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Research on map matching algorithm based on priority rule for low sampling frequency vehicle navigation data

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Abstract

Purpose – There is a certain error in the satellite positioning of the vehicle. The error will cause the drift point of the positioning point, which makes the vehicle trajectory shift to the real road. This paper aims to solve this problem.

Design/methodology/approach – The key technology to solve the problem is map matching (MM). The low sampling frequency of the vehicle is far from the distance between adjacent points, which weakens the correlation between the points, making MM more difficult. In this paper, an MM algorithm based on priority rules is designed for vehicle trajectory characteristics at low sampling frequencies.

Findings – The experimental results show that the MM based on priority rule algorithm can effectively match the trajectory data of low sampling frequency with the actual road, and the matching accuracy is better than other similar algorithms, the processing speed reaches 73 per second.

Research limitations/implications – In the algorithm verification of this paper, although the algorithm design and experimental verification are considered considering the diversity of GPS data sampling frequency, the experimental data used are still a single source.

Originality/value – Based on the GPS trajectory data of the Ministry of Transport, the experimental results show that the accuracy of the priority-based weight-based algorithm is higher. The accuracy of this algorithm is over 98.1 per cent, which is better than other similar algorithms.

Keywords Algorithm, Crowdsourced big data and analytics

Paper type Research paper

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1. Introduction

With the increase in car ownership, the application of car networking technology has developed rapidly. Based on the driver's driving behavior data acquired by the vehicle network terminal, vehicle networking insurance services such as vehicle network insurance, traffic supervision, route recommendation, travel time estimation and prediction and urban planning can be carried out. The acquisition of this data is mainly collected by GPS vehicle terminal and on-board diagnostic. However, the existence of positioning error makes it impossible to directly apply it, especially the specificity of some vehicle networking applications, such as transportation. The GPS data of the “two passengers and one danger” national vehicle supervision platform is generally sent every 30 s. It is difficult to accurately match the GPS data and the GIS road network by using the existing map matching algorithm (MMA).

MMA is an algorithm to precisely match the location with the digital map in GIS. At present, a large number of scholars at home and abroad have studied and improved the GPS MMA (Oller0, 2007; Boucher et al., 2013; Paefgen et al., 2014; Perrine et al., 2016). Through analysis and induction, it is found that the existing MMA is applied to vehicle track data with a low sampling frequency (sampling interval of 15 s and above for adjacent points), and its MM precision is low. Marchal et al. (2005) proposed a scoring model for large-scale data. Considering the point-to-segment distance and connectivity principle, a weight formula was set up and the parameter settings were discussed. The results show that the algorithm has good timeliness. Blazquez and Vonderohe (2009) consider the difference of different positioning data, propose a parameter adjustment idea for the MM algorithm of rule decision and find that different parameters have an influence on the matching result accuracy of the positioning data of different sampling frequencies. Mohktari et al. (2014) proposed an integrated-weighted MMA for particle filtering. The algorithm considers two factors: heading angle and speed. It has a good matching effect when the GPS signal is shielded in the case of complex road network. Quddus and Washington (2015) considered the acquisition frequency of GPS data to carry out experiments and proposed an algorithm of MM weight model based on distance and driving direction. Hashemi and Karimi (2016) proposed an MMA with dynamic weight considering the course angle, distance outside the distance and the distance between adjacent points. The above all algorithms have much lower matching precision when applied to GPS points with low sampling frequency. Ming and Karimi (2009) proposed a global map matching method based on markov model for wheelchair navigation (low speed and low sampling frequency). Goh et al. (2012) improved the HMM algorithm based on the state transfer probability determined by SVM and conducted experimental analysis on the same data. The algorithm has high precision but high time cost. Based on this, Raymond et al. (2013) did not consider the information between observation points and directly calculated the distance between the two points as the calculation parameter of the state transition probability, and the experimental results performed better. The above three algorithms are too complex to determine the state transition probability and cannot guarantee the matching precision of the low-frequency sampling points.

Therefore, this paper draws on the idea of the existing MMA, considering the angle between the speed direction and the road traffic direction, and the shortest distance from the point to the candidate road segment. Based on the high-precision GIS electronic map, the two departments for the Ministry of Transport Based on the application range of the algorithm, a map matching based on priority rule (MMPR) is designed and compared. The effectiveness of the algorithm. The innovation of the algorithm lies in:

- MMPR finds the candidate road segment by setting the priority of the factor, which is different from the existing weight algorithm, so that the importance of the two factors of speed direction and distance can be effectively measured.
The innovative MMPR accurately calculates the angle between the speed and the road traffic direction. First, find the closest point to the candidate road segment, comprehensively consider the tangential direction and road traffic type of the point and finally determine the angle between the road traffic direction and the speed direction through angle conversion.

2. Research and design of map matching algorithm

The specific process of the algorithm is as follows: First, the candidate road segment and the electronic map are input, the candidate road segment is determined by the candidate radius and then the angle between the speed direction and the road traffic direction is calculated to find the candidate segment with the smallest angle, and then based on the point to the shortest distance of the candidate road segment finds the best candidate point, and finally the coordinate information of the observation point is corrected based on the coordinate information of the candidate point and the trajectory is drawn. The process essentially repeats the process of iterating forward according to the timestamp of the observation point, and the algorithm ends when all the points match.

2.1 Factor selection

Based on the research status of MMA, it is found that the current map matching mainly considers three factors: speed direction, distance from observation point to candidate point and road accessibility. In this paper, the MMA based on the priority rule first considers the speed direction and, second, considers the distance factor and ignores the road accessibility factor. Next, the factors of the MMA are selected and calculated from the perspectives of the existing algorithms and factor analysis. The limitations of the existing algorithms are analyzed as follows:

- The rule-based comprehensive weight MMA has different advantages and disadvantages. The reason is mainly the complexity of GPS data set and the diversity of road network structure, which makes it difficult to dynamically adapt the weight coefficients of distance and speed direction. Therefore, it is necessary to find an efficient method to measure the importance of the two directions of speed direction and distance. It can be known from the GPS data observation that the distance between the observation points and the real road segment is not the smallest among all the candidate road segments. The fundamental reason is that the error region of the GPS system positioning is an elliptical domain, and the candidate segment is not closer to the center point in the elliptical domain. Therefore, the distance factor is actually less important than the speed angle factor.

- The HMM model solves the map matching problem, and the road accessibility problem is considered in essence. As shown in Figure 1, the frequency statistics of the length of the broken line segment of the electronic map, after statistical analysis of the road network structure of the electronic map, the measurement range fluctuation range of the element of the road segment, that is, a single broken line segment is 0~1000 m. Comparing the distance between the broken line segment of the electronic map and the distance of the adjacent GPS points, it can be found that the reference value of the accessibility factor of the road is unstable. As can be seen from the figure, 95 per cent of the length of a single road segment is distributed at (0m, 200m). Assume that the average speed is \( v = 50 \text{ km/h} \approx 13.8 \text{ m/s} \), then the threshold of the acquisition frequency of the road adjacent to the GPS point is \( f = \frac{200}{13.8} \approx 15 \text{ s} \). Therefore, it can be initially considered: When \( f < 15 \text{ s} \), the GPS
sampling frequency is high, and the adjacent points are close, and the road accessibility is considered to be good. When \( f > 15 \) s, the GPS sampling frequency is lower and the adjacent points are far away, and the road accessibility factor has little reference significance.

If we consider different GPS algorithms for different sampling frequencies to use different algorithms to match, then we need to identify the sampling frequency of GPS points according to time, and then use different algorithms. However, the actual GPS data noise may be large. According to the data observation, the sampling frequency of the GPS point sequence changes, and the time difference of the adjacent points fluctuates between 0 and 30 s. Therefore, for the GPS point with the noise sequence, if the frequency is matched, the switch is switched back and forth. The matching algorithm is obviously less efficient. At the same time, when considering the candidate matching road reachability, if the last point matches the wrong candidate road segment, the next time point will match to the same road segment, so that consecutive multiple point matching errors will occur.

Based on the above analysis, the MMPR algorithm proposed in this section first considers the speed, and secondly considers the distance factor, and the road accessibility factor is not considered in the MMPR algorithm.

### 2.2 Candidate segment selection

The selection of candidate road segments is the first step of map matching. Selecting suitable candidate road segments can improve the computational efficiency of the algorithm on the one hand and improve the matching accuracy on the other hand. The GPS real point generally falls within the elliptical area of a certain length and length axis centered on the observation point. To simplify the calculation, the ellipse area can be abstracted into a candidate circle. By using the observation point as the center of the circle, the buffer is constructed with a certain radius, and the space cross-query operation is performed through the buffer and the road network to obtain the candidate road segment. The calculation method of the candidate circle radius can be calculated according to equation (1):

\[
\rho = \alpha + \omega/2 + \beta - m/2
\]

where \( \alpha \) represents the positioning error of the road network, generally 5m, \( \omega \) represents the width of the road, taking an average of 20m, \( \beta \) is the GPS error, the pseudo-random code C/A used in the civil signal system, the ranging accuracy is 29.3 meters between 2.93 meters, the average error \( \beta = 16m \) can be taken first. \( m \) represents the width of the vehicle, the width of the vehicle is generally 2m, and finally \( \rho = 30m \). After the initial setting of the candidate radius, the adjustment can be made through experimental analysis.
2.3 The angle between the speed direction and the road traffic direction

In the angle design, first find the point closest to the observation point on the candidate road segment, then draw the tangential direction of the curve of the point, and finally use the tangential direction of the point as the direction of the road segment. The range of the velocity direction in the GPS data is $(0, 360^\circ)$; the direction of the passage in the electronic map is represented by an ordered variable. By combining the start and end points of the fold line, the angle between the tangent of a point on the curve and the true north direction can be calculated, and then the difference between the speed direction angle and the absolute value can be used to obtain the angle between the speed direction and the road passing direction (indicated by $\lambda$). The determination of the angle of the road traffic direction (indicated by $\theta$) can be divided into two-way street and one-way street. In the electronic map, the one-way street can be divided into the forward path (the entrance of the road entry in the GIS electronic map is the starting point of the line segment) and the retrograde road (the road entrance is marked as the end point of the line segment in the GIS electronic map); therefore, the determination of the angle can be discussed in three cases.

2.3.1 Two-way street. As shown in Figure 2 (left), the road network in the electronic map is represented by a broken line segment, and the starting point and the ending point are generally marked. On a two-lane road segment, the vehicle can be from the start point to the end point, or from the end point to the starting point. When you do not know that the vehicle is entering from that intersection, you can ignore the difference between the start point and the end point and directly project the observation point vertically onto the line segment, the foot is, and then the tangent of the line segment at the foot point, the angle of the tangent is generally the angle of the horizontal positive direction, expressed by $\theta$, the speed angle is $\alpha$, generally in the GPS receiver is positive The north direction is the baseline calculation.

2.3.2 Antegrade road. As shown in Figure 2 (middle), the vehicle on the forward path travels from the starting point to the end point of the folding line segment. Therefore, the difference between the starting point and the ending point of the folding line segment cannot be ignored, and the finding point is found after the footing point on the candidate road segment. The foot is tangent, and the tangent is directional, and the direction is from the beginning of the fold line to the point of the foot.

2.3.3 Retrograde road. As shown in Figure 2 (right), the vehicle on the retrograde road travels from the end of the folding line to the starting point. Therefore, the difference between the starting point and the ending point of the folding line segment cannot be ignored. After finding the footing point of the observation point on the candidate road section, the foot point is tangent, and the direction of the tangent is from the end of the line segment to the foot point.

The GPS speed direction angle is based on the angle of the true north direction. The horizontal direction of the tangential angle of the road direction obtained by the above

Figure 2. Two-way tangential angle and velocity direction angle
calculation method needs to be converted into an angle with the true north direction to be able to be distinguished from the speed direction angle. Therefore, according to the geometry knowledge, design conversion rules are shown in Table I. The angle \( \lambda \) determined at this time and the road are in the range of \((0, 2\pi)\) and need to be converted to \((0, \pi)\) to participate in the calculation. Therefore, according to the geometric knowledge, the rules for the conversion of the design are shown in Table I.

### 3. Data preprocessing

#### 3.1 GPS track data processing

The GPS data in this paper come from the “two passengers and one danger” data of the Ministry of Communications. The data format is the offline DMP file format, which needs to be imported and reused through the Oracle database. Through data observation, the original GPS data includes 16 field information such as time stamp, latitude and longitude, speed and heading angle. There are data redundancy and data anomalies. Therefore, it needs to be preprocessed as follows.

**3.1.1 Remove data redundancy.** There are serious data redundancy situations in GPS data. There are two main types of situations. The first type of data redundancy refers to the existence of this duplicate record in the original GPS data table. This should be caused by the backup mechanism of the database. This article uses SQL statements to deduplicate in Oracle. At the same time of weight reduction, the massive GPS data is filtered and the GPS data to be used is selected. The second type of data redundancy means that there is no road network structure in the location of the GPS point. This is probably because the team has arrived in an area without a road network structure after work, usually because the GPS receiver has not been turned off after the vehicle is parked. Data are still being collected at this time, but this part of the data does not help map matching. Therefore, to improve the matching efficiency of the algorithm, a spatial query mode is adopted, and once the candidate segment is found to have no matching candidate segments, the deletion operation is performed.

**3.1.2 Abnormal data rejection.** GPS track data anomalies are mainly caused by terminal recording errors or data transmission, and are mainly classified into three types of abnormalities. The first is the abnormal speed extreme value. This kind of data is caused by the recording error. In the actual matching process, the upper limit of the speed can be set by the SQL statement to filter. Second, the latitude and longitude is extremely abnormal. Such data may cause the positioning error to be greater than 100 m due to the presence of the vehicle's surrounding obstructions. The reference data of this type of data in the actual matching process should be eliminated.

