

Data Mining - Report

James Donohue (16024143)

Abstract

This is the abstract.

Exercise choices: classification and clustering

Contents

1	Data Choice	2
1.1	Data Set	2
1.2	Attribute types	2
1.3	Coding of nominal data	2
1.4	Data relationships	3
1.5	Applicability of data mining techniques	3
2	Data Analysis	4
2.1	Number_of_Vehicles	4
2.2	Vehicle_Type	5
2.3	Date	8
2.4	Time	9
2.5	Data Preprocessing	9
2.6	Reducing dimensions	11
2.7	Importing into WEKA	11
2.8	Missing values	11
2.9	Choice of tools	11
3	Classification	12
3.1	Choice of classifier	12
3.2	Preprocessing	12
3.3	Parameters	14
3.4	Training and testing	14
3.5	Results	14
3.6	Visualisation	15
3.7	Tuning strategy	15
3.8	Final results	15
4	Critical review	15
4.1	Future work	15
5	Appendix: Summary of KNIME workflows	16
	References	16

1 Data Choice

1.1 Data Set

The open data set used in this report is the Department for Transport’s 2016 release of Road Safety Data (Department for Transport, 2017), which gives “the circumstances of personal injury road accidents ... the types (including Make and Model) of vehicles involved and the consequential casualties”. The data are published annually on the data.gov.uk website under a licence that permits non-commercial exploitation with attribution (The National Archives, 2017).

The source of the data is the ‘STATS19’ accident reporting form used by police and so the data is also referred to by this name. The STATS19 data has been recorded (with some changes in attribute semantics) since 1979 (Administrative Data Liaison Service, 2018). The Department for Transport also produces a ‘STATS20’ document which provides guidance on completing the form defines some of its terminology (Department for Transport, 2004).

The 2016 data set is distributed as three separate ZIP-compressed comma-separated variable (CSV) files, listed in Table 1 along with the number of data rows in each (each file also includes a single ‘header’ row providing metadata (Han, Kamber and Pei, 2012, p. 92) in the form of field names).

Table 1: Overview of 2016 data files

Link	Decompressed filename	Data rows
Road Safety Data - Accidents 2016	dftRoadSafety_Accidents_2016.csv	136621
Road Safety Data - Vehicles 2016	Veh.csv	252500
Road Safety Data - Casualties 2016	Cas.csv	181384

1.2 Attribute types

Every data row in each data file represents an object with a number of attributes that describe its features or characteristics (Han, Kamber and Pei, 2012, p. 40). The types of each attribute in the data set are summarised in Appendix A.

1.3 Coding of nominal data

Many attributes in the data set are of nominal data type (that is, representing names of things) but contain integer values. For example, an object in the *Accidents* file may have a value of 20 for the attribute *Police_Force*, but this number is not intended to be used quantitatively, instead it represents a nominal value (Han, Kamber and Pei, 2012, p. 41). In this case, 20 represents the West Midlands police force.

An accompanying Excel spreadsheet *Road-Accident-Safety-Data-Guide.xls* (linked under *Additional resources*) provides lookup tables of all possible values for such ‘coded’ nominal types. This means such attributes have an *enumerated value domain* (OECD, 2006). The spreadsheet also explains that the special value -1 represents “NULL or out of range values”.

1.4 Data relationships

The Excel spreadsheet that accompanies the data set also explains the relations between the individual files:

The ACC_Index field give a unique index for each accident and links to Vehicle and Casualty data. Casualties are linked to vehicles by “VEHREF”.

Each of the three files therefore constitutes a relation with its own primary key (Codd, 1970), with ACC_Index (given as Accident_Index in the CSV header rows) as a unique accident identifier and Casualty_Reference and Vehicle_Reference identifying each casualty and the vehicle with which they are associated, respectively. The primary keys for each relation are shown in the simplified Entity Relationship (ER) diagram in Figure 1.

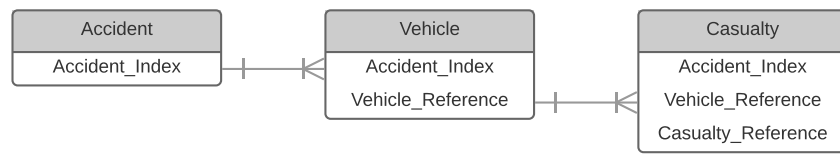


Figure 1: Simplified Entity Relationship diagram for data set

The Number_of_Vehicles and Number_of_Casualties fields in the *Accidents* file indicate the number of related rows in the other two files. For example, if Number_of_Vehicles is 2, there will be two rows in the *Vehicles* file with the same Accident_Reference, having a Vehicle_Reference of 1 and 2 respectively. The same applies to casualties.

1.5 Applicability of data mining techniques

1.5.1 Clustering

Cluster analysis involves “grouping objects that are similar to each other and dissimilar to the objects belonging to other clusters” (Bramer, 2016, p. 311). This technique, a form of unsupervised machine learning, might allow us to discover classes of accidents that have similar characteristics and make them the focus of further analysis. In practice this could eventually lead to recommendations about additional safety measures (for example, changes to road design or rider training) that might reduce the prevalence of such accident classes.

Two challenges of this data set for clustering analysis are its large number of attributes and the fact that it mainly consists of nominal attributes, since many clustering algorithms focus on numeric data and work best with a small number of attributes (Han, Kamber and Pei, 2012, p. 446–7).

