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ARTICLE

Using external data in a BI solution to optimise waste management

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ABSTRACT

BI solutions are constantly being developed to support decision-making at various organisational levels. These solutions facilitate the compilation, aggregation and summarisation of large volumes of data. Consequently, the business value created by these systems is increasing as they sustain more and more advanced analytics, ranging from descriptive analytics, to predictive analytics, to prescriptive analytics. However, most organisations work primarily with internal data. Despite many references in the literature to the value hidden in external data, details on how such data can be used are scarce. In this paper, we present the results of an extensive action case study at a public waste management company. The results illustrate how external data from several external data sources, integrated into an up-and-running BI solution, are used jointly to allow for descriptive and predictive analytics, as well as prescriptive analytics. In addition, details of these analytical values are given and related to organisational benefits.

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Business intelligence; external data; decision-support system; waste management

1. Introduction

To maintain their ability to compete in a globalised, ever-changing market, companies need highly complex and advanced systems that are capable of integrating, aggregating and summarising huge volumes of data and presenting tailored views of the organisation and its business in a timely and accurate manner (Davenport & Harris, 2007). Different (overlapping) solutions have been proposed in the literature, with a myriad of different concepts being used, such as decision support, business intelligence, business analytics, and big data. For this work, we use the concept business intelligence (BI) since it has attracted enormous interest in recent decades and executives still consider it one of the most promising technologies (Arnott & Pervan, 2014; Kappelman, McLean, Luftman, & Johnson, 2013). However, the findings of this research are relevant to a broader category of concepts sharing the commonality of integrating large volumes of different types of data with the aim of supporting data-driven decision-making at various organisational levels.

Initially, BI solutions focused on integrating internal data, but attention is increasingly turning to the benefits of working with external data as well (Anderson-Lehman, Watson, Wixom, & Hoffer, 2008; Jukic, Jukic, Sharma, Nestorov, & Korallus, 2017; Phillips-Wren & Hoskisson, 2015; Poleto, Diogho Heuer de Carvalho, & Paula Cabral Seixas Costa, 2017;

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Ponniah, 2010; Ram, Zhang, & Koronios, 2016). The literature now includes concrete examples of how external data are being used in BI solutions (Bani, Rashid, & Hamid, 2011; Ge, Liu, Xiong, & Chen, 2011; Hua et al., 2016; Wang, Ng, & Chen, 2012). However, detailed accounts of how external data are used in fully functional systems, aiding decision-makers in real business contexts, are harder to find. Therefore, in this work we present the results of an extensive action case study at a waste management company, including concrete examples of how external data are used in an up-and-running BI solution, supporting decision-makers at various organisational levels (operative, tactical and strategic).

To provide more detail about the benefits of the BI solution, we also categorise the analytical values created for the company. Phillips-Wren and Hoskisson (2015) claim that large volumes of data, internal as well as external, may create value for organisations *descriptively, predictively, or prescriptively*. The *descriptive* value includes summarisation of data describing current or historic events, which are then interpreted by a human; the *predictive* value concerns predictions about the future based on historic data; and the *prescriptive* value suggests optimised courses of action along with descriptions of the consequences.

The remainder of the paper is structured as follows. Section 2 gives the background for this work. In Section 3 the action case study and the case company are presented. Section 4 illustrates and exemplifies how data from various external sources are used. Section 5 concludes the paper by presenting the major results, bringing them into a wider context related to the organisational benefits and scientific values of this work. Ideas for future work are also proposed.

2. Background

2.1. Defining business intelligence

There are numerous definitions of business intelligence. It is not possible or meaningful to cover them all, but the following three definitions are included to illustrate that many definitions share a broad focus on the data itself, the underlying system or technologies and supporting or improving organisational decision-making. 1) Negash and Gray (2008, p. 176) define BI as '*systems that combine data gathering, data storage, and knowledge management with analysis to evaluate complex corporate and competitive information for presentation to planners and decision-makers, with the objective of improving the timeliness and the quality of the input to the decision process*'. 2) Davenport and Harris (2007, p. 12) describe BI as a broad term including the '*collection, management, and reporting of decision-oriented data as well as the analytical technologies and computing approaches that are performed on that data*'. 3) Wixom and Watson (2010, p. 14) define BI as '*a broad category of technologies, applications, and processes for gathering, storing, accessing, and analysing data to help its users make better decisions*'. For this work, all these definitions are relevant, but we have chosen to adopt the definition given by Davenport and Harris (2007) due to its wide acceptance and because it predates the other two.

