu Trends (Carneiro and Mylonakis 2009; Cook et al. 2011) offered an example of multi-indicator surveillance of online trends, and published influenza models in the 2008–2014 period through aggregation of time series of online search patterns relating to ILI tied to location (IP-address) (Vanja et al. 2012). While the efficiency of influenza detection based on social media monitoring varied from year to year relative to ILI-measurements (Lazer et al. 2014), they demonstrated the potential of monitoring social media feeds for the detection of key phrases. Santillana et al. (2015) demonstrates a fusion approach, which integrates real-time multi-indicator measurements based on an ensemble consisting of ILI-data, Google Trends data on search queries, Twitter trends, FluNearYou and Google Flu Trends weekly ILI estimates. The multi-indicator approach improves the accuracy of the data relative to analysis based on single indicators and provides a broader set of mechanisms to understand and predict the spread of influenza (Santillana et al. 2015; Timpka et al. 2009; Yan et al. 2017).

3.1 Norwegian Influenza Surveillance Structure

The NIPH carries the overall responsibility for monitoring influenza in Norway. The institute has a mandate to collect and manage information to monitor the occurrence and progress of influenza outbreaks (MSIS 2003), as well as to advice on public health matters resulting from effects of the seasonal influenza. The influenza monitoring system consists of six components (Table 1).

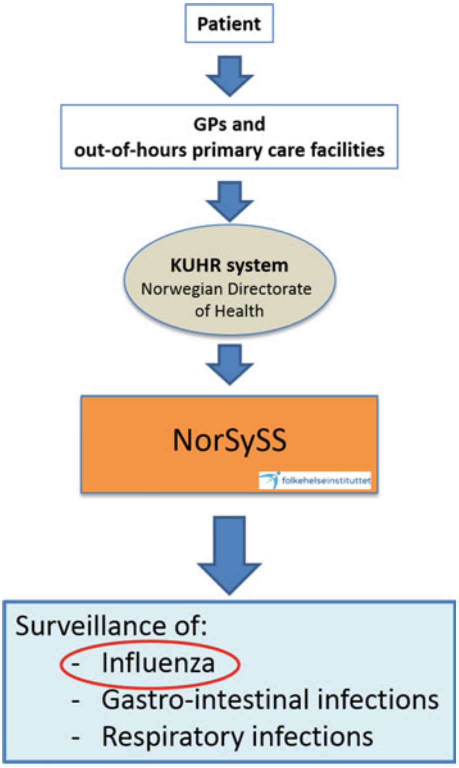
The virological part of the surveillance gathers information on laboratory confirmed influenza cases with in depth characterisation of circulating viruses all year round. The severity of the influenza season is assessed by hospital and ICU ward surveillance of laboratory confirmed cases as well as all-cause mortality numbers. In addition, the immunity of the population is assessed by yearly seroepidemiology studies. The NIPH generate weekly reports on influenza surveillance during the influenza season (week 40 to week 20). These reports provide the public, health care workers and decision-makers with an understanding of the week-by-week development of the influenza outbreak. The laboratory-confirmed influenza is most often reported one week after the sample was collected from the patient. The surveillance system covers nearly all laboratory confirmed cases diagnosed in Norway. The test activity in Norway is high, exceeding 190 000 samples tested during the 2017/18 season (Bragstad et al. 2018; Norwegian Institute of Public Health 2017c).

NorSySS (NIPH 2017a) receives data about the patient's age group, gender and the municipality of residence, the municipality where the consultation was performed, date and ICPC-2 diagnosis code (WICC 1998). The overall structure of

Table 1 The Norwegian surveillance system for influenza

System	Function
NorSySS	Indicator-based surveillance of influenza-like illness in primary health care
Hospital (all ward) surveillance	Laboratory-based surveillance of hospitalised influenza cases
ICU surveillance	ICU treated flu patients. Data collected by the Norwegian Intensive Care Registry (pilot project since 2016/17)
Virological surveillance	(1) Submission of data and samples from Norwegian laboratories testing for influenza. (2) Sentinel system, GP-based virological surveillance
Norwegian mortality monitoring system (NorMOMO)	Surveillance of weekly all-cause excess mortality
Seroepidemiological analysis	Annual survey of flu immunity in the population

Fig. 1 The Norwegian Syndromic Surveillance System (NIPH 2017a)