<table>
<thead>
<tr>
<th>Road type</th>
<th>Road traffic direction</th>
<th>Conversion formula</th>
<th>( \lambda ) range</th>
<th>Conversion formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-way street</td>
<td>((-\pi/2, 0))</td>
<td>(\pi/2 + \theta)</td>
<td>((\pi, 3\pi/2))</td>
<td>(\alpha - \pi)</td>
</tr>
<tr>
<td></td>
<td>((-\pi/2))</td>
<td>(-\pi/2 - \theta)</td>
<td>((3\pi/2, 2\pi))</td>
<td>(2\pi - \alpha)</td>
</tr>
<tr>
<td>Down the road</td>
<td>((-\pi, \pi/2))</td>
<td>(\pi/2 - \theta)</td>
<td>((\pi, 2\pi))</td>
<td>(2\pi - \alpha)</td>
</tr>
<tr>
<td>Retrograde road</td>
<td>((\pi/2, \pi))</td>
<td>(5\pi/2 - \theta)</td>
<td>((3\pi/2, 2\pi))</td>
<td>(2\pi - \alpha)</td>
</tr>
<tr>
<td></td>
<td>((-\pi/2, \pi))</td>
<td>(3\pi/2 - \theta)</td>
<td>((\pi, 2\pi))</td>
<td>(2\pi - \alpha)</td>
</tr>
<tr>
<td></td>
<td>((-\pi, \pi/2))</td>
<td>(-\pi/2 - \theta)</td>
<td>((3\pi/2, 2\pi))</td>
<td>(2\pi - \alpha)</td>
</tr>
</tbody>
</table>

Table I. Road traffic direction angle conversion
3.1.3 Attribute field filtering. The main fields used in the map matching process include time, latitude and longitude, and speed direction. For unnecessary fields, the filtering operation should be performed to improve the timeliness of the algorithm. The final GPS attributes are shown in Table II.

3.2 Electronic map processing

The data of this article’s electronic map are in industrial-grade shp format vector electronic map, which contains national roads, provincial highways, high-speed, county-level road network information, and takes up about 7 GB of disk space. Imported into the spatial database ArcSDE through ArcGIS software, the road network contains a total of 35 attribute fields. To improve the matching timeliness of the algorithm, the electronic map needs to be processed as follows.

3.2.1 Classification and screening of electronic map attribute fields. The electronic map belongs to spatial data, including spatio-temporal information and attribute information. The spatio-temporal information contains the spatial attributes and geometric topological relations of the map data object and is mainly used to satisfy the calculation requirements, and is automatically generated in the spatial database. The attribute information contains the feature attributes of the features in the map. It is mainly used for display and description. After analysis and filtering, the key road network attribute fields are selected as shown in Table III.

3.2.2 Space clipping of electronic maps. To improve the speed at which the front-end program loads the map, it is necessary to tailor the map. First, select the road network information in Zhejiang, including national roads, national highways and highway networks. Then according to the administrative division and latitude and longitude range of Zhejiang Province (118°-123°E, 27°-32°N), the national electronic map will be cut and the rectangular road network including Zhejiang Province will be obtained, as shown in Figure 3.

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Is it empty</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fstatusdate</td>
<td>Date</td>
<td>Y</td>
<td>Starting time</td>
</tr>
<tr>
<td>Fpassno</td>
<td>Nvarchar2(255)</td>
<td>Y</td>
<td>number plate</td>
</tr>
<tr>
<td>Flongitude</td>
<td>Number(38,8)</td>
<td>Y</td>
<td>longitude</td>
</tr>
<tr>
<td>Flatitude</td>
<td>Number(38,8)</td>
<td>Y</td>
<td>latitude</td>
</tr>
<tr>
<td>Fbearing</td>
<td>Number(38,8)</td>
<td>Y</td>
<td>Direction angle</td>
</tr>
<tr>
<td>Fspeed</td>
<td>Number(38,8)</td>
<td>Y</td>
<td>Velocity</td>
</tr>
</tbody>
</table>

**Table II.**

GPS data sheet

<table>
<thead>
<tr>
<th>Field name</th>
<th>Type</th>
<th>Is it empty</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objectid</td>
<td>Integer</td>
<td>N</td>
<td>Object ID</td>
</tr>
<tr>
<td>Name</td>
<td>Nvarchar2(128)</td>
<td>Y</td>
<td>Road name</td>
</tr>
<tr>
<td>Kind</td>
<td>Nvarchar2(30)</td>
<td>Y</td>
<td>Road grade</td>
</tr>
<tr>
<td>Direction</td>
<td>Nvarchar2(1)</td>
<td>Y</td>
<td>Passage direction</td>
</tr>
<tr>
<td>Snodeid</td>
<td>Nvarchar2(13)</td>
<td>Y</td>
<td>Line starting point number</td>
</tr>
<tr>
<td>Enodeid</td>
<td>Nvarchar2(13)</td>
<td>Y</td>
<td>Line ending point number</td>
</tr>
<tr>
<td>Length</td>
<td>Nvarchar2(8)</td>
<td>Y</td>
<td>Route length</td>
</tr>
<tr>
<td>Speedclass</td>
<td>Nvarchar2(1)</td>
<td>Y</td>
<td>Velocity grade</td>
</tr>
</tbody>
</table>

**Table III.**

Road network attributes field table
3.2.3 Spatial coordinate transformation. The position description of any object requires a reference coordinate system. In the process of map matching, it involves the unification of the spatial coordinate system of GPS coordinates and electronic maps. The map used in this paper is an electronic map of China. The domestic electronic map mainly uses the geographic coordinate system of Beijing 1954 coordinate system or Xian 1980 coordinates. The GPS uses WGS1984 (1984 geodetic coordinate system). The result of this coordinate system is displayed in latitude and longitude and altitude (B, L, H). Therefore, WGS1986 needs to be transformed into a geographic coordinate system. The conversion process is carried out according to equation (2):

\[
X = (M + H)\cos \phi \cos \lambda, \quad Y = (M + H)\cos \phi \sin \lambda, \\
Z = [M(1 - e^2) + H] \sin \phi
\] (2)

In the above formula, \((X, Y, Z)\) represents the coordinates of the geographic coordinate system, and \((\lambda, \phi, H)\) represents the WGS coordinates. After transforming the coordinates of the above formula, the GPS coordinates can be converted into Beijing 1954 coordinate system or Xian 1980 coordinates by referring to the reference plane parameters in the earth ellipsoid data table. After the coordinate conversion is completed and the reference coordinate system is unified, the map matching work can be performed. Otherwise, the GPS display error in the road network will exceed 100 m, so that map matching cannot be performed.

4. Experiment analysis
4.1 Analysis of results
4.1.1 Analysis of overall matching results. Figure 4 shows the overall result of matching GPS traces at low sampling frequencies. Take the trajectory of a certain day of the car as an example. The original data of the day have 2,833 points. After data preprocessing (removing data redundancy), there are 130 points left. The trajectory passes through G15-Shenhai Expressway, G104, S10-Wenzhou Ring Expressway and G1513-Wenli Expressway.

There are 128 points matching the correct MMPR algorithm and 2 points matching the error. The error reason is that the head angle of the GPS point is recorded incorrectly. The
matching accuracy is 98.46 per cent, the matching time is 1.72 s, and the matching speed is 76/s. The computer CPU configuration is I5-5257 dual-core 4 thread 2.7GHZ, based on the .net framework 4.0 component, running in Visual Studio 2010 C# environment.

The weighting algorithm considers the angle between the velocity and the road direction and the distance factor. First, the two factors are normalized. Through iterative experiments, it is found that the weighting coefficient is 0.6 and the distance weighting coefficient is 0.4, which has the highest matching precision. The results show that there are 109 points with correct weight algorithm matching, 21 points with matching errors, matching precision of 83.3 per cent, matching duration of 1.23 s, matching speed of 106/s, and testing under the same environment.

4.1.2 Analysis of local matching results. In Figure 5, the X shape represents the original point, the dot represents the corrected point, the arrow indicates the traveling direction, the green bold curve indicates the traveling trajectory and the other curves indicate the road network.

Figure 5 (left) is the result of using MMPR to match on the road network with roundabouts and parallel roads. There are four points in the figure, all matching to the correct road. Figure 6 (right) is the same weight algorithm. The geographical location is matched, but there is an error in the matching of two points, and one point in the lower left corner matches the roundabout. The reason is that the point is closer to the inner section of the roundabout, and the uppermost point matches the other side of the parallel road. So that
the trajectory on the left side and the trajectory on the right side intersect, the reason for the matching error is that the point is closer to the right-hand road.

Figure 6 (left) is the result of matching the complex intersection using the algorithm of this paper. Figure 6 (right) is the result of matching the same position by the weight method. It is found through observation that the matching points of the matching algorithm in this paper are all matched correctly, and the weighting method has a point on the lower left corner of the island that is misaligned and matched to the adjacent road segment. The reason is that the point is closer to the inner side of the roundabout.

4.2 Algorithm performance evaluation

To eliminate the contingency, the 10-day GPS trajectory data of ten vehicles with low-frequency sampling rate points were selected for experimental analysis. The results are shown in Table IV. The left side of the symbol “||” is the MMPR result, and the right side is the result of the weighting method. The final matching accuracy of the algorithm is 98.10 per cent, the standard deviation is 0.012, the matching duration is 73/s and the standard deviation is 1.748.

To visually represent the effectiveness of the MMPR algorithm, in addition to comparing the performance of the matching results with the weighting method, the calculation results in the two documents are also cited (Ming and Karimi, 2009; Liu et al., 2007). It is GPS data for wheelchair navigation, and the sampling frequency is low. The literature (Liu et al., 2007) collects bus data every 30 seconds, so it is comparable.

It can be seen from the table that the average accuracy of the algorithm is 98.10 per cent, 15.82 per cent higher than the weight algorithm, 2.10 per cent higher than the algorithm in Ming and Karimi (2009) and 0.30 per cent higher than the algorithm in Liu et al. (2007). The algorithm processing speed average reaches 73 points per second; the running speed is
5. Conclusions and discussion
Based on the existing MMA theory, this paper does the following work: A priority-based MMA is designed. On the basis of demonstrating the factors that the angle between the speed direction angle and the road traffic direction is higher than the distance from the point to the candidate road segment, a method for calculating the angle between the speed direction and the road traffic direction is designed and based on the Ministry of Transport. The “two passengers and one danger” GPS trajectory data, the experimental results verify that the accuracy ratio based on the priority ratio weight-based algorithm is higher, the accuracy of the algorithm in this paper exceeds 98.1 per cent, which is better than other similar algorithms. On the physical machine used in the experiment, the map matching speed reached 73 per second.

In the algorithm verification of this paper, although the algorithm design and experimental verification are considered considering the diversity of GPS data sampling frequency, the experimental data used is still a single source. The road network structure that the experimental vehicle trajectory data can match on the electronic map is mainly three kinds of road network structures: national highway, provincial highway and high-speed highway. When the algorithm is applied to inter-city road matching or some other more complex environment, the accuracy and timeliness of the proposed algorithm may be reduced. Therefore, the next research direction is to collect vehicle trajectory data of more complex road network structure for algorithm testing, find the problems in actual matching, find the reason and further improve the algorithm of this paper.
References

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Abstract

**Purpose** – Previous dynamic prediction models rarely handle multi-period data with different intervals, and the large-scale patient hospital records are not effectively used to improve the prediction performance. This paper aims to focus on the prediction of cardiovascular disease using the improved long short-term memory (LSTM) model.

**Design/methodology/approach** – A new model based on the traditional LSTM was proposed to predict cardiovascular disease. The irregular time interval is smoothed to obtain the time parameter vector, and it is used as the input of the forgetting gate of LSTM to overcome the prediction obstacle caused by the irregular time interval.

**Findings** – The experimental results show that the dynamic prediction model proposed in this paper obtained a significant better classification performance compared with the traditional LSTM model.

**Originality/value** – In this paper, the authors improved the LSTM by smoothing the irregular time between different medical stages of the patient to obtain the temporal feature vector.

**Keywords** Cardiovascular disease, Dynamic prediction, LSTM

**Paper type** Technical paper

1. Introduction

Cardiovascular disease (CVD) is a class of diseases that involve the heart or blood vessels (Mendis et al., 2011). CVD is the chronic disease that poses the greatest threat to people, and now it has become one of the leading causes of death around the world (Gibbons et al., 1999). According to data released by the World Health Organization in May 2017, approximately 17.7 million people died of CVD in 2015, accounting for 31 per cent of the global death. Therefore, medical professionals and researchers have carried out extensive studies on the treatments and interventions for CVD (Kagashe et al., 2017; Yan et al., 2016; Zhu et al., 2017).

Unlike acute diseases, there are many stages during the development and evolution of chronic diseases, and the characteristics of chronic diseases vary across stages (Asaria et al., 2007). To take early interventions and maintain the healthiness of patients with CVD, various predictive models were developed to identify high-risk groups or predict the
development of disease. Most previous disease prediction models were based on case-cohort study to investigate the relationship between potential high risk factors and morbidity and mortality (Ganna and Ingelsson, 2015). It is found that body mass index (Rost et al., 2018), waist-hip ratio (Zwakenberg et al., 2018) and sitting time and sitting posture (Howell et al., 2017) have high correlations with the morbidity of CVD. However, due to the high cost of case-cohort study, the training data of these models are insufficient, and the prediction performance needs further improvement.

In recent years, with the development of information technology and the wide application of information systems in medical industry, hospital information system (HIS) has accumulated large-scale and multi-dimensional data including patient demographics, disease symptoms and diagnosis and biochemical indicators (Ahmadi et al., 2017). HIS is an ideal data source to support risk assessment and the development of prediction models of CVD with machine learning algorithms (Goldschmidt, 2005). Long short-term memory (LSTM) is a recurrent neural network (RNN) that is suitable for processing and predicting important events with relatively long intervals and delays in time series. However, in the context of medical industry, the time interval between multiple hospitalizations of patients is different, and the traditional LSTM cannot effectively learn the important characteristics of patient’s medical condition, which limits the practical application of LSTM in medical problems.

In this paper, we improved the LSTM by smoothing the irregular time between different medical stages of the patient to obtain the temporal feature vector. The temporal feature vector is used as the input of the forgetting threshold, which can effectively deal with the irregular time interval between the multi-period data and improve the predictive performance of the model.

2. Literature review
Machine learning algorithms have been used in various fields including disease prediction. Using logistic regression, Zhou et al. constructed a risk score model for type 2 diabetes in middle-aged male populations in rural China (Zhou et al., 2017). Lin et al. considered the problem of co-occurring diseases and constructed a Bayesian multi-task learning model for chronic diseases and their corresponding complications (Lin et al., 2017). To improve the accuracy of prediction, Long et al. proposed a hybrid heart disease prediction method, which combines rough set theory, clustering algorithm, genetic algorithm, naive Bayes and support vector machines, and the model showed obvious advantages over baseline models (Long et al., 2015). Based on electronic medical record data, Ye et al. used the xgboost algorithm to predict the risk of hypertension of patients (Ye et al., 2018).