1.5.1.1 Choice of algorithm

Partitioning methods find mutually exclusive clusters that are spherical in shape, using a distance function to measure the similarity of objects within a cluster and therefore minimise the amount of within-cluster variation (Han, Kamber and Pei, 2012, p. 489). Of these methods, the popular *k*-means algorithm uses the arithmetic mean to find the centroid of each cluster and therefore needs numerical

attributes. The k -modes method put forward by Huang (1998) is an extension to k -means which supports nominal (categorical) attributes, utilising the mode instead of the mean. k -modes was therefore selected as an initial basis a clustering workflow.

Since KNIME does not support k -modes natively, a *Python Script* node was used to provide the algorithm using an external Python interpreter, using de Vos' open-source implementation [cite]. The result of this was an additional numeric attribute dataset that identifies the cluster with which each object has been associated.

1.5.2 Literature review

Hill (2005) evaluated the usefulness of several cluster analysis methods in identifying relatively homogeneous groups of accidents from the STATS19 data from 1997 and 2002 for further investigation with a goal "to generate ideas for how the number of these accidents might be reduced". SPSS TwoStep, CHAID and cross-tabulation were evaluated, with the last two being the most promising. For Hill two-step cluster analysis on these data requires too much subjective intervention by the analyst and produces less 'transparent' results than the latter two methods.

Although the TwoStep algorithm (SPSS, Inc., 2001) is efficient on large datasets and supports a mixture of continuous and categorical variables, SPSS was not available for this report to compare with Hill's findings.

Castro and Kim (2015) approached identifying the factors that contribute the most to accident severity in STATS19 datasets as a classification problem, where the classifier models created were used to predict the class (severity) of the accident. WEKA was used to create a Bayesian (belief) network, a C4.5-based decision tree and a multi-layer perceptron (neural network) and the accuracy of each in classifying unseen instances was tested using crossfold validation. The results showed that the Bayesian network was the most accurate and that light conditions and road type were the most significant factors. However, extensive filtering and other preprocessing was performed on the data.

Ehsaei and Evdorides (2011) used data mining techniques to analyse the temporal variation in contribution of road infrastructure features to accident severity over a five-year period, in response to changes in national road policies. The researchers again used WEKA and a Bayesian network, but limited their study only to accidents in the Greater Manchester area and to road infrastructure features. Training and testing was performed using a 66%/34% split. However, rather than attempting to demonstrate the accuracy of their model, in their results they extracted the the probabilities of different road features (such as 'Junction Detail') occurring in conjunction with different severities from the classifier. This served as a way of identifying the most high-risk locations on the road network.

2 Data Analysis

As the data set contains over 70 attributes this section will focus only on selected attributes as illustrations of the process of data analysis.

2.1 Number_of_Vehicles

The attribute `Number_of_Vehicles` (in the *Accidents* file) represents how many vehicles were involved in each accident. It is a numeric ratio-scaled attribute (that is, has an inherent zero-point) however as

a typical ‘count’ attribute its values are only integers. In the 2016 data set it has no missing values.

Using the *Statistics* node in KNIME we can calculate some basic statistical descriptions for this attribute. The minimum and maximum values are 1 and 16 respectively. The **mean** number of vehicles in an accident is 1.8482, however as the data are positively skewed for this attribute (skew = 1.5756) a better measure of the centrally tendency is the **median** (Han, Kamber and Pei, 2012, p. 46). Here we can say that the median accident involved 2 vehicles. The **mode** is also 2. The histogram in Figure 2 shows the distribution of values for this attribute. Values of 6 and above are grouped together as they account for only a very small proportion of the data.

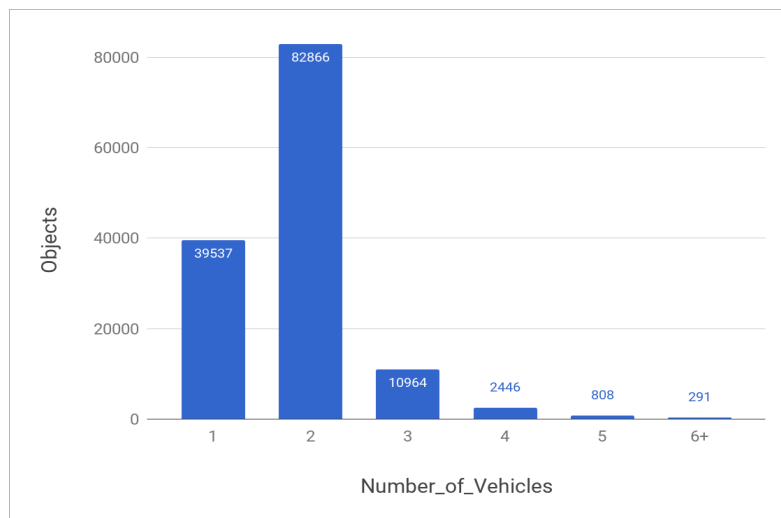


Figure 2: Histogram for Number_of_Vehicles

2.2 Vehicle_Type

The *Vehicle_Type* attribute in the *Vehicles* file indicates the type of each vehicle involved in an accident. It is a nominal (categorical) attribute. Although represented as an integer, it does not make sense to perform mathematical operations on it so we cannot calculate the mean vehicle type (Han, Kamber and Pei, 2012, p. 78), however the mode (most commonly occurring) type is 9 (Car). The integer values correspond to values in the *Vehicle Type* sheet of Excel spreadsheet that accompanies the data.