2.2. Defining external data

The externality of data may be considered in two ways. From the perspective of database theory, external data is any data stored or maintained outside the particular database of interest. The external sources may be organisationally internal, centralised data repositories or distributed databases (Morzy & Wrembel, 2003). However, in BI, decision support system (DSS), and analytics-oriented literature, the widely accepted view of external data is that the data cross organisational boundaries (Davenport & Harris, 2007; Devlin, 1997; Kimball, 1996; Phillips-Wren & Hoskisson, 2015). The latter perspective on external data was adopted in this work. In addition, according to Meredith, Remington, O'Donnell, and Sharma (2012), an organisation's overall IT capabilities may be conceptualised as having two different capabilities. Either, *outside-in*, where the organisation's externally-facing systems allow for the collection and management of information related to external actors (e.g. customers, suppliers, or competitors), or *spanning*, where the IT solution has the capability to integrate information from externally-facing as well as internally-facing systems. In this work, the proposed BI solution has spanning IT capability due to its design and its ability to integrate both internal and external data.

3. The action case study

The research approach for this work is an action case study, as described by Vidgen and Braa (1997). Scientifically, an action case method is a hybrid between an interpretative case study and interventional action research (Vidgen & Braa, 1997). The action case method is aimed at balancing the potential conflict that arises because the researcher is both an observer of a particular case and a participant who interferes with the process by contributing knowledge and ideas as part of progressing the work towards a solution or towards established goals. The action case method has been criticised (e.g. by Baskerville & Wood-Harper, 1996). To reduce the risks they identify, we adopted an iterative approach inspired by Susman (1983). In Susman's generic model, five cyclic activities guide the process: diagnosing, action planning, action taking, evaluation, and specifying learning.

The action case study started in 2010 and is still ongoing. It is being conducted at a public waste management company and arose from the company's need to optimise route planning for waste pickup. The company is currently responsible for emptying approximately 134,000 waste bins once or several times every 2 weeks. The pickup frequency normally follows a predefined time-schedule, but customers may also initiate on-demand emptying. Approximately 50 employees work in the company (the number has varied slightly since 2010). During the case study, the annual turnover increased from 8.7 to 11.8 million euros.

In 2010 route planning was strictly manual and experience-based; the transportation planners worked with maps printed on paper and indicated routes with pencils. In addition, at project start-up, the company had no BI solution whatsoever. However, the management of the company was forward-looking and asked for a prescriptive solution rather than a descriptive or predictive solution. Moreover, the optimisation problem was addressed as a general pickup problem (Savelsbergh & Sol, 1995) in which the company carries out a number of transportation requests using a fleet of vehicles.

Given the situation with a total absence of existing IT-support for the route planning process, the actual requirements engineering and design of the system became an extensive undertaking. First of all, and in alignment with the action case study approach, the development process was iterative and started out with by identifying key functional requirements. These requirements were identified during 21 workshops with different roles represented. The number of workshops were initially planned to be much fewer, but during the iterative development of the list of key functional requirements, every prototyping session added on additional requirements. We consider this rather normal, since the waste management company had a rather low general IT competence and the workshops became the catalyser for articulating needs and requirements. Furthermore, 35 interviews were conducted with transportation planners and garbage truck drivers, as well as with managers at several levels. In addition, observations, document analysis, analysis of existing IT systems, and prototyping contributed material to developing the BI solution. There were many key functional requirements identified during the development process, of which seven requirements specifically related to external data sources. These seven requirements are presented in Table 1.

Once the list of key functional requirements was considered as complete (at least from a version 1 perspective), the potential sources of data for fulfiling the needs were identified. Since the waste management company were lacking the proper IT-solution, it relatively quickly became evident that data sources outside the organisation were needed. However, before that, internal data sources (manual and IT-based) were considered but shown to be old or not fulfiling the requirements for an automated system, with continuous updates. Since the participating researcher had previous experience of working with external data sources, potential suppliers were relatively quickly identified and mapped to the key functional requirements in the Table 1. Still, although the external data sources are, with a few exceptions, hosted by Swedish governmental organisations and thereby are open, some of them needed further negotiations and contracts. Table 2 shows the relationship between the key functional requirements identified and the external data source chosen. In addition, Table 2 also describes what data were incorporated from each external source and

Table 1. Key functional requirements related to external data sources.