However, existing models usually take a single period of sample data as input, and ignoring the time-series characteristics of clinical medical data, especially for chronic diseases. Therefore, many studies began to consider the inclusion of time series features in the model of chronic disease static prediction to construct a dynamic prediction model of chronic diseases. Marini et al. used the dynamic Bayesian model to simulate the long-term disease state of type 1 diabetes. The model can dynamically simulate the development of type 1 diabetes and predict future status (Marini et al., 2015). Bueno et al. proposed to use a dynamic Bayesian network to model the patient’s data over multiple periods to study the potential physiological changes that may occur after the patient received the drug treatment (Bueno et al., 2016). Jackson et al. constructed a three-stage hidden Markov model (HMM) to characterize and predict chronic rejection after six months of lung transplantation (Jackson and Sharples, 2002). Forkan, et al. combined the HMM with neural network algorithms to learn and construct the probability of future disease in chronic diseases for elderly people living alone (Forkan and Khalil, 2017). However, both the dynamic Bayesian model and the HMM assume that the time interval between successive observations is fixed, and the
computational complexity increases rapidly as the number of variables increases, which limits the ability to learn complex data.

RNN is a kind of neural network used to process sequential data (Graves et al., 2013b). The network memorizes the previous information and applies it to the calculation of the current output, that is, the nodes between the hidden layers of each segment also establish a connection. In addition, the input of the hidden layer at time step $t$ includes the input of the input layer at time step $t$ and the output of the hidden layer at time step $t-1$ (Graves, 2013a). However, in the process of learning long-term data, RNN may have the problem of gradient disappearing. In light of this, an improved version of RNN named LSTM was proposed to solve the problem of gradient disappearance in the long-dependent learning process by introducing structures of forgetting gates (Graves, 1997).

However, the existing LSTM model also assumes a fixed time interval between different time slices, which limits its practical application in medical problems. In view of the above problems, this paper improves the internal structure of the LSTM unit through parameterizes the time interval between time slices, thus obtaining important information of the influence of time interval on the development of disease.

3. Model framework
This paper investigates how to predict the diagnosis result at time step $t$ ($Y_t$), in the case of a given patient’s records from time step 1 to time step $t$ ($X_1, X_2, ... , X_t$). Among them, the number of records per patient and the time interval between samples $X_{t-1}$, $X_t$, and $X_{t+1}$ could be different.

To use LSTM to process sequence data with irregular time intervals, we first adapt the threshold structure of the LSTM unit to learn the temporal characteristics associated with CVD evolution at different time intervals. After that, we propose to use the target repeat prediction method for the output of hidden layer at each time step, which can simplify the model training process with different lengths of time series. Finally, for the output layer of the model, the Sigmoid function is introduced as the activation function of the multi-tag output, so that the patient’s multiple diagnostic tags are predicted as output. The overall structure of the model is shown in Figure 1.

3.1 Introduction to long short-term memory
A common LSTM unit is composed of a cell, an input gate, an output gate and a forget gate. The cell remembers values over arbitrary time intervals, and the three gates regulate the flow of information into and out of the cell.

Figure 2 shows the structure of a traditional LSTM cell and illustrates the operations of the gates. There are three gates (input, forget and output) in the basic cell of LSTM, and each gate has a sigmoid activation function and a point-wise multiplication operation. The basic cell of the LSTM is defined as the following equations:

$$f_t = \sigma(W_f[h_{t-1}, x_t] + b_f)$$

$$i_t = \sigma(W_i[h_{t-1}, x_t] + b_i)$$

$$o_t = \sigma(W_o[h_{t-1}, x_t] + b_o)$$

where $f_t$ denotes the output of forget gate to the network at time step $t$, where $\sigma$ is the logistic sigmoid function. $i_t$ and $o_t$ denote the output of input gate and output gate,
respectively. \( x_t \) and \( h_{t-1} \) are the input and the previous hidden state, respectively. \( W_f, W_i, W_o, b_f, b_i \) and \( b_o \) are weight matrices which are learned.

3.2 Improved long short-term memory
In the medical situation, patients with chronic diseases will go to the hospital because of the development of the disease, such as deterioration or recurrence. However, different patients may have different time intervals between hospitalizations due to their physical condition, condition, etc., and the difference may range from less than 1 month to several years. The lack of time interval brings certain difficulties and challenges to the study of clinical time series data.

To solve the problem of irregular time interval, we propose to smooth the time interval to obtain the time parameter vector and use it as the input of LSTM forget gate. The improved LSTM cell is shown in Figure 3. We will introduce the forward propagation process of the LSTM network.

The first step in the forward propagation of the LSTM network is the calculation of the forgotten threshold. This threshold determines which of the input information will be forgotten and will not affect future time step. In detail, the time interval between the time step \( t-1 \) and the time step \( t \) is smoothed to obtain a three-dimensional vector, and the time vector is used as an input parameter of the forget gate, as shown in equation (1).
In equation (4), $P_f$ represents a vector after the smoothing of the time interval between time slices, and the smoothing formula is shown in equation (5):

$$p_{\Delta t} = \begin{cases} \frac{\Delta t}{60}, & \frac{\Delta t}{180}, \\ \frac{\Delta t}{365} \end{cases}$$

In equation (5), $\Delta t$ represents the time interval, in units of days. Because patients rarely re-hospitalize in the same month, we choose two months as the denominator, then half a year and one year, making the vector $p_{\Delta t}$ within a reasonable range.

$p_f$ is a connection weight parameter corresponding to the time interval vector, which needs to be optimized for training to handle the memory effect generated by the irregular time interval.

The second step of forward propagation determines what information is saved in the cell state. First, you need to generate a temporary state and then update the old cell state. The formula is shown in equations (6) and (7).

$$\tilde{C}_t = \tanh(W_C[h_{t-1}, x_t] + b_C)$$

$$C_t = f_t \ast C_{t-1} + i_t \ast \tilde{C}_t$$

where $W_C$ and $b_C$ are the connection weight and offset of the temporary state. $\tilde{C}_t$ is a temporary state containing new candidate values. $C_{t-1}$ is the status information of the previous time step. $C_t$ is the state of the time step $t$ after the update.

The third step of forward propagation determines the final network output, as shown in equation (8).

$$h_t = o_t \ast \tanh(C_t)$$

where $h_t$ is the current hidden state, and $h_t$ and $C_t$ will be used as input for the next time step.

### 3.3 Target repeat prediction

When constructing a traditional LSTM network model, generally, only the output prediction of the last time step is given, and the error of the entire network is calculated to update the
network weight. However, when a sample has or is truncated into a short time series, the prediction performance could be worsened.

To solve the above problem, this paper adopts the target repeat prediction method. For the output of the hidden layer of each time step, the prediction probability of the diagnosis is calculated by the Sigmoid activation function, and the prediction loss of each time step is obtained by combining the real classification label. Finally, we use the weighted summation of the prediction loss of all time slices and the prediction loss of the last time slice as a loss function of the entire model to update the parameters of the entire model.

For a single time step, the loss function is calculated as follows:

$$\text{loss}(\hat{y}, y) = \frac{1}{|C|} \sum_{i=1}^{i=|C|} - (y_i \cdot \log(\hat{y}_i) + (1 - y_i) \cdot \log(1 - \hat{y}_i))$$

In equation (9), $\hat{y}$ represents the disease diagnosis classification probability vector calculated by the Sigmoid function in a single time slice, and $\hat{y}_i$ represents the output probability of the corresponding i-th disease diagnosis. $y$ indicates the actual class label of the current sample, and $y_i$ indicates the classification label of the i-th disease diagnosis, taking 0 or 1. $C$ represents the dimension of the classification label vector. The overall loss function for the entire model is shown in equation (10):

$$\text{loss} = \alpha \frac{1}{T} \sum_{t=1}^{T} \text{loss}(\hat{y}^{(t)}, y^{(t)}) + (1 - \alpha) \cdot \text{loss}(\hat{y}^T, y^T)$$

In equation (10), $y^{(t)}$ is the real classification label of time slice $t$, and $\hat{y}^{(t)}$ represents the corresponding classification label prediction probability vector. $\alpha$ is the hyperparameter of the model, which is used to measure the sum of the predicted losses of all time slices and the weight of the last time slice prediction loss for the overall loss of the model.

3.4 Multi-label classification

In actual medical scenes, doctors make a disease diagnosis based on patient's laboratory indicators. Patients may have multiple diseases at the same time, such as coronary heart disease and type 2 diabetes. Thus, we define the disease diagnosis task as a multi-label classification task. This paper proposes a prediction model for multi-label classification, while the traditional model normally handles the single classification problem.

In the selection of the classification label, in addition to CVD, diseases that may cause CVD and diseases that may be caused by CVD are also included (Jonnagaddala et al., 2015), such as hyperlipidemia, diabetes and so on, which can be divided into eight categories ($c_1$, $c_2$, ..., $c_8$). The diagnosis output for each sample is represented as eight-dimensional vectors with Boolean values. The i-th dimensional of the vector is 1 if the diagnosis belongs to $c_i$ and 0 otherwise.

Compared to logistic and Softmax function, all elements in the output probability vector of Sigmoid function are not equal to 1, which is more suitable for multi-label classification problems. Therefore, we use Sigmoid as the activation function of our model. In existing multi-label classification studies, the classification result is the k-value element with the highest numerical value in the output probability vector, and the value of k is determined according to the actual problem (Tsoumakas et al., 2007). In this paper, the average number of labels for all samples is about 3, and k is set to 3.
4. Experiment analysis

4.1 Data description
In the study, we used the data collected from the HIS of a hospital. The data set contained age, sex, 23 test indicators and nine disease diagnosis labels. The specific test indicators we used are shown in Table I. The disease diagnosis labels are shown in Table II. All information of patients that are recorded during hospitalization was identified by the patient ID and hospital ID. The disease diagnosis uses International Classification of Diseases 10th Revision (ICD-10) coding, and the test and inspection items use the system-defined code, which can be uniquely identified.

4.2 Data preprocess
To make the data meet the requirements and specifications, we only keep the records of patients whose “patient ID” and “hospital ID” is non-empty, the number of hospitalizations is more than twice, the “discharge method” is “normal”, “age” is 18 or older, “admission time” and “discharge time” is valid, and the diagnostic records include cardiovascular or related diseases.

After preprocessing, we obtained 12,545 hospital records generated by 3,805 patients collecting from 15 March 1999 to 7 July 2010 and calculated the length of time series for each sample. As shown in Figure 4, the length of samples is mostly concentrated from 2 to 5. Therefore, in the subsequent model training process, we set the maximum length of all samples to be 5. Samples with length less than 5 are complemented by 0, and samples with length longer than 5 are truncated.

The data set consists of 2,176 males and 1,629 females. The age distribution is shown in Table III.

<table>
<thead>
<tr>
<th>Column</th>
<th>Test indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Serum albumin (g/L)</td>
</tr>
<tr>
<td>2</td>
<td>Low density lipoprotein cholesterol (mmol/L)</td>
</tr>
<tr>
<td>3</td>
<td>Triglyceride (mmol/L)</td>
</tr>
<tr>
<td>4</td>
<td>High density lipoprotein cholesterol (mmol/L)</td>
</tr>
<tr>
<td>5</td>
<td>Glutamic-pyruvic transaminase (IU/L)</td>
</tr>
<tr>
<td>6</td>
<td>Glutamic oxalacetic transaminase (IU/L)</td>
</tr>
<tr>
<td>7</td>
<td>Creatine kubase (IU/L)</td>
</tr>
<tr>
<td>8</td>
<td>Creatine Kinase Isoenzyme (IU/L)</td>
</tr>
<tr>
<td>9</td>
<td>Creatinine (umol/L)</td>
</tr>
<tr>
<td>10</td>
<td>Kalium (mmol/L)</td>
</tr>
<tr>
<td>11</td>
<td>Alkaline phosphatase (mmol/L)</td>
</tr>
<tr>
<td>12</td>
<td>Fasting plasma glucose (IU/L)</td>
</tr>
<tr>
<td>13</td>
<td>Chlorine (mmol/L)</td>
</tr>
<tr>
<td>14</td>
<td>Sodium (mmol/L)</td>
</tr>
<tr>
<td>15</td>
<td>Urine-specific gravity (mmol/L)</td>
</tr>
<tr>
<td>16</td>
<td>urea nitrogen</td>
</tr>
<tr>
<td>17</td>
<td>Uric Acid (umol/L)</td>
</tr>
<tr>
<td>18</td>
<td>Urine ph</td>
</tr>
<tr>
<td>19</td>
<td>Globulin (g/L)</td>
</tr>
<tr>
<td>20</td>
<td>Lactic dehydrogenase (IU/L)</td>
</tr>
<tr>
<td>21</td>
<td>Direct bilirubin (umol/L)</td>
</tr>
<tr>
<td>22</td>
<td>Total cholesterol (mmol/L)</td>
</tr>
<tr>
<td>23</td>
<td>Total bilirubin (mg/dl)</td>
</tr>
</tbody>
</table>

Table I.
The missing values of continuous variables are filled with mean values, and the missing values of discrete variables are filled with the majority.

To meet the input requirements of LSTM, we encode classification features using one-hot encoding. On the test project, the mean, maximum and minimum values of the sequence data are extracted to achieve feature extraction and dimensionality reduction.

Different variables have different value range and units, and the value range and unit dimensions have great impact on the weight learning process of the model. Generally, in classification and clustering algorithms, the z-score algorithm is usually used for normalization, which can achieve better results. Therefore, this paper uses the z-score standardization method to preprocess the input data.

4.3 Performance evaluation metrics

This paper focuses on the classification of disease diagnosis, and the classification performance of the diagnosis of different diseases. Therefore, the $\text{Precision}_{\text{micro}}$, $\text{Recall}_{\text{micro}}$,
and \( F_{1\text{micro}} \) are selected as evaluation metrics. These three indicators are adapted from the corresponding single label classification model, and the calculation formulas are as follows:

\[
\text{Precision}_{\text{micro}} = \frac{\sum_{j=1}^{q} TP_j}{\sum_{j=1}^{q} TP_j + \sum_{j=1}^{q} FP_j} \quad (11)
\]

\[
\text{Recall}_{\text{micro}} = \frac{\sum_{j=1}^{q} TP_j}{\sum_{j=1}^{q} TP_j + \sum_{j=1}^{q} FN_j} \quad (12)
\]

\[
F_{1\text{micro}} = \frac{2 \cdot \text{Precision}_{\text{micro}} \cdot \text{Recall}_{\text{micro}}}{\text{Precision}_{\text{micro}} + \text{Recall}_{\text{micro}}} \quad (13)
\]

In addition, the AUC indicator indicates the area under the ROC curve and is often used to evaluate classifier performance. Therefore, in the multi-classification problem of this paper, we use micro AUC as one of the model evaluation indicators.