The KNIME workflow *Vehicle type correlation matrix* produces a correlation matrix for vehicle types in accidents involving two vehicles. In the resulting table, both the rows and columns represent a given vehicle type and the intersecting cell gives the number of accidents involving that combination of vehicles. This can be further visualised as a ‘heat map’ such as Figure 4 in order to reveal possible patterns. Cells are highlighted in different shades of red depending on their value; the highlighting midpoint was set to the 85th percentile after some experimentation to produce the clearest differentiation between cells. Note that cells along the top diagonal need to have their values halved to avoid showing a double count; this is because of the way the Joiner and Pivoting nodes work.

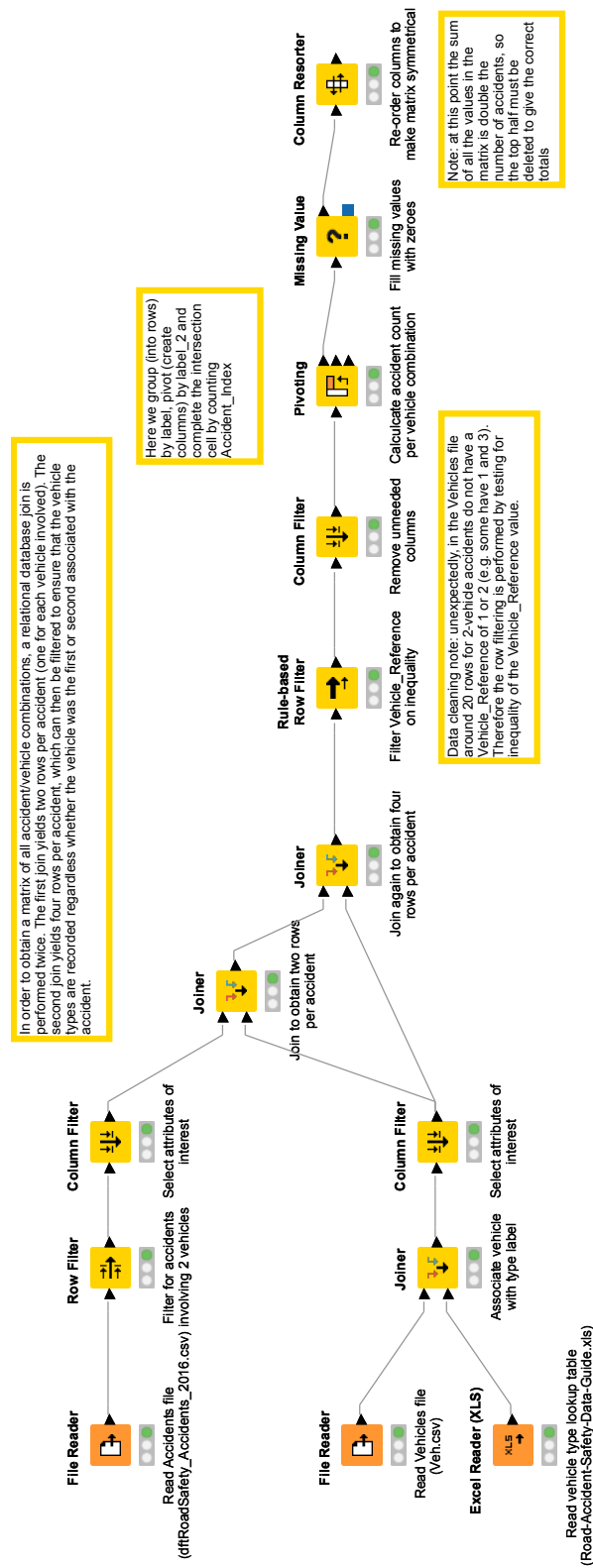


Figure 3: Workflow for vehicle type correlation matrix

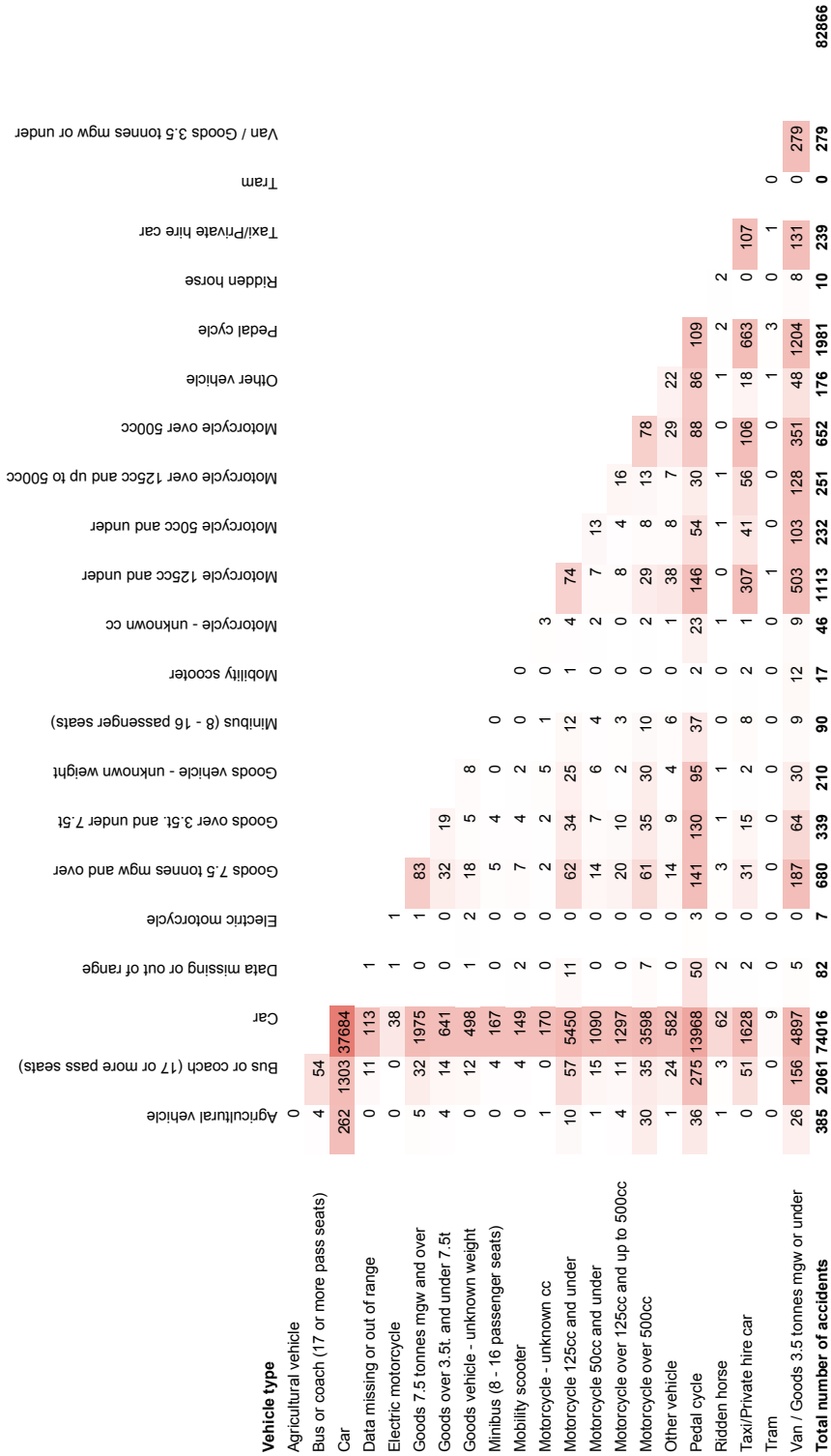


Figure 4: Heat map for Vehicle_Type in two-vehicle accidents

2.3 Date

The Date attribute in the *Accidents* file is a string representation (with the format MM/dd/YYYY) of the calendar date between 1 January and 31 December 2016 that each accident occurred. It is considered interval-scaled because it is measured on a scale of equal-size units (here days) but no true zero-point (Han, Kamber and Pei, 2012, p. 80).

Every date occurs at least once in the data set. Using the *Statistics* node in KNIME we can determine that the date that occurs the most (i.e. with the most accidents) was 25 November, with 566 accidents. This is therefore the mode date. However least-occurring date (i.e. with the least accidents) was 25 December, with only 138, which is likely due to fewer people travelling on Christmas Day. For comparison, since 2016 was a leap year with 366 days and the *Accidents* file contains data about 136621 accidents, we can say that the mean number of accidents per day was 373.28.

Although analysis of accident numbers over the year might reveal seasonal trends, to be sound any conclusions would need to be supported by comparison with data from other years. Since reviewing multiple years' data is out of scope for this report, an alternate approach is to look for trends within the year under study. For example, we may wish to know if significantly different numbers of accidents occur at weekends. Figure 5 uses a box plot to visualise the distribution of accidents per day of the week. Each bar represents a different day. Data points that are more than 1.5 times the inter-quartile range (IQR) are plotted separately, all of which are classified by KNIME as 'mild' outliers.