Key functional requirement	Why important
Visualising the geographic placement of waste bins on a general reference map.	Helps both the planning and execution of collection routes.
Visualising the real appearance of the collection sites using photographic representation.	Helps the driver to locate the waste bin when close to, or on, the collection site.
Visualising roads and road characteristics.	Helps the driver to make decisions regarding the choice of route to use when collecting bins, based on factors such as speed limit, maximum carrying capacity, one-way roads, etc.
Obtaining information about the owner of a property.	Makes it possible to identify the person responsible for paying the waste handling fee.
Obtaining information about individuals of a household.	Makes it possible check whether the size of the waste bin and the collection frequency for a site are reasonable in relation to the site’s profile.
Obtaining information about real-time traffic situation.	Makes it possible to replan the collection routes, both on a short time horizon (e.g. due to traffic accidents) and on longer time horizons (e.g. due to roadwork).
Obtaining information about predicted weather on shorter (next few hours) and longer (next few days) horizons.	Aids re-planning in case of extreme weather, especially heavy snowfall which is troublesome for waste collection.

Table 2. Relationship between key functional requirements identified and external data sources.

Key functional requirement	Data incorporated	Data source	Type of data source
Visualising the geographic placement of waste bins on a general reference map	Map data	OpenStreeMap Foundation	Open Source
Visualising the real appearance of the collection sites using photographic representation.	Orthophotos	Swedish Mapping and Land Registration Authority	Governmental
Visualising roads and road characteristics.	Road data	Swedish National Road Database	Governmental
Obtaining information about the owner of a property.	Property data	Swedish Mapping and Land Registration Authority	Governmental
Obtaining information about individuals of a household.	Civil data	Swedish Tax Authority	Governmental
Obtaining information about real-time traffic situation.	Traffic data	Swedish Transportation Administration	Governmental
Obtaining information about predicted weather on shorter (next few hours) and longer (next few days) horizons.	Weather data	YR	Governmental

type of data source. It can be noted that all data sources are publicly available, being provided either by governmental or open-source organisations. Besides the economic benefits of using only publicly available data sources, a significant benefit is that legal issues do not have to be considered. A more extensive description of each data source and the data incorporated therefrom are provided in the next section.

4. External data usage in the BI solution

4.1. The BI solution front-end

To provide complete, dynamic, and updated information to the users, the BI solution programmatically incorporates data from seven external sources (Figure 1). The BI solution also incorporates data from five internal sources, but since the focus of this paper is on external data incorporation, the internal sources have been omitted from Figure 1. The front-end of the system supports strategical, tactical and operational decision-making. Since the operational support of the BI-solution is described in more detail in the following section (presentation of the usage of different external data types), the following gives a short account on how the BI-solution support strategic and tactic decision-making. From a top-level management view, the BI-solution mostly delivers predefined reports showing, e.g. total mileage covered, total fuel-consumption and aggregated data on bins collected in various geographical regions/subregions. Top-level managers may also state ad-hoc queries towards the BI-solution, but that has only been done on rare occasions. From a tactic view, the system supports the transport-planners by showing, in real-time, the whereabouts of each truck and how far they have progressed on their individual daily route. The transport planners also get support by the system for identifying and handling exceptions reported by the drivers, such as broken bins or road passages that are blocked. These exceptions are sometimes directly related to individual customers, who needs to be contacted and informed on, e.g. the need for a replacement bin or information explaining why their bins may have been left unemptied. The transport planners also receive predefined reports from the system, with less aggregated data on shorter timespans than top-level management receives.

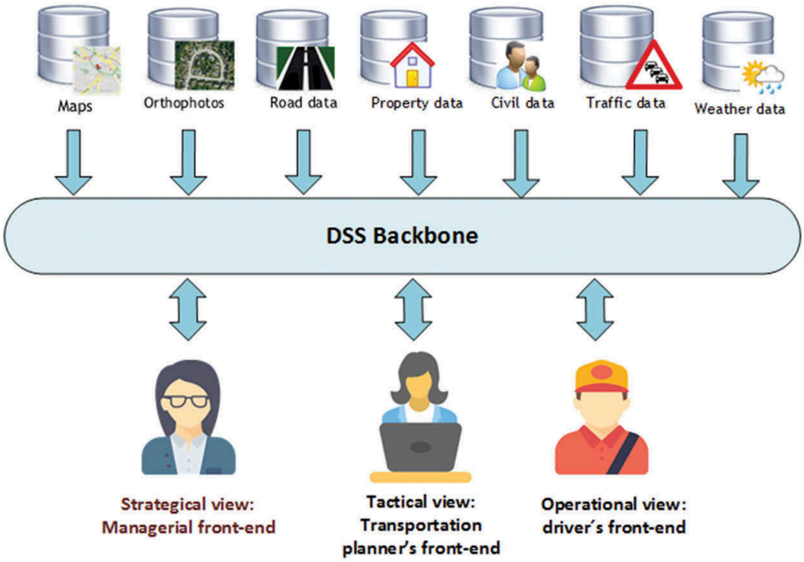

Figure 1. External data incorporated in the BI solution back-end.