4.4 Experimental result
LSTM learns the characteristics of data set from training set and predicts the classification labels of new samples. The hyper parameters of LSTM model need to be set. The proposed improved LSTM model is defined as T-LSTM-TR. We train and tune the parameters of our model using 10-fold cross-validation method.

The hyper parameters need to be adjusted and optimized during training process, including the number of hidden layer neurons \( H \), the end time slice loss function weight \( \alpha \) and the dropout parameter. The model is trained by setting different parameter sets separately, and then the test results are compared. Finally, the optimal parameters of the T-LSTM-TR model is set as \( H = 120, \alpha = 0.5 \) and Dropout = 0.4.

This paper selects the traditional LSTM model as the benchmark model for performance comparison. As shown in Table IV, the performance of T-LSTM-TR model proposed in this paper is similar to that of the LSTM model in terms of precision, while the performance of T-LSTM-TR is significantly superior compared to that of the traditional LSTM model in terms of other indicators. The results show that the classification performance of our model is effectively improved by adapting the departmental structure of traditional LSTM unit. As shown in Figure 5, we can more clearly compare the performance of T-LSTM-TR and LSTM through the ROC curve.

For the hidden layer feature processing of all time slices, the average pooling process is an alternative method, and the output prediction result can be obtained using the Sigmoid function. To validate the effectiveness of the proposed target repeat prediction method, we

<table>
<thead>
<tr>
<th>Models</th>
<th>Precision</th>
<th>Recall</th>
<th>F1</th>
<th>AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-LSTM-TR</td>
<td>0.492</td>
<td>0.811**</td>
<td>0.608*</td>
<td>0.896***</td>
</tr>
<tr>
<td>LSTM</td>
<td>0.478</td>
<td>0.754</td>
<td>0.584</td>
<td>0.844</td>
</tr>
</tbody>
</table>

Notes: *\( p < 0.1 \); **\( p < 0.05 \); ***\( p < 0.001 \)
compared the performance of average pooling process and target repeat prediction method. The average pooled model is defined as T-LSTM-MP, and the comparison results are shown in Table V. As shown in Table V, the T-LSTM-TR model obtained higher results compared to the T-LSTM-MP model in all the four indicators, indicating that the target repeated prediction method is significantly better than the average pooling method. As shown in Figure 5, we can more clearly compare the performance of T-LSTM-TR and T-LSTM-MP through the ROC curve.

5. Conclusion
Based on the traditional LSTM, this paper proposed a new model by improving the internal forgetting gate input. First, the irregular time interval is smoothed to obtain the time parameter vector, and then it is used as the input of the forgetting gate to overcome the prediction obstacle caused by the irregular time interval. The experimental results show that the dynamic prediction model proposed in this paper has a significant improvement in classification performance compared with the traditional LSTM model, which verifies the effectiveness of the proposed model.

There are still some limitations in this paper for future studies. First, this paper assumes that the diagnostic labels of the samples are independent to each other, which in fact there are varying degrees of correlation between many diseases. Second, due to the limits of data size, although the model of this paper has a significant improvement over the existing models in the performance evaluation indicators, the model still need further improvement to meet the requirements of practical applications.

<table>
<thead>
<tr>
<th>模型</th>
<th>Precision</th>
<th>Recall</th>
<th>F1</th>
<th>AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-LSTM-TR</td>
<td>0.492***</td>
<td>0.811***</td>
<td>0.608***</td>
<td>0.896***</td>
</tr>
<tr>
<td>T-LSTM-MP</td>
<td>0.478</td>
<td>0.787</td>
<td>0.591</td>
<td>0.879</td>
</tr>
</tbody>
</table>

Notes: *p < 0.1; **p < 0.05; ***p < 0.001
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Alignment of business in robotic process automation

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Abstract

Purpose – This paper aims to find out how business aligns with robotic process automation (RPA) and whether the alignment has the same factors as for IT–business alignment.

Design/Methodology/Approach – Condition configurations for positive and negative impact for business alignment with RPA.

Findings – The positive and negative configurations that possibly impact business alignment with RPA.

Research limitations/implications – There are some human instincts during conditions dichotomization and limited number of cases.

Practical implications – The findings can be used to guide practice application in real industry.

Originality/value – This paper adopted crisp-set qualitative comparative analysis to find condition configurations for alignment of business and RPA for more generalization.

Keywords Robotic process automation, Crisp-set QCA (csQCA), IT–business alignment

Paper type Research paper

1. Introduction

With the development of science and technology, the automation technology, as the most possible way to replace human workers, has become mature. Robotic process automation (RPA) is a software robotic tool that can mimic human actions with computer systems to automate repetitive tasks (Oliveira, 2016). It is the most mature solution and has attracted enterprise managers’ attention. Some studies have focused on the IT–business alignment that IT and business aligned into one whole together (Baker et al., 2011; Sabegh and Motlagh, 2012). From these research studies, five possible key factors can be found: environmental shift, sustained low performance, influential outsiders, new leadership and perception transformation (Sabherwal et al., 2001).
How does business align with RPA? To answer this question and to summarize the RPA–business alignment key factors, this research is based on IT–business alignment theory and literatures to.

2. Literature review
2.1 Robotic process automation
RPA is a software robotic tool that automates routine tasks (Berruti, et al., 2017; Oliveira, 2016). It is proved by scholars to be an effective way to cut costs (Hellström, 2016). Some studies have begun to explore the possible way to deploy it based on some real experiences.

RPA, as the replacement of human worker, can be deployed in many industry areas, for example, financial (Lacity et al., 2017; Mary et al., 2016), telecommunication (Lacity et al., 2015a, 2015b), business process outsourcing (Lacity et al., 2016a, 2016b), education (Herbert, 2016), banking (Willcocks et al., 2017) and legal (Holder et al., 2016). Most empirical studies have assessed the possible ways for and obstacles to RPA deployment in the real industry. These studies are based on case studies. From empirical studies, researchers can find the key factors that aligns business with RPA.

2.2 IT–business alignment
The definition of IT–business alignment is applying IT in an appropriate and timely manner to harmonize with business strategies, goals and needs. The alignment addresses both how IT is in harmony with business and how business should or could be in harmony with IT (Luftman, 2004). The famous IT–business alignment model – strategic alignment model (SAM) – includes four fundamental domains: business strategy, information technology strategy, organization infrastructure and process and information technology infrastructure and process (Henderson and Venkatraman, 1999). The SAM model consists of six dimensions, including communications, competency/value measurement, governance, partnership, scope and architecture and skills (Luftman, 2004; Luftman and Kempaiah, 2007).

There are two kinds of traditional IT–business alignment theories. One theory is that if IT and business are aligned, it can achieve the end-to-end close connection at strategic, organizational and operational levels (Baker et al., 2011; Sabegh and Motlagh, 2012) to improve finance performance and catch competency advantage. The other theory is IT–business alignment needs more investment for reconstruction in infrastructure, organization and business process reengineering. If IT–business alignment is a failure, the IT initiatives will also be failure (Ravishankar et al., 2011) and will impact business performance (Chan et al., 1997). Even if there is “the alignment paradox” that better IT alignment cannot lead to business gains because of a too inflexible IT backbone (Tallon, 2003).

The latest studies are based on a punctuated equilibrium theory that recognizes that alignment is not a static event but a process of continuous adaption and adoption (Sabherwal et al., 2001). There are five possible antecedents of revolutionary change: environmental shift, sustained low performance, influential outsiders, new leadership and perception transformation. In another research result, two more antecedents were added: government support and organizational inertia (Wang et al., 2011).

2.3 Literature review summary
From review result, the existing RPA literatures are based on case studies or concept explorations that have special backgrounds and these studies lack generalizations. This
research aims to find out the key factors for business–RPA alignment in generality and whether they are the same key factors for IT–business alignment.

3. Empirical study
3.1 Research method
Qualitative comparative analysis (QCA) is a methodology for obtaining summarizations from cases. This based on set-theoretical logics method can characterize through causal asymmetry and well applicability of small-N sample sizes because causal conditions or combination conditions can lead to an equifinality (Ragin, 2014; Fiss, 2007).

There are three types of QCA: crisp-set QCA (csQCA) (Ragin, 2014), fuzzy-set QCA (fsQCA) (Ragin, 2009) and multi-value QCA (mvQCA) (Berg-Schlosser and Cronqvist, 2005). The csQCA handles the variable as “0” or “1” dichotomous variable and allows researchers to directly compare statistical techniques to better. The fsQCA is an extension of csQCA, which investigates how causal relationships are dependent on non-contextual conditions, and is more closed to statistical approaches. It provides a flexible tie between qualitative and quantitative characteristics because of variables that show a continuous degree of “belonging” or “membership.” A fuzzy-set variable changes continuously in a 0-1 closed interval. The mvQCA is another extension of csQCA. It allows some explanatory conditions to have more than two values and can be viewed as the middle-way between csQCA and fsQCA.

QCA can bridge the gap between qualitative and quantitative approaches with small-N cases support. This research will use the csQCA method to identify whether antecedents are the same key factors for the RPA-business with IT-business history researches.

3.2 Data source
For this research, the data sources are the literatures and RPA websites. First, by searching Google Scholar with the keywords “Robotic Process Automation” from 2015 to present with English or Chinese language, there are total 263 studies. Then searching public website with the keywords “Robotic Process Automation” from the year 2015 to present also. After a full review, there were 21 companies to be studied, as shown in Table I.

3.3 Conditions definition and dichotomization
The first step of the QCA method is antecedent definition by the inductive or deductive approach (Ketchen et al., 1993). For this research, the deductive approach is applied. By reviewing literatures about the IT–business alignment, five possible antecedents of revolutionary change were found: environmental shift, sustained low performance, influential outsiders, new leadership and perception transformation (Sabherwal et al., 2001). There are two more antecedents, government support and organizational inertia, that may impact IT–business alignment (Wang et al., 2011), as shown in Table II. The next step is the condition setting or dichotomization, as can be seen in Table III.

3.4 Outcome definition and dichotomization
Delphi as a qualitative method is suitable for achieving consensus from a panel of consultants to address the maturity level. The same evaluation procedure is used to find business alignment with RPA maturity level (Assessing Business-IT Alignment Maturity,
### Table I. RPA adoption reference cases

<table>
<thead>
<tr>
<th>Reference topic</th>
<th>Object company</th>
<th>Author or source</th>
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</thead>
<tbody>
<tr>
<td>RPA at Xchanging</td>
<td>Xchanging</td>
<td>Willcocks et al., 2015</td>
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<td>Robotizing global financial shared services at Royal DSM</td>
<td>Royal DSM</td>
<td>Lacity et al., 2016a, 2016b</td>
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<td>Service automation: cognitive virtual agents at SEB Bank</td>
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<td>Annu et al., 2016</td>
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<td>Lacity et al., 2016a, 2016b</td>
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<td>RPA at Telefónica O2</td>
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<td>Lacity et al., 2015a, 2015b</td>
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<td>Employing US military families to provide business process outsourcing services: a case study of impact sourcing and reshoring</td>
<td>Liberty Source</td>
<td>Lacity et al., 2016a, 2016b</td>
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<td>RPA: mature capabilities in the energy sector</td>
<td>European energy supplier</td>
<td>Lacity et al., 2015a, 2015b</td>
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<td>Vodafone Shared Services: exploring RPA opportunities</td>
<td>Vodafone Shared Services (VSS)</td>
<td>Salvatore, 2016</td>
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<td>RPA for real: Ascension Health takes on leading role</td>
<td>Ascension Health</td>
<td>Hanna, 2016</td>
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<td>The rise of robots</td>
<td>BNY Mellon</td>
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<td>Strategy symposium of SINOCHEN Group was held</td>
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<td>Union Bank accelerates time to revenue for mortgage loans</td>
<td>MUFG Union Bank</td>
<td>KOFAX, 2017a, 2017b</td>
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<td>RPA enables 100% process efficiency and 45% cost reduction in AP for global plastic manufacturer</td>
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<td>Auxis, 2017</td>
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<td>Wipro’s success through hyper automation</td>
<td>Wipro limited</td>
<td>Obtv-admin, 2016</td>
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<td>Global convenience: Jacob Schram</td>
<td>Circle K</td>
<td>CEO Magazine, 2017</td>
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<td>Accenture and Blue Prism team to provide RPA to help clients accelerate business results, improve employee and customer experience</td>
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<td>Accenture, 2017</td>
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<td>Rise of the machines as ANZ brings in robot workers to do the ‘boring’ jobs</td>
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<td>DBS Bank accelerates digitalisation transformation with robotics program</td>
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### Table II. RPA–business conditions form

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Labels for conditions</th>
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<tr>
<td>Environmental shift</td>
<td>ENVSHI</td>
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<tr>
<td>Sustained low performance</td>
<td>LOWPER</td>
</tr>
<tr>
<td>Influential outside</td>
<td>INFOUT</td>
</tr>
<tr>
<td>New leadership</td>
<td>NWLDER</td>
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<tr>
<td>Perception transformation</td>
<td>PERTRA</td>
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<tr>
<td>*Organizational inertia</td>
<td>*ORGINE</td>
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<tr>
<td>Outcome</td>
<td>RBALIG</td>
</tr>
</tbody>
</table>

29
2000). Two IT consultants with 15 years of experiences each in the enterprise IT field evaluated the alignment level with an average result. The outcome (RPA–business alignment [RBALIG]) set 1 when the level is above level 2, otherwise the outcome (RBALIG) set 0 in Table IV.