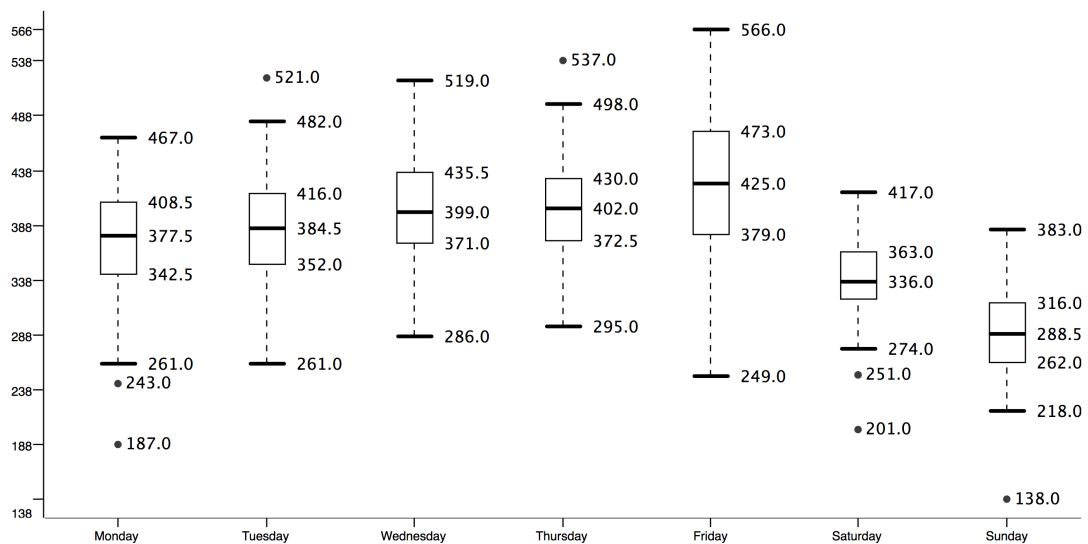


Figure 5: Box plot of accidents by day of week

From this we can see that the number of accidents increases slightly as the week progresses, and that weekends have significantly fewer accidents. It is also notable that the 'whiskers' (representing the maximum and minimum values) for Friday are much longer for other days. Table 2 confirms that Friday has a much larger standard deviation than other days of the week, meaning that it has the greatest dispersion of values.

Table 2: Distribution of accidents by day of week

Day of week	Min	Max	Mean	StdDev
Monday	187	467	370.69	57.34
Tuesday	261	521	386.62	46.42
Wednesday	286	519	401.37	47.73
Thursday	295	537	402.87	47.43
Friday	249	566	426.02	63.82
Saturday	201	417	336.19	42.73
Sunday	138	383	288.92	42.34

Note that this analysis does not allow us to conclude that weekends are somehow inherently safer - there may simply be less traffic. In order to know for sure we would need to cross-reference data about how many vehicles are on the road on each day, which is beyond the scope of this study.

2.4 Time

The *Time* attribute in the *Accidents* file represents the time of day that an accident occurred. Like *Date*, it is an interval-scaled attribute with values ranging from 00:00 (midnight) to 23:59. By extracting the hour and minute components from each time we can produce histograms that reveal patterns in the data.

Figure 6 shows the number of accidents that occur during each hour of the day, from 0 to 23, across the whole data set. This shows that the fewest accidents occur between 04:00-04:59, while there are noticeable peaks between 08:00-08:59 and 17:00-17:59. These peaks could be predicted as they correspond to the usual ‘rush hours’ at the start and end of the working day. Nearly 25% of accidents occurred between 8am and 9am or between 4pm and 6pm.

Similarly, Figure 7 shows the number of accidents that occur during each minute of the day, from 0 to 59, across the whole data set. It is apparent that the most frequent times are on the hour and half-past the hour, with smaller peaks every five minutes. Although this could mean that accidents happens more frequently at these points, a more likely explanation is that the police offers reporting the accident often round their approximation of the accident time to the nearest 5- or 30-minute boundary. This ‘snapping’ effect implies that attempting to analyse the *Date* and *Time* attributes with a resolution of less than 5 minutes is unlikely to be successful. A comparable level of accuracy in police reporting road accident times was inferred for road accident data collected about Helsinki’s Ring Road (Innamaa et al., 2014, p. 18).

2.5 Data Preprocessing

We can use the knowledge that the majority (around 60%) of accidents involve two vehicles to focus this study and eliminate some of the complexity that arises from one-to-many data relationships. By considering only accidents involving two vehicles, we can ‘denormalise’ the *Accident* and *Vehicle* files to allow for further processing.