4.2. Using different types of external data

This subchapter describes the identification, acquisition and integration of the seven external data sources. All sources were identified after an extensive search for suitable data suppliers.

Since this paper is focused on the back-end of the case company's BI solution, the descriptions on how the data are used are deliberately kept short. However, for clarity, a short paragraph has been included at the end of each section to contextualise the contribution of each data type.

4.2.1. Map data – OpenStreetMap

In the BI solution, maps are used for several purposes. In the transportation planner's front-end, an important purpose is to visualise the geographical placement of waste bins as this makes it possible for the transportation planner to decide whether the placements are optimal or if they need to be adjusted. An optimal placement of the bins contributes to a collection process that is efficient, safe and convenient for the driver. Optimal placement is mainly related to three aspects: the distance to the place where the truck stops, the avoidance of left turns, and the avoidance of driving backwards. The latter two are very important for safety.

In the transportation planner's front-end, maps are also used to visualise the current location of trucks that are out driving. Each truck is equipped with a GPS that sends its position to the BI solution once per second using a mobile connection. By being able to monitor the location of the trucks, the transportation planner can make decisions on the potential redistribution of work between trucks. For example, the transportation planner can detect whether a driver is behind schedule and needs help, or is ahead of schedule and can aid other drivers who have encountered problems. The transportation planner can also use the location information to decide which truck is the most suitable for allocation to a hasty request for immediate pickup, which customers randomly call for.

Figure 2 shows an example of a map in the BI solution. In the screenshot, the grey arrow shows the current location of a truck with registration number CNT414 (the direction of the arrow indicates the current direction of the truck). The blue dot marks the next bin to be emptied by the truck, while the green dots mark bins that have already been emptied. Red dots mark bins that the truck has visited but was not able to empty (e.g. because a car was blocking the bin). The visualisation on the map helps the transportation planner quickly obtain an overview of the truck's status and make real-time decisions about possible changes in the collection route and/or redistribution of work.

A similar map view is implemented in the driver's front-end to support the driver in finding the bins and selecting the best route between bins. Without the map information, the driver would be required to remember the placement of all bins and the best route between them. This is virtually impossible considering that an average of 500 bins may be emptied on a working day.

4.2.2. Orthophotos – Swedish mapping and land registration authority

In the BI solution, orthophotos are provided as an alternative to the ordinary map in both the transportation planner's front-end and in the driver's front-end. For the transportation