3.5 Calculation procedure

Every case is equally important for theory exploration. There will be contradiction configuration in certain situations. Researchers need a base on the real cases to

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Threshold of the condition dichotomization</th>
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<tr>
<td>ENVSHI</td>
<td>Environment or business strategy change = &gt;1, else 0</td>
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<tr>
<td>LOWPER</td>
<td>Shrink market share or reduced profits = &gt;1, else 0</td>
</tr>
<tr>
<td>INFOUT</td>
<td>Macro-environment change or policy change &gt; 1, else 0</td>
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<tr>
<td>NWLDER</td>
<td>Leadership or report process change = &gt;1, else 0</td>
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<tr>
<td>PERTRA</td>
<td>Realize the digital transformation = &gt;1, else 0</td>
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<tr>
<td>*ORGINE</td>
<td>The barrier to organization change = &gt;1, else 0</td>
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<tr>
<td>RBALIG</td>
<td>IT–business maturity level above level 2 = &gt;1, else 0</td>
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Table III. RPA–business conditions dichotomization threshold

<table>
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<tr>
<th>Communications</th>
<th>Competency/ value measurement</th>
<th>Governance</th>
<th>Partnership</th>
<th>Scope and architecture</th>
<th>Skills</th>
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<th>Outcome (RBALIG)</th>
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Table IV. RPA–business alignment maturity evaluation result

summarize the generalization with previous results to resolve the contradiction (Ragin, 2014; Fiss, 2007). The environment condition and outside have some overlap, for example, the business strategy shift may impact some outsider factors. So, the condition influential outsiders (INFOUT) can be replaced by organization inertia (ORGIN), as shown in Table V.

With the help of TOSMANA 1.5 software, the csQCA calculation finds the conditions combination that can drive business alignment with RPA and solve the contradiction. Finally, there are 11 configurations, as can be seen in Table VI.

4. Conclusion

4.1 Positive result

To minimize with tools, there are two possible configurations that may prompt business alignment with RPA (Table VII):

First, the new enterprise strategy with new leadership that has a digital-transformation perception can prompt RPA–business alignment. Managers realize the digital prompt enabler to the enterprises, they will make the alignment quicker and better.

Second, low performance with stable leadership that has a digital-transformation perception can also prompt RPA–business alignment. When financial results or market shares are down, the leadership will think about the future and a method that can improve this. If the managers also have a digital view and transformation perception, business alignment with RPA can be prompted.

<table>
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<tr>
<th>Case ID</th>
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<th>LOWPER</th>
<th>ORGIN</th>
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4.2 Negative result

To minimize with tools, there are three possible configurations that may slow down business alignment with RPA (Table VIII):

First, digital-transformation perception can be a negative factor that can slow RPA–business alignment; enterprises do not realize the power of digital transformation for revolutionizing industries. There are many facts to prove this.

Second, when an enterprise’s financial performance or market share is down, even if there is stable leadership, RPA–business alignment can slow down because managers’ first priority would be to improve performance. Business is the root of an enterprise.

Third, a business strategy adjustment with stable leadership and small organization inertia may also slow down RPA–business alignment. The enterprise/organization strategy orients operations daily. The strategy change is at a high level so that it may result into some turbulence for the enterprise/enterprise. Finally, it will slow RPA–business alignment.

<table>
<thead>
<tr>
<th>Case ID</th>
<th>ENVSHI</th>
<th>LOWPER</th>
<th>ORGIN</th>
<th>NWLDER</th>
<th>PERTRA</th>
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**Table VI.**

Configurations true table without contradiction


**Table VII.**

Configurations true table without contradiction

**Note:** Minimizing: 0 Including: 0 C

**Table VIII.**

Configurations true table without contradiction

**Note:** Minimizing: 0 Including: R
Robotic process automation

5. Future research
RPA aligns with business to make enterprises achieve more productivity and better quality. By adopting RPA, organizations will enjoy a “Triple win” from automation (Fig 2): a win for customer, a win for employees and a win for stakeholders. Finally, RPA—business alignment can definitely improve business performance.

Future research on RPA implications can be from the perspective of the customer or stakeholder or business performance.

References


Further reading


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Intelligent transaction: definition, modes, and research directions

Leiju Qiu, Yang Zhao, Qian Liu and Baowen Sun

China Center for Internet Economy Research, Central University of Finance and Economics, Beijing, China, and

Xiaolin Wu

Department of Finance, China Mobile Communications Group Co. Ltd, Beijing, China

Abstract

Purpose – In the crowd intelligence networking era, the smart connections of human, machines and things enable point-to-point trustable transactions and distributed efficient collaboration; the smart connections among government, enterprises, organizations and the public would enable active participation of the public in society management and decision-making and improve the efficiency of government management and services. All interactions among various agents can be viewed as the transaction activity. The social division of labor system drives the evolution of transaction. The transaction mode also differentiated into different patterns with the development of human society. What will be the intelligent transaction in the crowd intelligence networking era? What will be the transactions modes and rules in the crowd intelligence networking era? The answers to these questions are of great importance to the future development of transactions.

Design/methodology/approach – The authors review the evolution of traditional transaction and transaction modes and analyze the driving forces of it. They attempt to give the definitions of intelligent transaction and intelligent transaction mode. They also review the traditional transaction modes and rules, analyze the characteristics of the intelligent transaction and classify the intelligent transaction modes.

Findings – The authors find the intelligent transaction is mainly reflected in the intellectualization of transaction subject, transaction object and transaction process. They summarize the characteristics of intelligent transaction and develop four modes for the intelligent transactions based on the modularization level of the transaction objects and the quantity of transaction subjects, including the demand side and the supply side. The authors also show representative examples to further illustrate rules and features of these transaction modes and point out the potential research directions.

Originality/value – This study is among the first to analyze the characteristics of the intelligent transaction, and the proposed division framework of the intelligent transaction modes could not only add value to the future research of intelligent transaction modes and rules but also help to guide the transactions in the crowd intelligence network.

Keywords Crowd science, Crowd intelligence network, Intelligent transaction, Transaction mode, Transaction rule

Paper type Conceptual paper

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1. Introduction

With the breakthrough and continuous development of the new generation of information technology, such as internet of things, cloud computing, big data and artificial intelligence, the future society is becoming an intelligent interconnection system, which is open, ecologcial, large-scale and self-organized, known as “crowd intelligence network” (Chai et al., 2017). The crowd intelligence network is a fusion system comprised with physical space, information space and conscious space. Due to the interactions of the above components that conform to different laws of movement, the behavioral results of crowd intelligence networks express the following characteristics: the unity of stability and mutation, the unity of order and disorder, the unity of determination and randomness, the unity of heter-organization and self-organization, the unity of knowable and unknowable and the unity of controllability and uncontrollability. These changes will have subversive effect on the future industrial structure and industrial forms, resulting in the individuation of products, the decentralization of production, the miniaturization of government and the publicity of means of production.

In the crowd intelligence networks, all kinds of interactions between intelligent agents can be regarded as some form of transaction (Chai et al., 2017). Compared with traditional transaction, transactions in crowd intelligence networks express the following characteristics. The first one is the diversity of transaction subject. In addition to individuals and institutions, the intelligent goods are taking a more and more important role as emerging transaction subject. The second one is the richness of transaction object. Under crowd intelligence networks, the transaction object includes both product and service, and information and conscious. The third one is the variety of transaction forms. Most of the traditional transactions are between individual and individual. While, the transactions under crowd intelligence networks include both the interactions among individuals and transactions between individual and crowds, and transactions among crowds. The above characteristics may breed different transaction mode and transaction rules, which consequently bring different transaction structure, transaction efficiency and transaction effect. Since now, the study of crowd intelligence networks is still in the exploration stage, and there is no consensus on the universally mechanism or law behind various crowd intelligence phenomena. What’s more, discussion on the transaction modes and transaction rules under crowd intelligence networks is still blank.

To better understand the transactions in the crowd intelligence networks, this paper reviews the evolution of transaction and finds the driving force of transaction evolution is the social division of labor system. We review the transaction modes and discover the differentiation mechanism of them underlies in the transaction cost, efficiency and risk. Based on them, we attempt to give the definitions of intelligent transaction and intelligent transaction mode. The intelligent transaction is mainly reflected in the intellectualization of transaction subject, transaction object and transaction process.

Focusing on the modes and rules of intelligent transaction in crowd intelligence networks, this study also innovatively proposes the concept on the division of transactions, and further uses this concept to deconstruct the connotation of “crowd.” We divide the mode of intelligent transaction into four categories, which are single-demand- single-supply mode (S-S), single-demand-multi-supply mode (S-M), multi-demand- single-supply mode (M-S) and multi-demand-multi-supply mode (M-M). Furthermore, this study discusses the general and special transaction rules for different transaction modes and provides further illustrations in combination with
representative examples. This study tries to extend the discussion of transaction modes and rules to the crowd intelligence networks and to provide a basis for the further research on transaction structure and transaction efficiency.

The remainder of this paper is arranged as follows: Section 2 reviews the driving force of transaction evolution. Section 3 analyzes the differentiation mechanism of transaction mode. Section 4 defines the intelligent transaction and intelligent transaction modes. Section 5 introduces the classification framework and rules of intelligent transaction mode in the crowd intelligence networks. Section 6 is the research conclusion and prospect.

2. The driving force of transaction evolution
2.1 The definition of transaction
In general, transaction is an act in which one party gives one right in exchange for another (He, 2010). The above definition implies that there are three elements in a transaction: the subject of transaction, the object of transaction and the process of transaction.

The subject of transaction refers to the individuals or organizations involved in a transaction. Traditionally, there are two kinds of subjects in a transaction: the buyer and the seller. But in modern times, the technological progress promotes multi-agent collaboration, which results in the diversification trend of subjects of transactions.

The object of transaction refers to the things exchanged by the subjects of transaction. Essentially, the object of transaction is a kind of value or right, but it has different forms of expression. Traditionally, they are physical goods or services; while at present, most of them are digital goods or information.

The process of transaction defines how the object of transaction transfers from one party to another. It includes a wide range of connotations, such as how to match the supply and the demand, how to determine the price, whether through an intermediary and so on.

2.2 The evolution of transaction
In the long history of human society, transaction is not the inherent social behavior. In the primitive society, it was only a casual exchange between tribes. And for quite a long time, transactions are carried out in the form of difficult barter exchange, until money was created and widely used as a trading intermediary. At present, transaction has become the frequent social behaviors among individuals or organizations and has developed into a convenient commodity circulation. Through the review of the history, we conclude that the evolution of transactions is mainly carried out in the following three aspects.

The first is that the scope of the transaction subjects is becoming wider and wider. In primitive and agricultural societies, transactions are mainly carried out within the nearby regions. While after the great geographic discovery, transactions began to break through the geographical restrictions. And today, a global trading system has been fully established.

The second is that the types of transaction objects are becoming more and more abundant. Traditionally, the objects of transaction are mainly physical commodities and services. While in nowadays, various transaction objects are emerging, such as information, knowledge, emotion and so on. In short, all things with value have the potential to become transaction objects.
The third aspect is about the transaction process. Different from the above two aspects, there is no fixed trend in the evolution of transaction process. In some area, the process is becoming simpler (such as e-business commerce), while in other area, it is becoming more complex (such as modern financial derivatives). For some transaction, the degree of intermediation is getting higher and higher (such as the external audit), while for other transaction, it shows de-intermediation tendency (such as P2P lending). But there is still some consensus, especially in the era of digital economy, including intellectualization, personalized, visualization credibility and dynamic.

2.3 The driving force of transaction evolution
Reviewing the history of transaction, one interesting question would be: what drives the evolution of transaction? The answer to this question will help us to understand the development of transaction in the future.

We believe that the core driving force determining the evolution of transaction is the social division of labor system, which is determined by the social productivity. In the primitive society, the extremely under-developed productivity led to the situation that human beings can only survive in the way of group cooperation, production and consumption had not yet been separated, and transaction was in the embryonic state. During the period of agricultural revolution, the progress of productivity brought about three social divisions of labor (animal husbandry, handicraft and commerce separate form agriculture). For the first time, the production and consumption of commodities were separated, resulting in the need for exchange among individuals with different skills to survival. Since then, transactions have sprung up. During the period of commercial revolution, the progress of compass and shipbuilding technology promoted the great geographical discovery, which led to the integration of America, Africa, Asia and Oceania into the global division of labor system, and the indeed international trade was rising. During the period of industrial revolution and electric revolution, the progress in science and technology continuously promoted the development of social productivity, which further expanded the scope and depth of social division of labor, resulting in the enrichment of transaction content and diversification of transaction modes. The social productivity and division of labor system will form the transactions in the intelligence era.

3. The differentiation mechanism of transaction mode
Another phenomenon we have observed is that under a given system of productivity and division of labor, different groups have different transaction modes for different goods/services. To understand the differentiation of transaction patterns, we need clarify the following issues.

3.1 The definition of transaction mode
What is transaction mode? Although there are many appellations in business world, there has been a lack of clear definition in academia. One of the closest terms comes from the management discipline, that’s business mode, which is defined as the way enterprises create and deliver value to their customers (Johnson, 2010). But the emphasis of business mode is completely different from that of transaction mode. We try to define the connotation of transaction mode using reductionism method.

First, what is mode? Mode is the general way of subjects’ behavior, which has the characteristics of generality, simplicity, stability and structure. At the philosophy level,
mode is a subjective explanation of the structure of things, and it is an abstract summary of phenomena. Referring to the above definition, transaction mode is the subjective summary of the structure of transactions. According to the viewpoint of systematics, structure is the organizational mode of elements. While, the elements of transaction include transaction subject, transaction object and transaction process. Hence, transaction mode can be defined as the way by which value exchanges between transaction subjects. It is a formal summary of the transaction structure.

3.2 Typical patterns of transaction mode

Because transaction elements include transaction subject, transaction object and transaction process (pricing method, delivery time, contract relationship, etc.), the specific form of transaction mode can be summarized from three dimensions: transaction subject, transaction object and transaction process.

As to transaction subjects, transaction mode can be classified into B2B, B2C, C2C and some variant mode, such as C2M, C2B2C and B2B2C. The B2B mode refers to the transactions between the enterprise and the enterprise. The B2C mode refers to the transactions between the enterprise and the individual. The C2C mode refers to the transactions between the individual and the individual (Brynjolfsson and Smith, 2000). C2M (transaction between individual and manufacturer), C2B2C (transactions among individual and enterprise) and other variant mode are extended based on the specific characteristics of the transaction subject and the characteristics of the transaction process.

As to transaction objects, transaction mode can be divided into wholesale mode and retail mode (Kotler and Armstrong, 2010). The wholesale mode refers to the transaction of goods or services that are bought for the purpose of reselling or for the specific use of enterprises. The retail mode refers to the transaction of goods or services that are bought by the end consumers, for non-commercial purposes.