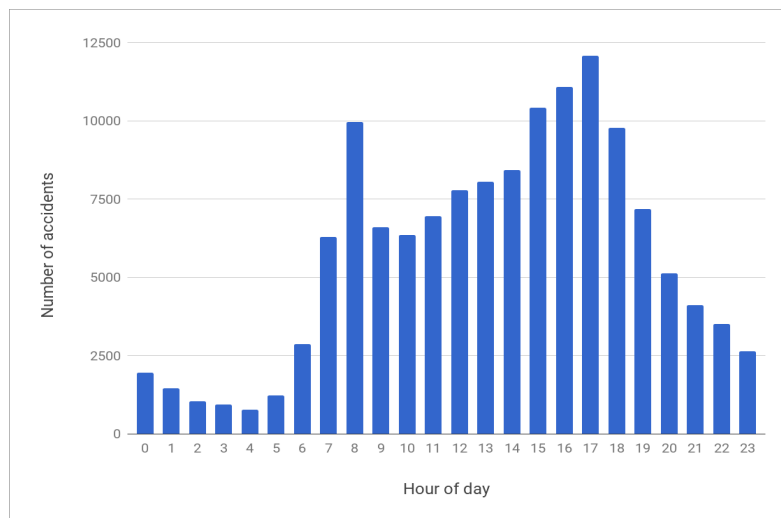


Figure 6: Histogram of number of accidents occurring during each hour of day

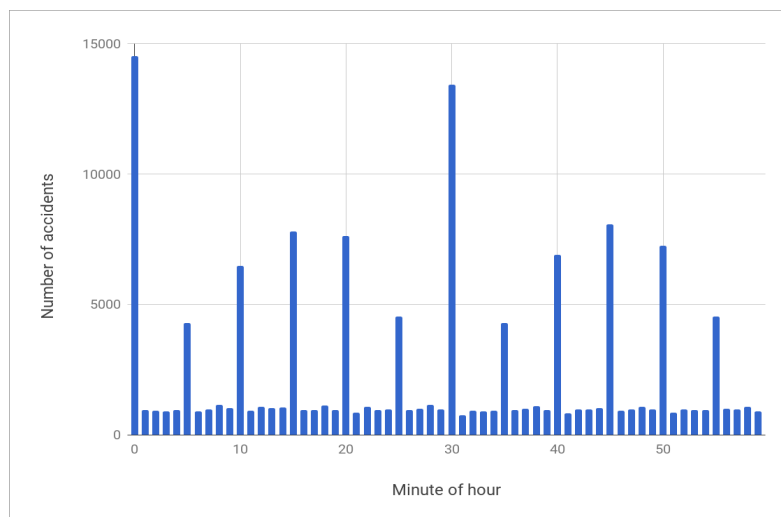


Figure 7: Histogram of number of accidents occurring during each minute of hour

2.6 Reducing dimensions

As the dataset contains a very large number of dimensions, the amount of storage space and processing time required to cross-tabulate every possible combination of attributes and then examine could be prohibitive (an example of the so-called ‘curse of dimensionality’ (Han, Kamber and Pei, 2012, p. 158)). In order to simplify exploration of the data in WEKA the following attributes were removed from the data before exporting to ARFF format:

- 1st_Road_Number and 2nd_Road_Number
- TWMV_Was_Vehicle_Left_Hand_Drive? (the value of this is always No since it does not make sense for TWMVs)
- Vehicle_IMD_Decile (this attribute is not described in the lookup tables, and inspecting it in KNIME shows that its values are always identical to Driver_IMD_Decile)

2.7 Importing into WEKA

In order to import the dataset into WEKA for exploration it must to be converted to WEKA’s ARFF format (Paynter, 2002) which includes type information. The *ARFF Writer* node in KNIME supports creating files in this format, however it does not seem to support WEKA’s DATE type but outputs these attributes as STRING instead. In order to work around this the file must be post-processed after generation, such as by using `sed(1)`:

```
sed -ipe "s/^@ATTRIBUTE DateTime.*/@ATTRIBUTE DateTime DATE yyyy-MM-dd'T'HH:mm/" \
    Accidents-2Veh-TWMV.arff
```

2.8 Missing values

There are two different types of missing values in the dataset. For example, the *Accidents* file contains 7 objects with missing longitude/latitude and 37 with a missing speed limit, represented as empty strings and the literal NULL in the input CSV, respectively (this can be determined through the *Statistics* node in KNIME). However, the lookup tables show that many of the nominal attributes (e.g. *Road_Type*) support an explicit code for missing or unknown values, usually -1 defined as *Data missing or out of range*. Some attributes also specify an additional code defined as ‘Unknown’ or ‘Not known’.

For consistency and to enable WEKA to identify and handle missing values, all such nominal value codes were folded to ‘true’ missing values during pre-processing in KNIME by limiting the number of rows read by the *Excel Reader* node prior to being looked up by *Cell Replacer*. Note that this process did not include values such as *Unclassified* for *Road_Type*, since despite the name this is a valid type of road rather than missing data.

NB two accidents have a missing value for Time.

2.9 Choice of tools

KNIME 3.5.1 was chosen ... (talk about metanodes, documentation etc.)

Python 2.7.13 with the pandas, protobuf and Jedi extensions (installed as per the [KNIME documentation](#) and the *kmodes* extension (installed following the steps on the [the k-modes GitHub repo](#)))

Other extensions used: - matplotlib - scikit-learn

In addition, the histogram and heat map figures in the report were prepared using Google Sheets for improved visual clarity.

3 Classification

Classification is a data mining functionality that divides up objects (instances) into a number of categories or classes. These classes are typically mutually exclusive and exhaustive (Bramer, 2016, p. 21).

In order to perform classification on the dataset it is necessary to select a suitable attribute to represent the 'class' of each accident. The `Accident_Severity` attribute was selected as it represents a significant feature of the accident that we would like to be able to predict based on other features. In real world terms, this means that an accurate classifier model could predict which types of accidents are likely to be the most serious based on their other characteristics.

3.1 Choice of classifier

Hill used cross-tabulation to identify clusters of vehicle manoeuvres that are heavily represented in the accident data, including one where another vehicle turns right while the TWMV performs any manoeuvre (2005, p. p10). It is of interest to know which combination(s) of manoeuvres are likely to result in a severe or fatal accident. Put another way, we would like to be able to predict the probability of an accident belonging to a given severity class, based on the manoeuvres involved. We will assume that the type of each manoeuvre is independent of the other.

The naïve Bayes algorithm uses probability theory to find the most likely classification (Bramer, 2016, p. 22). It is called naïve because the algorithm operates on the assumption that the effect of each attribute value on the classification is equally important and independent of the other attributes, but is known to often give surprisingly good results in practice (Bramer, 2016, p. 26). By exploring this relatively straightforward probabilistic model, we follow Witten et al.'s advice to try the simplest things first (2016, ch. 4).

One reason for choosing this algorithm is that the dataset contains a large number of missing values, and naïve Bayes naturally handles missing values by omitting any such attribute from its calculations (Witten et al., 2016, ch. 4). By contrast, algorithms such as decision trees require special handling for missing values (such as treating them as values in their own right, or splitting instances; (Witten et al., 2016, ch. 3)).

3.2 Preprocessing

The naïve Bayes approach assumes that all attributes are nominal (Bramer, 2016, p. 29) therefore other attribute types must be converted to that type, or discarded. For a first attempt we take the approach of discarding the non-nominal attributes. The `RemoveType` WEKA filter can be used to remove the attribute of non-nominal type (i.e. numeric or date) as follows:

```
weka.filters.MultiFilter -F "weka.filters.unsupervised.attribute.RemoveType -T \
    date" -F "weka.filters.unsupervised.attribute.RemoveType -T numeric"
```

The WEKA Explorer interface with these filters applied is shown in Figure 8.