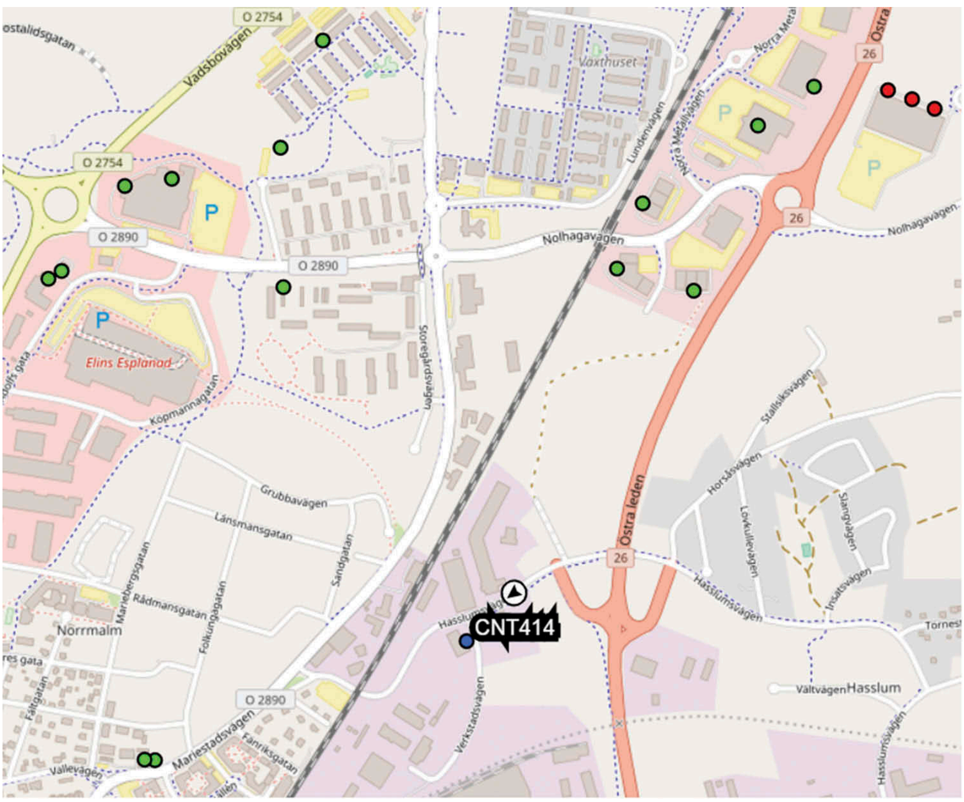

Figure 2. Screenshot from BI solution showing an example of map data used in the system.

planner, orthophotos are important to continuously improve the collection process and make decisions on how the placement of bins should be changed to make collection more efficient and safer. For example, the transportation planner makes sure that bins are placed so that they are easily spotted from the road and, if turning is needed, that they are placed close to a suitable turn space that can be used in order to avoid driving backwards. For the driver, orthophotos are useful for locating bins at collection sites as the orthophoto visualises the placement of a bin in relation to buildings and vegetation. Figure 3 shows the appearance of the orthophoto in the driver's front-end (the coloured dot marks the bin). Using the orthophoto, the driver can easily locate the bin and decide on the best spot to park the truck, taking into account the real conditions at the collection site.

4.2.3. Road data – Swedish national road database

In the front-end, the road data are visualised as overlays on a map. The screenshot provided in Figure 4 shows the appearance when the user has activated the two layers 'one-way roads' and 'carrying capacity'. The red lines on the map show one-way roads, the yellow lines show roads with a maximum carrying capacity of 16 tonnes, and the green lines show roads with a carrying capacity that is higher than the garbage truck's maximum payload. Additional layers that can be shown on the map include height limitations and roads that are suitable or unsuitable for dangerous goods (certain types of waste are classified as dangerous goods). The transportation planner uses the road information to decide which garbage trucks should serve different areas; for example, smaller trucks must be allocated to areas that include roads with limited carrying capacity. The information can also be used to decide which driver should operate the allocated truck. The area shown in Figure 4, for example, must be handled by an experienced driver since there are many one-way roads that make it difficult to operate efficiently in the area while ensuring that one-way regulations are not violated.

4.2.4. Property data – Swedish mapping and land registration authority

Property data are used in the BI solution to decide who is responsible for paying the waste fee for a certain property. According to Swedish law, a waste fee must be paid for all

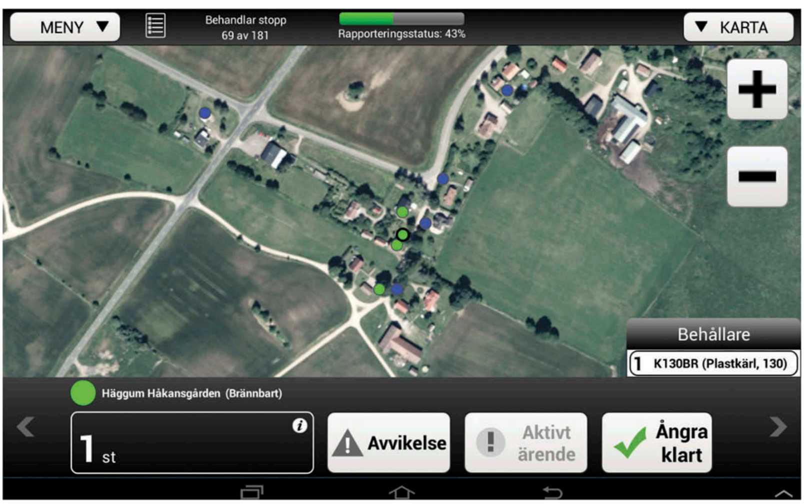

Figure 3. Screenshot of orthophoto view in the driver's front-end.

Figure 4. Screenshot showing how road information is visualised in the front-end.

occupied properties, and the person owning the property is responsible for paying the fee, regardless of whether they live on the property. In most cases, it is the property owner who reports ownership to the waste management company, but there are cases when this does not happen and it is unclear who should pay the fee. Property data are then used to make a decision so that invoicing can be done correctly. Property data are also used in the BI solution to check the placement of bins in relation to lot borders. According to the regulations, bins should be placed close to the border of the lot in order to minimise the walking distance for the garbage collector.