NorSySS and other component systems can be seen in Fig. 1. The datasets are compiled and anonymized through the KUHR system, before being passed on to NIPH and NorSySS for further analysis. ILI, ICPC-2 code R80, is used as an indicator for influenza activity. The NIPH compiles weekly reports on influenza surveillance during flu season (week 40 to week 20), where ILI % is used to describe the occurrence of flu and the intensity of the outbreak compared with the intensity of previous outbreaks. The epidemic threshold for seasonal influenza (ILI %) is based on the Moving Epidemic Method (MEM) (Vega et al. 2013). These reports provide the public, health care workers and decision-makers with an understanding of the week-by-week development of the outbreak. The data provided through the NorSySS has a high reliability, with data from nearly all GPs and out-of-hours primary care facilities in Norway and a firmly established routine and reporting methodology. The timeliness of the data is on the other hand lower, as most GPs accumulate the diagnosis data for a week or two before submitting to the KUHR system. This creates a situation where the datasets are not temporarily consistent, with some reports being submitted within a few days, while others lag by weeks. The lack of completeness is taken into account in the influenza surveillance by using the ratio of influenza consultations to the total number of consultations.

4 Building Societal Indicators for Detection of Influenza Patterns

To augment the existing influenza surveillance systems, it is of interest to establish a monitoring system that enables immediate detection of emerging trends and patterns of influenza outbreaks, whether epidemic or pandemic. One possible way to build this understanding is to use data produced within existing non-clinical surveillance systems. Data streams from infrastructures provides interesting data that combines a high spatiotemporal resolution with frequent update schedules. Public transport, power utilisation, distribution of goods, and data traffic can be used as indicators of the day-to-day and hour-to-hour functioning of the societal systems that make up urban societies. The hypothesised interdependencies between usage of critical infrastructures and increased influenza activity is illustrated in Figs. 2 and 3. These interdependencies should be measurable in historic datasets on use patterns and influenza activity, with increased influenza activity being reflected in a decrease in daily use of public transport networks in major cities.

Indicators from multiple systems can be collected and monitored, giving an understanding of the level of functionality and the ability of inhabitants to make use of these functions. Differences between expected and actual use of these systems based on spatial and temporal factors allows for a contextual understanding of the current societal state, and to understand emerging trends in relation to systems that are a critical part of the day-to-day urban life. Composite indicators based on these datastreams can be used to monitor the development of societal behaviour over

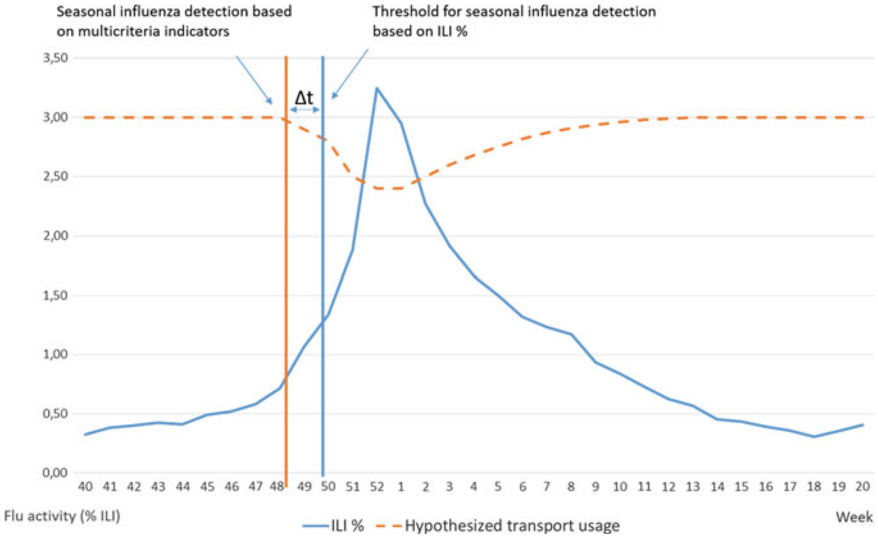


Fig. 2 Theoretical correlation between weekly public transport utilization and influenza activity (ILI %) in an urban population