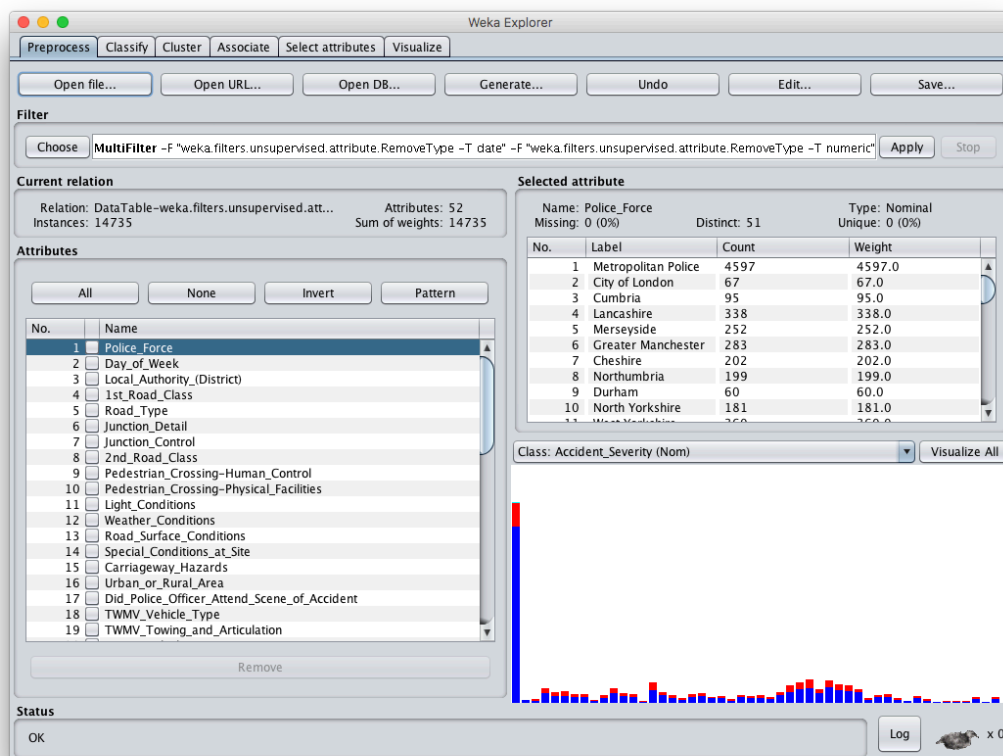


Figure 8: WEKA Explorer showing RemoveType filters applied

3.3 Parameters

?

3.4 Training and testing

3.5 Results

3.5.1 Accuracy baseline

In order to have a baseline accuracy against which to compare the model, we can use a method such as ZeroR (University of Waikato, 2018). This allows us to demonstrate whether the classifier is a significant improvement on simply guessing the class based on the most prevalent one (i.e. the mode, as here in the case of a nominal class).

When ZeroR was used as a classifier in WEKA, with the entire dataset used for testing (since holding out some of the data is unnecessary), the results were as shown in the confusion matrix in Table 3, which also gives totals for actual (Y axis) and predicted (X axis) class. The recognition rate for each class is given as well as overall, to two decimal places.

Table 3: Confusion matrix for ZeroR classifier showing recognition rates

	Slight	Serious	Fatal	Total	Recognition (%)
Slight	10673	0	0	10673	100.00
Serious	3862	0	0	3862	0.00
Fatal	200	0	0	200	0.00
Total	14735	0	0	14735	72.43

Since ‘Slight’ is the most common class, 100% of these instances are correctly classified by ZeroR, however no ‘Serious’ or ‘Fatal’ accidents are correctly classified. The overall recognition rate of ZeroR is 72.43%, meaning it recognises that proportion of classes correctly; this is also known as its accuracy (Han, Kamber and Pei, 2012, p. 366).

3.5.2 Class imbalance

The ‘class imbalance problem’ describes a situation where the class (or classes) of interest are rare (Han, Kamber and Pei, 2012, p. 367). This applies to the current dataset, since we are interested to know which circumstances produce the most severe accidents, and fatal accidents represent just over 1% of the dataset. Moreover, the cost of more severe accidents (both financial and social) is likely to be greater than for slight accidents.

To help assess this we can use the ‘sensitivity’ (true positive rate) and ‘specificity’ (true negative rate) for each class [TBD].

3.6 Visualisation

?

3.7 Tuning strategy

- Laplace?
- Dependencies - attribute selection
- Normal distribution of numeric attributes

3.8 Final results

4 Critical review

4.1 Future work

4.1.1 Missing values

Missing values could occur because of a number of reasons, such as error on behalf of the police officer or during data entry. However, as Witten et. al (2016) point out, some missing values can be due to a conscious decision rather than error. One area for further investigation could be to identify those missing values which may mean 'not applicable'. For example, 28% of instances have a missing value for 2nd_Road_Class - this could be because there was no second road. Reviewing official guidance on completing the form (Department for Transport, 2004) might inform further data preprocessing to handle these values correctly.