Data about Swedish real properties are held in a register maintained by the official Swedish Mapping and Land Registration Authority. This register is the only official source of property information in Sweden. It contains detailed information about each property's identification number, current and historical ownership, exact boundaries, land characteristics and mortgages. To keep this register up-to-date, the authority collaborates with the 290 municipalities in Sweden and with the Swedish Tax Agency. These actors collect property-related data and relay it to the Mapping and Land Registration Authority, which updates the register. In return, the municipalities get free access to the data, which means that the waste management company can use the register without cost.

In the front-end of the BI solution, property data are visualised as an overlay on a map, similar to the road data. The screenshot in Figure 5 shows lot borders in relation to the placement of bins. The marked bin is placed too far from the border and so causes unnecessary walking for the garbage collector, which is both time-consuming and causes physical strain as the collector has to drag the heavy bin for a long distance. When misplaced bins are found, the transportation planner usually contacts the customer and asks that the bin be moved to a location closer to the lot border. Considering that there are almost 23,000 bins to collect, correct placement of the bins has a large impact on efficiency and the working environment.

4.2.5. Civil data – Swedish tax authority

In Sweden, as in many other countries, everyone living in the country is registered in a civil register by the tax agency for census purposes. In the BI solution, data from the civil

Figure 5. Screenshot from BI solution showing lot borders (red lines) in relation to placement of bins (orange dots).

register are used to obtain information about the configuration of a household by checking the individuals registered at the living address. This information is used to decide on the size of the bin and the frequency with which is it emptied.

To protect the privacy of individuals, the Swedish Tax Agency is the only organisation allowed to keep a civil register, which means that there is only one source of personal data in Sweden. In the BI solution, data from the register are acquired using a web service provided by the Swedish Tax Agency. The waste company had to apply for access to the register by filling out an electronic form stating the reason it needed access to this data. Personal data are under strict protection in Sweden and are not to be spread without control. The web service also requires a specific server certificate to guarantee secure transfer of the data. Once granted access, using the web service is straightforward. The web service is called with an address as argument, and information about all people registered at the address is returned. The information includes their complete names, dates of birth and formal relationships (such as parent–child relationships and marriages). To protect the data from unauthorised access, the BI solution requires personal login information and all data to and from the system is encrypted with 1024 bit RSA keys.

The information about which individuals are part of a certain household is integrated in the BI solution through a user-triggered, in-house developed procedure. When viewing the information page for a specific collection site in the system, the user can press a button to retrieve information about which persons are registered at that address. When the button is pushed, the system calls the web service online and immediately returns the results. The reason the procedure for fetching personal data is user-triggered, rather than automatic on opening the information page for a collection site, is that each call to the web service has a cost. Due to the rigorous restrictions on how personal data may be handled, the information is never saved but appears in a dialogue box and disappears as soon as the dialogue box is shut down. These restrictions also prevent us from including a screenshot showing the appearance of personal data in the BI solution.

Information about the configuration of a household supports the transportation planner in making two types of decisions: (1) whether the size of the bin is reasonable in relation to the number of people living at the address, and (b) if there are children under the age of three living at the address. Families with babies in diapers have their waste bin emptied more often to avoid smells.

4.2.6. Traffic data – Swedish transportation administration

In the BI solution, traffic data are used to replan collection routes in the event of traffic accidents or roadwork. While traffic accidents call for immediate replanning, roadworks are usually announced long in advance and can therefore be planned for well in advance.

Traffic data can be obtained from suppliers such as Google, Garmin and the Swedish Transportation Administration. An inventory and analysis of the various suppliers showed that the Swedish Transportation Administration seemed to be the actor providing the most accurate and complete traffic data for Sweden. The traffic data it provides is also free for anyone to use through an open and well-documented API, which is a great advantage. The Swedish Transportation Administration was thus selected as the supplier of traffic data for the BI solution.

The transportation planner uses traffic information to detect the need to re-plan collection routes in order to avoid delays. Re-planning takes different forms depending on the type of event that has occurred. In the simplest case, rerouting may be all that is needed. However, sometimes the order in which the bins are visited may need to be changed, or the bins may need to be redistributed among trucks. The traffic information displayed to the user includes a description of the assumed length of the event and its effect on the traffic, which aids the transportation planner in re-planning efficiently (Figure 6).

4.2.7. Weather data – YR

Weather data are used to aid the transportation planner in making decisions related to replanning in the event of extreme weather. Heavy snowfall and icy roads can cause trouble and slowdown the whole waste collection process.