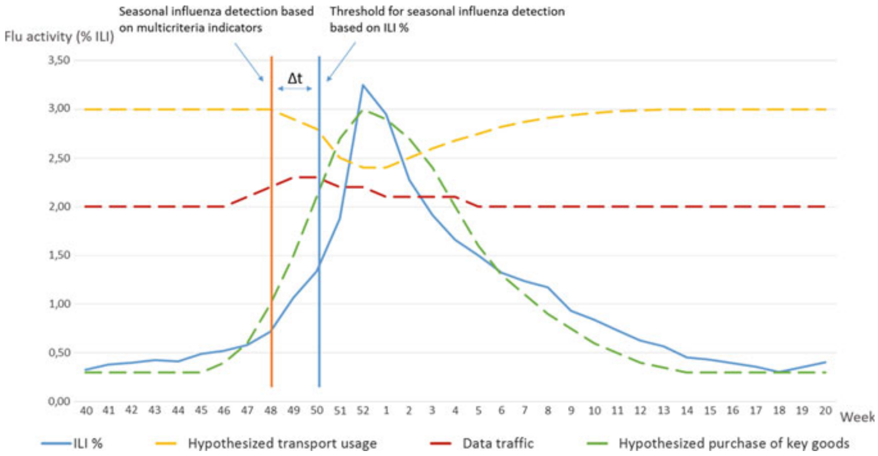


Fig. 3 Multicriteria pattern detection based on indicator surveillance

time, with deviations from expected patterns across multiple systems, combined in a manner that minimises indicator interdependency outside the specific target domains.

4.1 Study Approach

Our goal is to augment the existing influenza surveillance system with an approach that monitors trends in society for indicators of influenza activity. A search for similar works in the scientific literature at the thematic crossroads between epidemiological intelligence, spatial epidemiology and outbreak management has revealed limited results.

The initial concept of an indicator-based seasonal influenza monitoring system is presented to explore the role that spatial information and GIS can play in epidemiological intelligence. We believe that disruptions to the social patterns can be detected through spatial analysis on key metrics, such as daily travel patterns, consumption statistics and sales of key indicator goods.

4.2 Preliminary Hypotheses

We need a research design that can reveal metrics, which are somehow interrelated with occurrence of seasonal influenza. In order to improve abilities for influenza management we hypothesize that we will be able to become aware of the influenza outbreak Δt prior to the normal identification of an influenza outbreak, Fig. 2 shows our hypothesized transport usage curve in a region combined with the actual clinically diagnosed influenza (ILI%) curve in the 2016/2017 and 2017/2018. The first step of the study will focus on investigating and testing the two main hypotheses:

Hypothesis 1: A significant drop in commuting habits predicts seasonal influenza outbreak.

Travel at specific times of day signifies ability to move between residential areas, work places, and leisure activities, and major disruptions to this ability should be traceable at daily level. To account for this, the transport-based monitoring systems will serve as a primary indicator for detecting changes in social patterns. Transport data will be augmented by other data sources, to strengthen the signal strength of patterns and eliminate sources of statistical noise that may falsely indicate pulses in influenza impact. The idea in this hypothesis is that changes in commuting habits fairly momentarily will detect seasonal influenza. Such drops might be followed up with a more detailed investigation system. However, the rate and absolute change will be interesting quantities to follow up in the study. We will also prepare the research on geospatial commuting data to explore severity levels and other characteristics of the seasonal influenza.

Hypothesis 2: A significant increase in sales data on painkillers/antipyretics and antivirals predicts seasonal influenza outbreaks.

In order to have a more robust system and even compare information we will investigate significant local changes in sales data of relevant pharmaceutical products, such as painkillers/antipyretics and antivirals. If sales metrics for these goods can be tied to pulses of the seasonal influenza, this provides a powerful and readily available indicator that can be applied throughout the country.

We start with two fairly independent societal systems in which geospatial data is easy to retrieve and analyse. Further studies could implement other quantities, which could be historical datasets from public transport, road traffic data, as well as consumption-based metrics such as key indicator goods, utility usage and other available information sources from the city of Oslo. These data will be analysed for change patterns against the daily and weekly influenza data delivered from NorSySS at the NIPH. The presence of detailed epidemiological datasets for Norwegian influenza outbreaks will provide the necessary historical backdrop to demonstrate whether corresponding patterns and correlations between use of urban services and the presence of seasonal influenza exist. We believe that it is possible to identify Δt when seen the data in retrospect and throughout some years develop a framework for seasonal influenza surveillance.

4.3 Proposed Metrics

The seasonal influenza management within societies is relatively well-understood (Wolf 2017), with clearly defined roles for the various actors in the civil society. For the outbreak management hierarchy, one of the key requirements is the availability of information that indicates the prevalence and impact of the influenza outbreak in local societies. The dynamic nature of these phenomena lessens the role of static information sources, as the ground situation develops quickly over time. Applying these concepts to an information management perspective indicates a need for relevant information throughout all phases of an outbreak, to ensure that the stakeholders have the sufficient situational awareness.