4.1.2 Using Bayes' Theorem to classify fatal manoeuvres

Following the work done in the Classification task, a new Bayesian classifier could be built that can predict the severity of an accident based on the manoeuvres involved, with a variable threshold. This was not attempted in this study, but some of the calculations required are described below:

Let A be an accident involving two manoeuvres (the 'evidence', in Bayesian terms). H is the hypothesis that A is fatal, that is it belongs to the 'fatal' class. We want to determine $P(H|A)$, the probability of this hypothesis conditioned on the observed manoeuvres (the posterior probability).

$P(H)$ is the prior probability of H , here meaning the probability that any accident will be fatal regardless of manoeuvres. This can be estimated by counting the number of fatal accidents in the dataset and dividing it by the total number of accidents: $200/14735 = 0.014$.

$P(A|H)$ is the posterior probability of A conditioned on H , i.e. the probability that an accident involves two specific manoeuvres, given we know the accident is fatal. By assuming there is no dependency between the manoeuvres m_1 and m_2 , we can calculate this as $P(m_1|H) \times P(m_2|H)$ by counting the number instances in the training set where each manoeuvre occurs for a fatal accident. For example, there are 27 accidents where the TWMV was overtaking a moving vehicle out of 200 fatal accidents, so $P(m_1|H)$ here is $27/200 = 0.135$.

$P(A)$ is the prior probability of A , meaning the probability that any accident in the dataset involves the two given manoeuvres, i.e. $P(m_1) \times P(m_2)$.

We could then use Bayes' theorem to estimate the probability that any new accident with those manoeuvres is fatal:

$$P(H | A) = \frac{P(A | H) P(H)}{P(A)}$$

The final step would be to determine a probability threshold for identifying an accident as fatal. For example, we could say that if the probability is > 0.75 then the accident is fatal, and test by holding out some of the data. The results from this investigation could be used to validate Hill's findings described earlier.

5 Appendix: Summary of KNIME workflows

Table 4 summarises the KNIME workflows included with this report.

Table 4: Summary of KNIME workflows

Workflow	Purpose
Accident date distribution	Creates a box plot for accidents by day of the week and statistics table
Vehicle Type correlation matrix (Figure 3)	Generates a correlation matrix of vehicle types in two-accident collisions suitable for rendering as a heat map
Accident date distribution	Generates a box plot showing distribution of accident dates and statistical summary

References

- Administrative Data Liaison Service (2018) *STATS19 Road Accident dataset details*. <http://www.adls.ac.uk/department-for-transport/stats19-road-accident-dataset/?detail> Accessed 18 May 2018.
- Bramer, M. (2016) *Principles of Data Mining*. 3rd edition, Springer.
- Castro, Y. and Kim, Y. J. (2015) Data mining on road safety: factor assessment on vehicle accidents using classification models. *International Journal of Crashworthiness*, 21(2), pp. 104–111.
- Codd, E. (1970) A Relational Model of Data for Large Shared Data Banks. *Communications of the ACM*, 13(6), pp. 377–387.
- Department for Transport (2004) *Instructions for the Completion of Road Accident Reports*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/230597/stats20-2005.pdf Accessed 18 May 2018.
- Department for Transport (2017) *Road Safety Data - 2016*. <https://data.gov.uk/dataset/cb7ae6fo-4be6->

[4935-9277-47e5ce24auf/road-safety-data](#) Accessed 29 April 2018.

Ehsaei, A. and Evdorides, H. (2011) Temporal Variation of Road Accident Data Caused by Road Infrastructure. In *3rd International Conference on Road Safety and Simulation*, Indianapolis, USA, 11 September, <https://trid.trb.org/view/1290409> Accessed 6 June 2018.

Han, J., Kamber, M. and Pei, J. (2012) *Data Mining: Concepts and Techniques*. 3rd edition, Morgan Kaufmann.

Hill, J. P. (2005) *The innovatory analysis of road traffic accident data*. <https://trl.co.uk/reports/PPRo56> Accessed 18 May 2018.

Huang, Z. (1998) Extensions to the k-Means Algorithm for Clustering Large Data Sets with Categorical Values. *Data Mining and Knowledge Discovery*, 2(3), pp. 283–304.

Innamaa, S., Norros, I., Kuusela, P., Rajamäki, R. and Pilli-Sihvola, E. (2014) *Road traffic incident risk assessment*. <https://www.vtt.fi/inf/pdf/technology/2014/T172.pdf> Accessed 18 May 2018.

OECD (2006) *Glossary of Statistical Terms: Value Domain*. <https://stats.oecd.org/glossary/detail.asp?ID=2849> Accessed 30 April 2018.

Paynter, G. (2002) *Attribute-Relation File Format (ARFF)*. <https://www.cs.waikato.ac.nz/ml/weka/arff.html> Accessed 6 June 2018.

SPSS, Inc. (2001) *The SPSS TwoStep Cluster Component*. https://www.spss.ch/upload/1122644952_The%20SPSS%20TwoStep%20Cluster%20Component.pdf Accessed 6 June 2018.

The National Archives (2017) *Open Government Licence v3.0*. <http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/> Accessed 29 April 2018.

University of Waikato (2018) *WEKA - ZeroR*. <https://weka.wikispaces.com/ZeroR> Accessed 15 June 2018.

Witten, I. H., Frank, E., Hall, M. A. and Pal, C. J. (2016) *Data Mining*. 4th edition, Morgan Kaufmann.