Weather data are provided by many suppliers, both small and large (e.g. Yahoo, SMHI, YR, OpenWeatherMap, DarkSky). In Sweden, YR (yr.no) is commonly used as it provides free, detailed weather forecasts for the country. YR is a government authority that is owned and financed by neighbouring Norway.

Weather data are acquired once every hour and integrated in the BI solution through a tailor-made XML parser. The implementation of this parser was straightforward as the

Figure 6. Screenshot from BI solution showing traffic information. The driver has clicked on the traffic accident symbol to get more information about the accident.

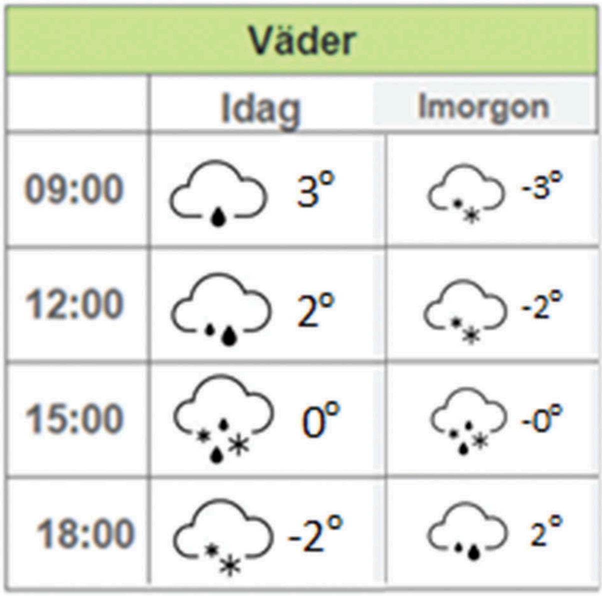

Figure 7. Screenshot from BI solution showing how weather data are visualised in the BI solution.

XML format is easy to interpret and well documented. The weather data are visualised in the transportation planner's front-end in the form of table displaying the current weather as well as the predicted weather for the next day, as shown in Figure 7. When heavy snowfall or icy roads are predicted, a warning triangle appears in the table to attract the user's attention. The transportation planner uses the weather data to make decisions related to re-planning when extreme weather threatens to delay the waste collection process. Winter weather in Sweden can be quite extreme, and so the transportation planner needs to be able to make fast, informed decisions on how to counteract problems before they occur. The planner may decide to reschedule collections, allocate backup trucks, inform customers and prepare the drivers. Such actions can avert many problems and make it possible to maintain a high-quality service regardless of the weather.

5. Results and discussion

The BI solution allowing for external data integration has substantially influenced the company and created numerous analytical values. From the evaluation phase of the action case study primarily conducted through interviews with stakeholders at the waste management company representing all three different views (strategical, tactical, and operational), the analytical values presented in Table 3 arise. The table exemplifies the analytical values of the external data at various organisational levels, according to the analytical value categories proposed by Phillips-Wren and Hoskisson (2015). The examples are not intended to be a complete account or to cover all the analytical values of the external data in the BI solution; rather they illustrate how the BI solution supports the waste management company in conducting and improving its business.

Table 3. Analytical value of external data.

Org. level/Value	Descriptive	Predictive	Prescriptive
Operative	Geographic data showing road network and buildings. Traffic incidents Bin placements	Prediction for avoiding over-/underweight for each truck (overweight is illegal and underweight means that the trucks are under-used).	Optimised routes for collecting bins.
Tactical	Time consumption per waste emptying route. Waste volumes per emptying route.	Predicted time duration for each route.	Optimisation of fleet utilisation on a weekly/monthly basis (allocation of individual vehicles and drivers to specific routes).
Strategic	Annual waste volumes. Total number of bins emptied in a year. Total reduction of CO_2 emissions.	Predicting next year's required emptying fee per type of bin.	Fleet optimisation (optimal vehicle configurations and optimal number of vehicles). Fuel optimisation.

More generally, the results show that external data may be a key asset for organisations, creating analytical business values that are descriptive, predictive and prescriptive. All these values contribute to sharpening the company's competitive edge, as well as making investments in increased decision-making capability visible and contributory. In line with the work by Phillips-Wren and Hoskisson (2015), it is clear that the prescriptive analytics value is worth striving for. For the company, in this case, the prescriptive features allowed for a complete change in, for example, how route planning and fleet-investments were done. The previous experienced-based decision-making culture of the organisation is in the process of being transformed into a data-driven decision-making culture, constantly allowing the company to gain new insights into how the main business may be further developed. In this way the company may also be considered to be handling the disadvantage of not having an analytical culture, which is one of the major pitfalls when moving into a data-driven decision-making culture (Gudfinnsson, Strand, & Berndtsson, 2015).