As to transaction process, transaction mode can be divided through different dimensions:

- According to whether there is platform intervened in the transaction process, transaction mode can be divided into platform mode and non-platform mode. The platform mode refers to transactions that supply side and demand side reach a transaction through the matching and security mechanism provided by the online virtual platform (Choudary et al., 2016).

- According to the difference of delivery time of goods and services, transaction mode can be divided into spot transaction, forward transaction and future transaction (Baba et al., 2012). Spot transaction refers to the way of buying or selling a commodity, security or currency for immediate settlement. Forward transaction refers to the transaction between buyers and sellers who sign a forward contract and stipulate a transaction at a certain time in the future. Future transaction refers to a standardized and legal agreement to buy or sell something at a predetermined price at a specified time in the future.

- According to whether there is a change of the real right of the transaction object, transaction mode can be divided into ownership transaction and usage right transaction. The ownership transaction refers to the transaction which is accompanied with the transfer of rights of possession, usage, benefits and disposition. The traditional trade of goods and services are mostly belonging to the ownership transaction. The usage right transaction refers to the transaction that only transfers the right to use the transaction object, while the right of possession, benefits and disposition are still belong to the initial
owners. The emerging sharing economy is mostly belonging to the usage right transaction (Sundararajan, 2016).

- According to the difference of pricing methods, transaction mode can be divided into static pricing transaction and dynamic pricing transaction. The static pricing transaction refers to the transaction that the price of goods or services does not vary with the fluctuation of supply and demand. The dynamic pricing transaction refers to the transaction that the price is changing dynamically with variety of the supply and demand, and the typical representative is auction. An auction is a process of buying and selling goods or services by offering them up for bid, taking bids and then selling the item to the highest bidder (Myerson, 1981).

3.3 The differentiation mechanism of transaction mode
Essentially, the driving forces behind the differentiation of transaction mode may include the following three categories.

The first one is transaction cost. Transaction cost mainly examines the effect of transaction from the economic dimension. For example, in the period of commercial revolution, the expansion of transaction scope and scale made the cost of long-distance transportation of currency rising rapidly. To reduce transaction cost, bill business replaced cash business as the mainstream form of cross-regional transactions.

The second one is transaction efficiency. Transaction efficiency mainly examines the effect of transaction from the time dimension. For example, in the period of agricultural revolution, the development of productivity and social division of labor increased the frequency of trade and the inefficiency of traditional barter trade resulted in the emergence of exchange medium, currency. As a general equivalent, currency greatly improved the efficiency of transaction matching and ultimately promoted the transformation of transaction mode from direct transaction to indirect transaction.

The third one is transaction risk. Transaction risk mainly examines the effect of transaction from the dimension of uncertainty. For example, the expansion of production scale leads to the rapid increasing of transaction scale, and the procurement cost of raw materials becomes a major burden for enterprises. And the price fluctuation of spot transactions becomes unbearable. To avoid price risk, various forward contracts have been created, and the mode of commodity trading has been changed from spot transaction to forward transaction.

4. Intelligent transaction
Intelligent transaction is defined as the process of realizing intelligent matching between supply and demand interaction activities among transaction subjects. Intelligent transaction is mainly reflected in the intellectualization of transaction subject, transaction object and transaction process.

The intellectualization of transaction subject refers to the improvement of intelligence of individuals, enterprises, institutions and governments. Individuals, enterprises, institutions and governments have become the intelligent digital entities in the crowd intelligence space by means of mapping. The formation of intelligent digital entity is the process of merging the physics, consciousness and information of the transaction subject. Figure 1 illustrates the intellectualization of transaction subject. The transaction subject as the basic attributes (e.g. gender, age, height, weight, location, intelligence level; scale, rating, position, structure, etc.) and ability attributes (e.g. skills, physical strength, price, product capacity, production
arrangement, function, etc.) of the physical entity realize informatization in the crowd intelligence space by means of mapping. At the same time, the consciousness of the transaction subject also realizes informatization in the crowd intelligence space by means of mapping. The consciousness is represented by the preference attributes, including quality, speed, price, friend evaluation and so on. The informatization of the physical and conscious characteristics of the transaction subject is integrated with its information characteristics to form an intelligent digital entity. As the intelligent digital entities carries out transaction activities in the crowd intelligence space, its intelligence realizes spiral promotion, which in turn reshapes and improves the physical entities and learns and corrects the consciousness preference. The physical entity of a transaction subject is interdependent with its consciousness preference.

The intellectualization of transaction object refers to the improvement of physical objects, services, virtual (or digital) products, which is embodied in the intellectualization of object generation, production and matching transaction subjects. Figure 2 illustrates the intellectualization of transaction object. The physical attributes of the transaction object form an intelligent digital entity in crowd intelligence space by means of mapping. Take physical products as an example, including location, materials, price, color, function and evaluation; take digital products as an example, including price, function, format and...
evaluation; take service products as an example, including location, price, function and evaluation. The feedback of intelligent digital entity modifies the transaction object, including the description of the modified attributes and modifying evaluation.

The intellectualization of transaction process refers to the intellectualization of transaction search, negotiation, implementation and supervision. Figure 3 illustrates the intellectualization of transaction process. The first step to realize intelligent transaction is the intelligent identification of the transaction subject by the intelligent digital entity, and the accurate identification of the fuzzy demand and supply of the transaction subject, which is embodied by clarifying the basic attributes, ability attributes and preference attributes of the transaction subject. Intelligent digital entity can play both the role of demand side and the role of supplier to achieve accurate intelligent matching of comprehensive information in crowd intelligence space. As a supplier, the intelligent digital entity collaborates to realize intelligent production and generate transaction object. Then, the intelligent logistics system forms an optimal path decision to implement intelligent delivery of the transaction object. Intelligent feedback and evolution, which automatically provides feedback to all transaction stakeholders based on transaction evaluation information and promotes the evolution of the entire crowd intelligence network.

5. Intelligent transaction mode
In the crowd intelligence networks, the interaction among various agents can be attributed to a certain transaction activity or behavior. Compared to the traditional transaction, intelligent transaction presents significant differences in the three aspects of transaction, including transaction subject, transaction object and transaction process. First, the intelligent transaction subject is more pluralistic. In the traditional transaction mode, the category of the transaction subject is limited to the individual and the enterprise. In the crowd intelligence networks, however, the individual, the enterprise, the organization and the goods are all transaction subjects with independent portals, which can play the role of both supply and demand side in the specific intelligent transaction.

Second, the intelligent transaction object is more abundant. The connotation of traditional transaction is narrow. It commonly refers in particular to economic transaction and appears as the buying and selling of goods and services. However, the transaction object in the crowd intelligence networks includes not only goods and services but also any
other interactions among the intelligent agents, such as information exchange, emotion interaction, public affairs and political consultation. Some of the transaction object is indivisible and not accumulative, e.g. the quality of air. The production or delivery of the transaction object can be divided to certain extent into different modules, which is so called the modularization. Different transaction objects have different modularization level according to different indivisibility in the production or delivery of them.

Third, the intelligent transaction process is more intelligent. The intelligentization of transaction process in the crowd intelligence networks is embodied in two levels. One is the intelligentization of a single transaction, which mainly refers to the adoption of the new generation of information technology, such as the internet of things, cloud computing, big data, etc., to reduce transaction cost and improve transaction efficiency. The other is the intelligentization of multiple transactions, which mainly refers to the intelligent coordination when single agent processes multiple transactions concurrently. At this level, the optimal problem is raised from the local transaction to the overall transactions.

Existing literature has conducted a lot of discussion on the transaction mode and formed some common agreement on transaction modes. However, these transaction modes are based on the traditional transaction environment, and we encounter some challenges when extend the previous findings to the crowd intelligence networks. First, in the existing literature, the word “transaction” usually refers to economic activities. While in the crowd intelligence networks, transaction means all the interactions between intelligent agents (Chai et al., 2017). Therefore, the division of transaction mode should include not only economic activities but also non-economic activities, such as corporations and public affairs. Second, the existing classification of transaction mode excessively depends on specific scenarios, and there is no general classification framework. While in the crowd intelligence networks, we will need a more universal framework to guide our analysis of transaction structure and efficiency.

5.1 Division framework of intelligent transaction modes
In the intelligent transaction, the essential relationship between various agents (individuals, enterprises, institutions and goods) in the crowd intelligence networks is still supply and demand, while the challenges lie in the distinguishing features of transaction subject, transaction object and transaction process. Because the transaction subject is more pluralistic, their organization forms are more complicated and the evolution from single intelligence to crowd intelligence needs to be considered. Because the transaction object is more abundant, which includes not only the economic area but also politics, social interactions, social management, etc., the non-accumulative and indivisible characteristics needs to be considered. Because the transaction process is more intelligent, the coordination and the dynamic switching between the transaction modes need to be considered.

This study analyzes the intelligent transaction mode from two aspects: the organization form of the buyer and the supplier and the modularization of the demand and supply. For the organization form, we mainly consider the quantity, and we divide the transaction subject into two categories, which are single-agent and multi-agent. Because of the indivisible characteristic, different transaction objects have different modularization levels. According to the high and low modularization level, we divide the demand and supply into two categories, which are single-supply and single-demand and multi-supply and multi-demand.

From the demand perspective, when the demand side is a single agent in the intelligent transaction, and the modularization level of the demand is high, this demand is classified as single-demand. When the demand side is a multi-agent in the intelligent transaction, and the
modularization level of the demand is low, this demand is classified as multi-demand. From the supply perspective, when the supply side is a single agent in the intelligent transaction, and the modularization level of the supply is high, this supply is classified as single-supply. When the supply side is a multi-agent in the intelligent transaction, and the modularization level of the supply is low, this supply is classified as multi-supply. The pair-wise combination of the demand and supply forms four types of intelligent transaction modes: single-demand-single-supply (S-S), single-demand-multi-supply (S-M), multi-demand-single-supply (M-S) and multi-demand-multi-supply (M-M). Figure 4 shows the classification framework of the intelligent transaction modes.

Same as the traditional transaction, the intelligent transaction also includes the parts of demand, supply, matching, pricing, fulfilling, evaluating and guarantee. Thus, the intelligent transaction modes share some general rules, which include description rules of supply and demand, search rules, matching rules, goods and service delivery rules, awards-and-penalties rules, etc. However, the transaction rules also vary with the intelligent transaction modes, which require special rules for different intelligent transaction modes. S-S intelligent transaction mode, taking the new generation of e-commerce as an example, may require some special rules on the management of market power polarization. S-M intelligent transaction mode, taking intelligent collaborative innovation as an example, may require some special rules on participation incentive rules and labor-division-and-cooperation rules. M-S intelligent transaction mode, taking the intelligent management of public affairs as an example, may require some special rules of procedure among the multi-demand side in the deeply integrated ternary space of physical, consciousness and information. M-M intelligent transaction mode, taking intelligent logistics information service as an example, may require some special rules on cost-sharing and responsibility-sharing among multi-demand and multi-supply as well as the regulation of market power polarization.

5.2 Representative examples and research directions
In this section, we take a representative example of each intelligent transaction mode to further illustrate features of these transaction modes and potential research directions.

5.2.1 S-S intelligent transaction mode: the new generation of e-commerce. The representative example of S-S intelligent transaction mode is the new generation of e-commerce, as the transaction objects are usually divisible and have high modularization level, and the

![Figure 4. Division framework of intelligent transaction modes](image)
The main difference of the new generation of e-commerce from the traditional e-commerce is disintermediation. It removes all the intermediaries and connects the consumers and producers directly. There are mainly two intelligent e-commerce transaction modes: demand-driven transaction mode and supplier driven transaction mode.

Traditional e-commerce treats consumers as passive product recipients. However, intelligent transactions recognize that consumers will play multiple roles in the transactions as consumers, investors and producers. Consumers have a wide range of choices and tend to put forward personalized needs and their demand might be fuzzy. Thus, on the intelligent e-commerce, we would:

- study the rules of the direct connection between consumers and goods or services;
- accurate identification methods of fuzzy demand;
- distinguish the supply driven transaction mode from multiple perspectives, e.g. distinguish the internet community-driven demand and the professional marketing patterns; and
- discuss the specific process and operating mechanism of the demand-driven transaction mode; etc.

5.2.2 S-M intelligent transaction mode: intelligent knowledge seeking. The representative example of S-M intelligent transaction mode is knowledge seeking, as the transaction objects are usually to certain degree indivisible and have medium level of modularization, and the demand side is usually single-agent, like individual, enterprise and institution, but the supply side is usually multi-agent. For example, the scientific research for knowledge creation. It usually needs existing knowledge from different knowledge suppliers and also requires research teams to collaborate closely to finally supply the new knowledge to the demand side.

Decisions in daily life and work need to be made based on specific accumulation of knowledge and information, such as whether a health check of new method is needed or whether a new project should be launched. Knowledge seeking includes knowledge transferring and knowledge production. Knowledge transferring requires high cost of search and transferring (including time and money), and knowledge production requires high investment costs and production costs, as well as the incentive and supervision costs of knowledge innovation with non-exclusiveness. The main goal of the knowledge seeking research in the intelligent network is to reduce the transaction cost through rules and techniques and to encourage the innovation of knowledge to improve the quality and efficiency of knowledge seeking. Thus, on the intelligent knowledge seeking, we would:

- study the rules, methods and techniques to reduce the cost of search and negotiation with the self-learning of the digital twin in the crowd intelligent networks, to quickly organize and integrate a lot of knowledge from the suppliers, and to quickly present the high-quality knowledge report to the demand side;
- build knowledge tank and study the knowledge transferring mechanism based on crowd intelligence network;
- develop intelligent collaborative innovation technologies in the knowledge production side, such as crowdsourcing technology; and
- develop the knowledge storage technology based on block chain technique to improve the existing priority system and intellectual property system in the field of knowledge production.
5.2.3 M-S intelligent transaction mode: intelligent management of public affairs. The representative example of M-S intelligent transaction mode is intelligent management of public affairs, as the transaction objects are usually to certain degree indivisible and have medium level of modularization, and the demand side is usually multi-agent, like the whole public including individuals, enterprises and institutions, but the supply side is usually single-agent. For example, the requirement of clean air. The demand side is the whole public, and the supply side is usually the government.