To fill the present in the current-day intelligence networks, we propose an indicator-structure that integrates information from a variety of urban systems and critical infrastructure to maintain an up-to-date awareness of changes in patterns and trends within these systems. Table 2 highlights an initial set of indicators, based on the urban information systems available within major Norwegian cities. We believe that these indicators provide a way to detect possible trends at an early stage and provides a capability to compare daily and sub-daily disturbance against historical and current influenza data. Use patterns of utilities, sales of key indicator goods (such as painkillers/antipyretics and antivirals), commercial activity and data traffic in residential areas provides powerful auxiliary information sources that are not mutually affected by events or incidents.

Changes in use patterns may be the result of a variety of reason—Public holidays, cold weather, or fluctuations in the gas price may drastically change the weekly and daily statistics from public transport. Similarly, the other indicators are influenced by internal and external factors that affects the day-to-day use of the monitored systems. To combat these uncertainties, specific indicator profiles must be developed by exploiting the spatial components inherent in all the measured data. Combined, the set of indicators provide a statistical foundation for further epidemic analysis, as well as the necessary data for implementation of analytical models for epidemiological work. The data-driven approach further will allow for rapid development of new indicator profiles and can be adapted to the varying

Table 2 Urban systems indicators

No	Indicator description
1	Public transport utilisation (Subway, trains, buses, light rail, etc.)
2	Toll road activations
3	Data traffic (internet traffic, cell phone networks)
4	Consumption of key indicator goods (Painkillers, Tamiflu, coughing medicine, etc.)
5	Utility use patterns in residential and commercial areas (Electricity, water, gas, etc.)
6	Use of key urban services (pharmacies, schools, GP offices, etc.)
7	Activity information from commercial stakeholders (convenience stores, restaurants, etc.)

information needs over the course of an outbreak. An example of applying trends from multiple urban indicators can be seen in Fig. 3. By monitoring changes in multiple systems, in this case transport usage, purchase of key goods, and data traffic, it may be possible to detect changes to regular use patterns an earlier stage than in existing surveillance systems. This would move the Δt for influenza detection forward, increasing the time and situational awareness to support planning and management efforts in influenza outbreaks.

5 Integrating Spatiotemporal Information into a Systems-Based Management Structure

The societal ability to respond to influenza outbreaks in an urban setting requires successful execution of processes at every hierarchical level of governance, ranging from the city district to national-level stakeholders and intergovernmental organizations (Wolf 2017). However, communication between hierarchical levels have often proved to be a serious obstacle to effective societal safety management, in which actors are more concerned with own responsibilities and tasks than being able to holistically combat the health related disease (Grottenberg and Njå 2017). Access to updated information is a fundamental requirement to accomplish a multisector and multidisciplinary approach to health disaster management, as outlined in the Pandemic Influenza Risk Management guidelines (WHO 2013). The proposed system would offer a method for integrating information from urban systems into decision-making processes in health-based disasters. A spatiotemporal model for analyzing and presenting data on an ongoing outbreak should be regarded as an instrument for structured and standardized communication between decision makers and managers from different societal sectors. A systematic approach to demonstrating spatiotemporal dimensions of an outbreak tend to be under-communicated or even lacking in cross sectoral, traditional risk analyses used when planning for and dealing with epidemics.

The role of the proposed system within the broader Norwegian influenza management system can be illustrated through a perspective founded in systems safety (Leveson 2011). The multi-indicator monitoring system provides a set of normal operating constraints. When threshold-values from the indicators are exceeded, this provides the information needed to assess whether the changes in use within the monitored systems correspond to influenza-related changes to public behaviour. The basic control loop for a societal indicator structure can be seen in Fig. 4. Influenza-related changes to public behavioural patterns are monitored through sensors emplaced within the urban system indicators from Table 2. These data streams are compiled and contextualized by an automated controller, to ensure that epidemic management specialists have access to timely and accurate information. This provides access to an up-to-date understanding necessary for the influenza management apparatus to implement targeted measures to manage and control societal processes related to influenza outbreaks.