Since the system was developed over a number of years, it has evolved into its current functionality and business importance. The fact that the users of the system have also been involved in its evolution (e.g. by expressing their need for additional data, new reports and visualisations) has fed into its success and contributed to the transformation of the decision-making culture. Involving end users is, as indicated by many (e.g. Safwan, Meredith, & Burstein, 2016), one of the key ingredients in the evolution of a BI solution. The actual continuous evolution is in itself a success factor for any BI solution (Shanks & Bekmamedova, 2012) as the existence of routines for constant renewal of analytical areas and functionalities contributes to the success of the BI solutions.

We strongly argue that in this case, the external data are not just the 'icing on the cake', but are actually the prerequisite for totally shifting the value-creating business. The BI solution including multi-source external data has generated a number of substantive savings for the company. Currently (2018), 25 trucks are needed to collect the waste compared to 20 trucks in 2010. This increase may raise questions about the success of the optimisations, but the increased number of trucks reflects the expanded geographical coverage since 2010, with far more bins to collect. If the company were still relying on traditional manual route planning, it is estimated that it would have needed approximately 32 trucks to do the same work. This estimate is based on the fact that the operations time per truck for collecting bins has decreased by approximately 25% since the BI solution was introduced. Each truck can now collect more bins per route. In addition, the optimisations have allowed the company to diversify the types of trucks (mostly with respect to size/weight capacity), allowing for reduced procurement costs per truck and less environmental impact such as carbon oxide emissions, approximately 21,300 kg of carbon dioxide and 187 kg of nitrogen oxides per year and truck. More detail can be found in Strand, Syberfeldt, and Geertsen (2017). The company has not allowed any exact numbers to be published, but the CEO states that the annual savings are in the region of 'hundreds of thousands of euros'.

Widening the perspective on this action case study, we can also recognise a number of antecedent factors that influenced its success. These factors have not been the main focus of this work, yet according to Meredith et al. (2012), they are often neglected in the literature but are worth considering. First of all, the company was rather 'IT thin' when the study started, meaning that there was no extensive system legacy to take into account. The company was also very aware of their BI immaturity, but very curious about the potential benefits. In addition, the initiative came from the company, meaning that there was no vendor 'sales-initiative' pushing the company into the development process.

Despite the limited ability to generalise from the findings of one action case study, we can argue that there are numerous other potential applications of this work, and many businesses that would benefit from a BI solution similar to the one presented here. Transport services (delivery/pickup services, bus services and taxi services) are obviously among them, but so also are chimney-sweeping services, snow-clearing services, and home care services. These are all businesses that would benefit from prescriptive routing that takes things like weather conditions and traffic incidents into account. Moreover, the particular study presented indicates that a data-driven and decision-making approach, supported by a fully functional BI solution, may benefit smaller companies, without being too resource-demanding. Most previous studies reported in the literature involved larger companies with a completely different resource capability (e.g. Harrah Casino and American Airlines (Davenport & Harris, 2007)).

The results are also intended to inspire companies to make more use of external data in their BI solutions, whether they are already incorporating external data or are just starting to consider doing so. In either case, the results of this work may help them to enhance their decision-making capabilities, knowing that others have done so successfully, and having seen a concrete example of the contribution of external data such as customer data, weather data and geospatial data. For data providers, our results may support their case on how beneficial external data may be when incorporated and combined with a clear purpose and careful selection.

From a scientific point of view, the results of this work contribute to increasing the current body of knowledge concerning external data incorporation into BI solutions. The details regarding how the data may be combined and used in an integrated tool are valuable, as also are the concrete examples of different analytical values at different organisational levels. By separating the results into categories of analytical values, this work contributes details concerning one of the critical issues facing BI practitioners, namely predictive analytics. O'Donnell, Sipsma, and Watt (2012) found that BI practitioners proclaimed the potential value of predictive analytics, but also recognised the importance of strategies, the need for a certain level of BI maturity, and the importance of identifying required organisational prerequisites for successful initiatives.

Further research is needed to be able to generalise the findings of this work. Additional studies are required to identify more nuances in the analytical values. In addition, external data incorporated from the Internet and governmental organisations are far less scrutinised in the literature than external data from specialised external data suppliers (sometimes referred to as syndicated data suppliers). More detailed accounts of how external data are actually used are needed to build knowledge as well as confidence for investing time and money in such data.

Disclosure statement

No potential conflict of interest was reported by the authors.

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