The greatest challenge for the management of public affairs is the free-riding problem of the demand side, forming the “Silent Majority” and eventually leading to the “Tragedy of the Commons.” The main goal of intelligent management of public affairs is to reduce transaction costs through rules and technologies to improve the efficiency of public regulation and decision-making. Thus, on the intelligent management of public affairs, we would:

- study the rules of procedure of the demand side in the crowd intelligent networks;
- from the supply side, develop the intelligent pollution detection technology for major air pollution sources, including vehicle exhaust, factory exhaust, private heating emission and establish a precise pollution warning system and intelligent remote-control technology, like remote locking technology; and
- research on the pricing of public goods considering the multi-agent demand and the single-agent supply.

Because the expenditure of public goods management is often covered by taxes or fees paid by the demand side, the intelligent ladder type pollution tax (pollution fee) pricing system might be developed by the government.

5.2.4 M-M intelligent transaction mode: intelligent logistics information service. The representative example of M-M intelligent transaction mode is intelligent logistics information service, as the transaction objects are usually indivisible and have low level of modularization, and the demand side is usually multi-agent, including individuals, enterprises and institutions that require the logistics information, and the supply side is also usually multi-agent.

Different from the existing logistics service for traditional commercial transactions, intelligent logistics information service provides the demand side with real-time and customized logistics information, including price, service, traffic, weather, transportation, etc., as well as the optimal logistics scheme. Government, logistics enterprises, users and goods work together to provide immediate or periodical logistics information. Lack of the demand information would affect the quality of the logistics information supplied to all the users, so intelligent logistics information is relatively integral and not in-completed. Thus, on the intelligent logistics information service, we would:

- study the consistency and difference of demand from different demand side and develop the measurement method of modularization degree to identify the demand of low modularization level; and
- study the coordination and cooperation mechanism between multiple suppliers and explore the interconnection and intercommunication mechanism between the online supply and the offline supply.

6. Conclusion
In this paper, we review the definition of transaction and transaction mode, analyze the driving forces of the evolution of them and develop and summarize the definition and
characteristics of intelligent transaction and intelligent transaction mode in the crowd intelligence network. In the crowd intelligent networks, all interactions among various agents can be attributed to a certain transaction activity or behavior. The concept of intelligent transaction is broader. The intelligent transaction subject is more pluralistic; the intelligent transaction object is more abundant; and the intelligent transaction process is more intelligent. We develop four modes for the intelligent transactions based on the modularization level of the transaction objects and the quantity of transaction subjects, including the demand side and the supply side. The four intelligent transaction modes are S-S, S-M, M-S and M-M. We also take a representative example of each intelligent transaction mode to further illustrate rules and features of these transaction modes and point out potential research directions.

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Further reading

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Crowdsourcing for search engines: perspectives and challenges

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Abstract

Purpose – As a relatively new computing paradigm, crowdsourcing has gained enormous attention in the recent decade. Its compliance with the Web 2.0 principles, also, puts forward unprecedented opportunities to empower the related services and mechanisms by leveraging humans’ intelligence and problem solving abilities. With respect to the pivotal role of search engines in the Web and information community, this paper aims to investigate the advantages and challenges of incorporating people – as intelligent agents – into search engines’ workflow.

Design/methodology/approach – To emphasize the role of the human in computational processes, some specific and related areas are studied. Then, through studying the current trends in the field of crowd-powered search engines and analyzing the actual needs and requirements, the perspectives and challenges are discussed.

Findings – As the research on this topic is still in its infancy, it is believed that this study can be considered as a roadmap for future works in the field. In this regard, current status and development trends are delineated through providing a general overview of the literature. Moreover, several recommendations for extending the applicability and efficiency of next generation of crowd-powered search engines are presented. In fact, becoming aware of different aspects and challenges of constructing search engines of this kind can shed light on the way of developing working systems with respect to essential considerations.

Originality/value – The present study was aimed to portrait the big picture of crowd-powered search engines and possible challenges and issues. As one of the early works that provided a comprehensive report on different aspects of the topic, it can be regarded as a reference point.

Keywords Search engines, Web 2.0, Information retrieval, Crowdsourcing, Human-computer interaction, Human computation

Paper type Research paper

1. Introduction

The days of relying only on machines for performing computing tasks and problem solving have gone. In fact, introduction of crowdsourcing (Howe, 2006) as a mold-breaking computing paradigm has changed the playground drastically. Despite many years of research and development, machines could not handle all computational problems completely and independently, especially when it comes to cognitive- and intelligence-intensive tasks (Zadeh, 2008; Del Prado, 2015; Whitney, 2017). Therefore, putting humans in the loop as collaborators, cooperators and even coordinators (rather than just users or supervisors) (Folds, 2016) can be
considered the silver bullet for tackling a wide variety of problems in different domains (Kamar et al., 2012; Weyer et al., 2015; Ofli et al., 2016; Holzinger et al., 2016). Narrowing down the view on a specific niche, there are some interesting common grounds between crowdsourcing and the Web 2.0 (OReilly, 2007) concepts in their perspectives on humans’ roles. According to the Web 2.0 manifesto (OReilly, 2007), Web users should evolve from merely consumers to active producers. In this regard, notable efforts such as Wikipedia – as a Web 2.0 iconic example of collaborative participation of users and a successful best practice of crowdsourcing-based knowledge acquisition- could be inspirational and motivating. Such an example, by the way, puts focus on invaluable applications of human-centered intelligence-oriented participation in Web-related workflows. Regarding the principal role of search engines in the Web and information society, it is worth studying the possible perspectives and also challenges of incorporating humans (i.e. Web users) into information retrieval, validation and evaluation processes. Such activities that can affect search engines and some of the related processes are discussed in this paper as in the following structure: some background and related works are introduced in Section 2. The rationale behind human-powered search engines is investigated in Section 3. Applications and perspectives of leveraging crowdsourcing for search engines and related challenges are studied in Sections 4 and 5, respectively. Moreover, a concise literature review is conducted in Section 6, and some suggestions for the future works are presented in Section 7.

2. Related works
Since the early days of introduction, crowdsourcing (Howe, 2006; Brabham, 2008; Ikediego et al., 2018) has provided many unprecedented opportunities to facilitate traditional workflows and processes in a wide variety of (mostly) technology-related domains. In this regard, one can see numerous example scenarios in a broad range of application areas from robotics (Breazeal et al., 2013; Jain et al., 2015; Moradi et al., 2016; Almosalami et al., 2018) and machine learning (Simpson et al., 2015; Wallace et al., 2017) to knowledge management (Callaghan, 2016; Dimitrova and Scarso, 2017) and much more. Following this working idea, information retrieval researchers have pursued the applicability of leveraging the people’s potential for improving related tasks. More specifically, taking advantages of collective human intelligence for corpus annotation (Krishna et al., 2017; Tayyub et al., 2017), query interpretation (Ciceri et al., 2016; Chen et al., 2016) and other database-related processes (Liptchinsky et al., 2015; Trushkowsky et al., 2015; Zhao et al., 2015) have gained momentum. To introduce some, the following are worth mentioning: as a notable work in this context, Franklin et al. (2011) proposed CrowdDB. The system leverages human input to process and answer queries that machines could not provide appropriate results for them. Additionally, they introduced CrowdSQL as an extension for SQL to support the underlying idea. To take advantages of Amazon’s Mechanical Turk (AMT) for more complicated tasks and processes, namely, database-related ones, Marcus et al. (2011) introduced a new query system, Qurk. Designing an algorithm for human-driven filtering of data items based on some attributes is the theme of the research reported in Parameswaran et al. (2012). As another inspirational work, benefits of crowdsourcing-based relevance assessment for XML retrieval are reported by Alonso et al. (2010).

On the other side, search engines are playing an integral role in dissemination of information in the Web. However, despite the remarkable advancements in the field (Deng and Feng, 2011; Hariri, 2013; Lewandowski, 2015), there are still several essential issues with search engines in identification of users’ intentions (Jansen et al., 2007; Ruotsalo et al., 2015) and providing them with most appropriate answers (Thelwall, 2008; Uyar, 2009).
Specifically, among the major challenges search engines face with, understanding humans (their intentions and exact needs) and providing them with human-level responses are of high importance. Due to intrinsic weakness of (current)machines in dealing with cognitive and intelligence-intensive tasks, such as interpretation of natural languages, one cannot expect perfect and flawless search engines with clear-cut results. As a result, optimum and dreamy search engines seems not to be in sight at least at this time. To fill this meaningful gap between what users (searchers) want from search engines and what search engines can bring to users, leveraging humans’ intelligence and cognitive/problem solving abilities can be considered a game changer (Figure 1). Therefore, the major motivations of this study are of two types:

(1) investigation of reasons, benefits and nuts and bolts of typical crowd-powered search engines, i.e. theoretical motivations; and

(2) studying best practices, current solutions, practical implications and challenges of relying on crowds’ power for evolving traditional search engines, i.e. practical motivations.

In this regard, this paper aimed to provide a reference point to reflect current status of the field and draw a road map for future works.

3. Why crowdsourcing is needed for search?

Although machines can easily outperform humans in (most of) computational tasks, when it comes to cognitive and intelligence-intensive problems, including natural language processing, they address several critical shortcomings (Poirier, 2017). To Deal with such issues, leveraging humans’ potential and abilities opened a new window toward taking advantages of man-machine cooperation. Over the years, many research studies have been conducted to benefit from such a hybrid strategy (Dounias, 2015; Kamar, 2016; Dellermann et al., 2018). Among them, some of the mostly human-centric application areas, including information search and relevance assessment, greatly depend on human intervention to

Figure 1.
Relatedness gap between what users want and what search engines provide.
provide reliable and accurate results. As everyone experiences in his daily Web browsing, even the highly-sophisticated search engines with the state-of-the-art algorithms and procedures are not as strong and accurate as users may expect, specifically in interpreting the search queries and consequently retrieving relevant results. In other words, demystifying users’ intention of search (terms), finding most relevant matches and ranking the results so that best conform to users’ goals and preferences cannot be achieved by relying only on machines’ intelligence and capabilities. In this regard, so-called crowd(human)-powered search engines (Parameswaran et al., 2014) have gained momentum. The main rationale behind such search systems is involving individuals to leverage their cognitive intelligence (and searching expertise) for the sake of providing users (i.e. initial searchers) with what they could not find by themselves. As a real-world example, Digle[1] – a people-powered search engine – crowdsources search queries to its large body of participants (search workers/searchers). To present more accurate and relevant results, users are asked to provide some additional information on their own requests, including the related category, etc. However, question and answer sites and forums provide similar facilities for years, and crowdsourcing-based search engines are in charge of generalizing the concept and presenting their users with specific, to-the-point, relevant and humanized information.

4. How does crowdsourcing help Web search?
Humans’ power – according to the context and applications – can be leveraged in many different ways from providing training data for the machine (Kairam and Heer, 2016; Chang et al., 2017) to collaborating with an algorithm to provide more precise outputs (Fan et al., 2014; Sarma et al., 2014), e.g. in the form of a quality controller or supervisor. When it comes to the Web search, crowdsourcing is mainly related to improving underlying processes or providing users (searchers) with some assistance on finding more relevant answers. In addition to analyze logs and query submission patterns (Park et al., 2015; Zahedi et al., 2017) to find out users’ requirements (indirect crowdsourcing or crowd analysis), game-based methods (Law et al., 2009a; Law et al., 2009b; Bennett et al., 2009; Ma et al., 2009), as a tacit approach for facilitating search process, are in the center of attention. From a general point of view, humans’ role in the search process could be categorized in the four major classes as follows.

4.1 Crowd-searching
In this category, it is supposed that the user could not find what (s)he is looking for. It may be cause of lack of adequate searching abilities, having no knowledge of the target topic and so on. In such a case, the aim is to crowdsource the problem (i.e. keywords to be searched) and get back the most relevant crowd-searched results to the user. To obtain more accurate answers, users should be asked to provide as much as possible additional information on what they want to find. Digle, DataSift (Parameswaran et al., 2014) and CrowdSearcher (Bozzon et al., 2012a) are major solutions that provide users with crowd-searched findings of desired topics. Following this idea, the people’s power have been leveraged in previous inspirational studies (Jeong et al., 2013; Spirin, 2014) for answering twitter questions and finding design examples, respectively. The obtained results in this approach may be used for further managerial processes, such as query interpretation.

4.2 Crowd-clarifying
One of the main issues search engines and information retrieval systems deal with is demystifying and clarifying submitted queries. As this problem is mainly related to natural language processing (a hard AI problem), machines face some difficulty to handle them.
Unfamiliarity with the search (target) language, entering long and ambiguous search terms, typos and semantic errors are among reasons that imply needs for crowdsourcing-based clarification of search queries. In fact, human intelligence is the best means to uncover humans’ intention of a specific query. Despite the crowd-searching (Bozzon et al., 2012b), this approach is not necessarily online or (semi)real-time. Human workforce, for this purpose, will be used to interpret the query, breaking down it to several essential meaningful parts, suggesting additional choices for expanding search terms and finding similar terms (Kim et al., 2013) and more appropriate alternatives for replacing the input search term(s) with. These will improve the query-result matching and retrieval processes.

4.3 Crowd-sifting
Conceptually similar to crowd-searching, crowd-sifting is an umbrella term for a set of activities devoted to preparation of intermediate information. Data labeling and classification are important tasks in this category. Doing so, in fact, the information that could be matched with the respective queries will be filtered and organized to achieve higher performance (Milne et al., 2008). From another point of view, the information retrieved through automatic searching process, to be calibrated and normalized, should be validated by the people (Yan et al., 2010). Such supervisory tasks are considered as a pre-processing step for the answer generation. Due to need for recruiting a relatively large body of participants, and performing precise computation and supervisory routines, this approach is a costly and time-consuming one.

4.4 Crowd-rating
Regardless of how answers are produced, there are two critical post-processing steps. First one is evaluating the relevance of candidate answer sets to the submitted query, which is a determining process for the final answer generation (Alonso et al., 2008; Lewandowski, 2015). This easily crowdsourcable process can also be performed tacitly through analyzing users’ feedback and satisfaction measuring. Second, ranking the results (Kim et al., 2013) plays an important role for helping to find the most relevant items. The aforementioned processes are inter-related and dependent, through which the ultimate results will be populated and organized in a user-friendly manner.

According to the aforementioned procedures, the human as the crowdworker can play two major roles (Figure 2):

![Figure 2. Different roles of the human in the crowd-powered search engines](image-url)
5. Challenges
Despite several remarkable benefits of crowdsourcing for facilitating the Web search process in different levels, relying on humans’ power addresses some essential challenges. Underestimating these issues and their consequences can greatly affect the efficiency of the process. These challenges are of two broad classes: human-related and technical ones.