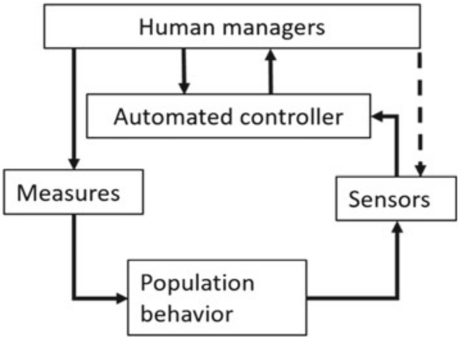


Fig. 4 Basic operating process for societal indicators (based on systems safety models (Leveson 2015)

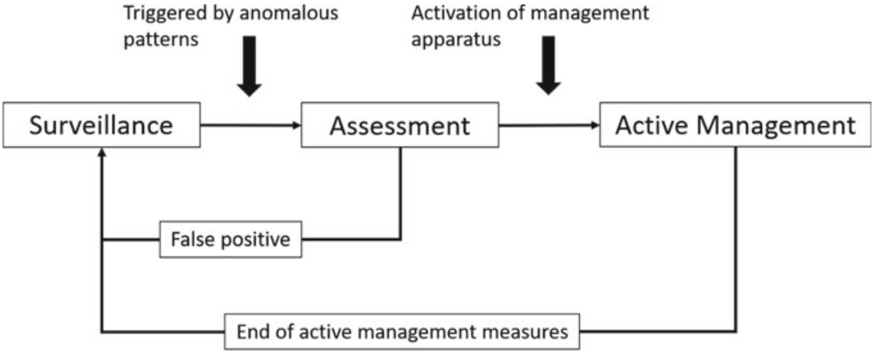


Fig. 5 Process structure for indicator-based monitoring system

The data streams feeds into a broader process structure (Fig. 5) which consists of different processes depending on the overall state of an outbreak—The routine surveillance gives a continuous awareness of the state of societal indicators that may indicate the presence of influenza within a society. When the observed values indicate a potential need for intervention, the system moves to an assessment stage. This process enables analytical capabilities to assess the state of the societal functions, and whether there is a need to activating the larger management system. This might be in the form mobilizing a surge capacity within the local and regional health services, or through controlling the spread of an outbreak through closure of societal functions like transportation systems or school networks. Table 3 showcase the initial stages of a conceptual management structure that is built upon continual surveillance of societal indicators. The system implements the processes structure found in Fig. 5 and seeks to provide a continuous systemic ability from routine

Table 3 Outbreak process structure

	Monitoring assessment		Initiation of management efforts	
Outbreak status	Discrepancy in use patterns	Outbreak suspected	Outbreak confirmed	Outbreak ongoing
Information collection methods	Continuous automated monitoring of use patterns	Automated information collected augmented by manual collection	Automated information collected augmented by manual collection	Continuous impact assessment
Activation of analytical capacity	Automated analytical process	Activation of manual epidemic intelligence capabilities	Deployment of field-based epidemic intelligence resources	Participation of national/transnational analytical resources
Epidemiological work	Mitigation and monitoring	Monitoring and notification of key stakeholders	Activation of response apparatus	Epidemiological response Containment Care/treatment
Societal activation	No activation of resources, day-to-day activity	Mobilisation of top-level analytical resources	Mobilisation of specialist domain	Mobilisation of surge capacity within health services and governance

surveillance to active management. The system would provide the know for escalation and de-escalation of management efforts, through giving access to data describing the severity and potential of ongoing outbreaks.

6 Conclusion

This paper outlines the design of an ongoing project to assess the suitability of data-streams from urban systems and critical infrastructures for epidemiological surveillance of influenza outbreaks. It is our belief that real-time information from urban systems can fill an important role in improving the understanding of societal functions during major disasters and crises, and that multisource spatial information from urban systems, critical infrastructure and sector authorities can be combined with epidemiological information to provide actionable intelligence for use in influenza management efforts.

Influenza outbreaks have a major impact on public health. Seasonal influenza is a re-occurring event every winter in the northern hemisphere, with significant loss of life and major societal losses. The regularity of these outbreaks produces a rich dataset of historical observations which can be used to test and validate the proposed indicator structure. We believe that pulses of seasonal influenza should be directly traceable in historical data on public transport utilisation in major urban areas, with increases in influenza activity corresponding to a drop in the utilisation of these service. Similar trends should also be present in data from other urban systems, providing a broad data-driven understanding of societal functions relating to management of infectious diseases.

By extending and formalising the information available to public health officials and decision-makers, the situational awareness of the impact and development of the seasonal influenza can be maintained over time. The initial step of this process is to build the tools needed to maintain a data-driven awareness of societal functions in urban areas, based on the integration of data-sources with a high spatiotemporal quality. The benefits of such an approach is threefold—(1) Models of influenza spread can be developed based on a broader set of information, (2) Secured access to information across the hierarchies of management organisations allows for increasingly collaborative systems and workspaces, (3) The societal effects of a seasonal or pandemic influenza can be mapped in near real-time.

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