5.1 Human-related challenges
No one could improve the Web search process better than (expert) users, and on the other side, no one else could undermine/affect it just like them, their behavior and operations. Regarding this fact, there are some influential factors that should be considered.

5.1.1 Motivation and incentives. However, crowdsourcing, in some cases, is established on the shoulders of volunteers; when it comes to critical and serious applications that should be performed in near real-time, it is not an effective approach. In this regard, recruiting active and responsible (and possibly expert) participants is a must-have need that imposes remarkable costs.

5.1.2 Challenging tasks. As mentioned earlier, a common type of tasks in the context of Web search is interpretation of long, ambiguous and complicated search terms. Due to some intrinsic issues in such cases, e.g. obscure submissions by users in language other than their own, crowdworkers may be disinterested to demystify those inputs. In other words, highly prolonged and erroneous inputs – that are prevalent in search engines – may affect the crowdsourcing process. To cope with such issues, applying a preliminary machine interpretation or increasing the payment for complicated submissions (tasks) are of working solutions.

5.1.3 Integrity and scalability. Machine interpretation of search terms and finding relevant answers are only dependent on underlying algorithms. Replacing it with a human-driven strategy can be influenced with several to many variables. For this reason, it is unlikely to expect similar answers for similar search terms in the case of lack of some further supervisory (integration) steps. On the other side, adversarial intentions can affect the answer seeking process (Harris, 2011; Difallah et al., 2012). Therefore, there is need to some quality control processes (Daniel et al., 2018); otherwise, the reliability of human-powered information searching may be questioned. Further, scalability is another challenging issue in this context, specifically when it comes to deal with a large number of users. In such cases, recruiting and managing many active crowd-searchers to guarantee the efficiency of the system will impose remarkable costs and technical considerations.

5.2 Technical challenges
In addition to usual technical complexities for search engines, to manage crowdsourcing-related issues, some further considerations are needed, including the followings.

5.2.1 Response time. An essential advantage (and performance measure) of search engines is reducing the retrieval time. Currently, most search engines retrieve the initial
answers in less than few seconds. Such a feature is one of the most important superiority of
traditional search engines over human-powered ones. Assigning search tasks to the crowd,
finding relevant results by the people, validation, integration and retrieval of most relevant
answers are time-consuming processes that not only exceed near real-time performance but
also impose a remarkable annoying delay. Although it is studied that in some cases users
prefer the slow search process to acquire more accurate results (Teevan et al., 2014), this is
not the case for general purposes.

5.2.2 Managerial overheads. Managing crowd-searched answers is a complex and
sophisticated process. In fact, machine-driven validation and relevance evaluation processes
may be subject to some inconsistencies. In this regard, some human-oriented supervisory
processes may be needed. Such an approach, by the way, can address the need for repetitive
human-mediated evaluation to reach an acceptable assurance level. Further, there are
several essential implementation considerations that should be taken into account to make
the system feasible and efficient enough.

5.2.3 Crowdsourcing platform. Due to its features and capabilities, AMT is the
first choice of researchers and practitioners for conducting crowdsourcing projects. Nonetheless,
its basic facilities may not completely support unusual tasks and procedures. Dealing with
such issues, some researchers proposed solutions (such as additional frameworks and
interface on the top of AMT) to handle the case (Marcus et al., 2011). While some others
introduced their own case-specific crowdsourcing systems. As a real world example, Digle
can demonstrate an appropriate and working instance. As there is not a size to fit all, there
should be a match between type of tasks and crowdsourcing platform’s capabilities. Clearly,
because Digle provides (or at least aimed to provide) near real-time answers, it is not a
rationale choice (for them) to use Mechanical Turk or similar systems. On the other side, for
background tasks such as relevance assessment and evaluation—as done in (Blanco et al.,
2011), adopting to the standard third party services is acceptable.

5.2.4 Economical side effects. Web-based commerce greatly relies on search engine
optimization (SEO) techniques and strategies. However, the underlying methods by which
search engines rank Web pages are not publicly revealed; over the years, SEO experts have
become aware of the nuts and bolts of the workflow. Therefore, if the crowd-powered search
engines gain momentum as a key player in the search engines’ playground, the current
(accepted, well-studied and documented) rules will be changed in a non-understandable way.
In addition to disorganizing the SEO approaches, targeted activities can affect the search-
based commerce in an adversarial and destructive manner.

6. Literature review
To investigate the current advancements in the field, in this section, a brief literature review
is conducted. In this regard, first and foremost, crowd-powered search engines are
introduced. Then, the works adhered to game-based methods for improving search process
are reviewed. For more information on general issues in the field, the research works
conducted earlier (Sushmita et al., 2009; Kazai et al., 2011; Kazai, 2011; Harris and
Srinivasan, 2013) are recommended.

6.1 Crowd-powered search engines
As one of the most interesting contribution in the field, Parameswaran et al. (2014) proposed
a crowd-powered search toolkit, entitled DataSift. The most important feature of this tool is
its capability to connect to any data set. The submitted query to the DataSift will be
processed in a dual approach: forwarding to the crowd and analyzing by means of keyword
processing subsystem. Finally, the user will be provided with a list of ranked results. To
improve the quality of Twitter question asking process, the authors introduced an embedded, crowd-powered search system – MSR Answers (Jeong et al., 2013). The system provides a novel facility to obtain answers from the crowd instead of relying only on the friends’ circle. It is claimed that the crowd-generated answers are as quality as what the friends can provide.

A crowdsourcing-based image search system for mobile phones, CrowdSearch, is proposed in Yan et al. (2010). In this work, the search process will be performed automatically; then a real-time crowd-mediated validation process will be applied on the generated results.

To fill the remarkable gap between automated search engines and humans’ information seeking behaviors, Crowdsearcher is introduced (Bozzon et al., 2012a). The main contribution of this study is to provide pure humanized answers by leveraging humans’ interaction and cognitive intelligence. In another similar study, Bozzon et al. (2012b) proposed a model-driven approach to take advantages of humans’ interaction and opinions for question answering.

6.2 Game-based approaches
Search War, a competitive game for improving Web search, was introduced in Law et al. (2009b). The users, in addition to collect data, take part in a relevance evaluation process for a specific search query and a Web page.

Ma et al. (2009) proposed three human computation games for improving Web search. The underlying idea of the first one, which is named Page Hunt, is to show the user a random Web page and ask him to suggest the most relevant search query for that. The suggested query will be checked in a real search engine, and the results will get back to the user for the sake of evaluation. This game, by the way, could be used for the search engines optimization purposes. The second game, called Page Race, is a competitive one with the aim of specifying the query (search phrase) that best matches the given Web page. As a collaborative game, the third one, Page Match, is intended to examine humans’ efforts to match similar Web pages based on their selected queries. In this game, players win points when both agreed on a decision, i.e. the Web pages are same or different.

The major contribution of Intentions, a human computation game proposed by Law et al. (2009a), is to collect relevant human-generated data for interpreting intentions behind search queries. Despite the Page Hunt, the game play for the Intentions is a reverse one: users will get an intention and will be asked to suggest some search queries which best match it.

Borrowing the underlying idea from ESP game, Picture This as a social collaborative game was proposed in Bennett et al. (2009) to collect data for image searching purpose. In the game, participants will be presented with a sequence of queries and several images. They will be awarded credit when they agree on an image for a specific query.

As an educational game, Koru (Milne et al., 2008) is developed to trace how users evolve queries, how they can improve their searching skills and find out what are their intentions for issued queries.

7. Future works
In addition to the general perspectives discussed in the paper, in this section, several specific suggestions for future works in the field are presented.

7.1 Leveraging collective machine intelligence
The idea of leveraging collective machine intelligence and performance has gained momentum within the recent years (Yampolskiy et al., 2012; Halmes, 2013). As an equivalent concept for crowdsourcing in the context of intelligent agents, such an idea can be used to provide Web searchers with more precise and comprehensive answers. Specifically, any search engine follows its own attitudes toward the query interpretation, information
retrieval and other similar procedures. Therefore, it is expected to obtain (partially) different answers when issuing same search query in different search engines. In this regard, taking advantages of different search engines and information retrieval systems to provide the user with most relevant answers can be an interesting and working strategy.

7.2 Location-based crowdsourcing
As location and temporal information (features) can affect the search and retrieval processes (Zhang et al., 2017; Ermagun et al., 2017), there is a strong need to incorporate such factors in the related workflows. When it comes to crowd-powered search engines, the key to consider location-related features is to adhere to location-based crowdsourcing. For example, to provide a user with (possibly) most relevant answers, it would be better to employ crowdworkers who are in the same geographical location that the initial query was issued.

7.3 Mining crowdsourced data
Within the recent years, researchers have paid a remarkable attention to discovering knowledge from crowdsourced data (Rahman et al., 2015; Gao et al., 2016). In fact, mining crowdsourced data can be regarded as delving into humans’ intelligence. In the context of search engines, analyzing crowd-selected and crowd-searched keywords is a powerful means to gain insight on common search patterns. Moreover, discovering the ranking and evaluation patterns can be used for constructing an expert system to automate the process and providing users with precise recommendations.

7.4 Rethinking the incentive mechanism
One of the most important drawbacks of crowd-powered search engines is the intrinsic delay. To overcome this shortcoming, it is needed to recruit a very large body of active participants. For this reason, a working strategy is to keep them active through (social and viral) games (Zeng et al., 2017). Also, establishing competitive environments and mechanisms can increase the rate of participation and accuracy. Looking back at the best practices for attracting mass human participation, such as the Google’s reCAPTCHA (Von Ahn et al., 2008), can also be inspirational.

8. Conclusion
The main contribution of this paper was studying effects of leveraging humans’ problem solving and information seeking abilities in the context of Web search engines. As the current search engines, despite their advantages and capabilities, could not provide human-level answers in some cases, it seems (and partially proved) that incorporating humans in the process can be the silver bullet to overcome current deficiencies of traditional approaches. In this regard, in addition to providing an overview of the respected literature, some important perspectives and challenges of the field were studied.

Note
1. www.digle.com

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A survey on VV&A of large-scale simulations

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Abstract

Purpose – Simulation is a well-known technique for using computers to imitate or simulate the operations of various kinds of real-world facilities or processes. The facility or process of interest is usually called a system, and to study it scientifically, we often have to make a set of assumptions about how it works. These assumptions, which usually take the form of mathematical or logical relationships, constitute a model that is used to gain some understanding of how the corresponding system behaves, and the quality of these understandings essentially depends on the credibility of given assumptions or models, known as VV&A (verification, validation and accreditation). The main purpose of this paper is to present an in-depth theoretical review and analysis for the application of VV&A in large-scale simulations.

Design/methodology/approach – After summarizing the VV&A of related research studies, the standards, frameworks, techniques, methods and tools have been discussed according to the characteristics of large-scale simulations (such as crowd network simulations).

Findings – The contributions of this paper will be useful for both academics and practitioners for formulating VV&A in large-scale simulations (such as crowd network simulations).

Originality/value – This paper will help researchers to provide support of a recommendation for formulating VV&A in large-scale simulations (such as crowd network simulations).

Keywords Large-scale simulation, Crowd network simulations, VV&A, Credibility

Paper type Literature review
1. Introduction

Due to rapid advancements in computer hardware and software development techniques, simulation technology is widely used in numerous application domains that include national defense, geology (Miller, 1981), human anatomy and biology (Snyder et al., 1968; Andrews and Graef, 1970), electronics (Shichman and Hodges, 2003), military (Kheir and Holmes, 1978) and railway systems (Goodman et al., 1987). It has also succeeded to achieve worldwide attention over the past several years due to its multiple features that include cost-efficiency, elimination of prototyping, better risk assessment, increased speed and optimized accuracy. Early concepts and theories of simulations and their applications are first introduced in previous works (Evans et al., 1967; A, 1967; Martin, 1968; McLeod, 1968; Rothenberg, 1989). According to Rothenberg (1989), simulation can broadly be defined as a behavioral or phenomenological approach to modeling: This means, it is an active and behavioral analog of its referent. Since the end of the twentieth century, to deal with simulation objects’ complexities and improving user’s requirements in the simulation application domains, it has entered into a new stage of large-scale simulations. This also brings new challenges to the credibility of evaluation due to the underlying characteristics of large-scale simulations that include multiple levels, multiple structures, multiple relationships, multiple models and large scale (Zhang et al., 2012).

For practical problems, simulations are of value only if the results of these simulations are reliable and accurate. Simulations that lack sufficient credibility are meaningless and will bring about catastrophic consequences (Zha and Kedi, 1997; Howard, 2011; Lent et al., 2003). The credibility analysis of simulations not only validates simulation and its results but also reduces the risks caused by the application of simulation. Moreover, it also helps developers to find out the shortcomings of the simulation during the design process (Li, 2012). Therefore, credibility analysis is an essential parameter for the acceptance and validation of simulation system results (Muessig, 2001). Since 1962, Biggs and Wigan conducted research on the credibility analysis of simulation to fully evaluate the simulation (Abrahamson, 1980; Fishman and Kiviat, 1967). In the mid-1970s, the American Society of Computer Simulation established a Technical Committee on Model Credibility to build verification terms. The credibility is defined as the degree of trust of a simulation system in the simulation and the output of the simulation under a specific application purpose (Li, 2012), which mainly includes four aspects of nature, i.e. purpose relevance, objectivity, comprehensiveness and hierarchy (Zhang and Wang, 2001).

Initially, the concept of verification, validation and accreditation (VV&A) of simulation models is defined to improve the credibility of simulations and to make simulations efficient considering user requirements. Therefore, the research on VV&A and credibility of the simulation is essential for every simulation application (Zhang et al., 2012; Figure 1). The term VV&A first appeared in the US Department of Defense (DoD) Modeling and

![Diagram of VV&A](Figure 1. The connections and effects of VV&A)
Simulation Office (DMSO) in 1996 for setting up a technical support team, named Military Simulation VV&A Technical Support Team (TST; DoD, 1996). The role of that team was to enhance the scientific and usable military simulations. Moreover, VV&A activities can also assist in reducing development and integration risk with considerable improvement in the simulation credibility (Muessig, 2001; Tang et al., 2006). Therefore, it cannot be accepted without the implementations of credibility analysis, or it cannot be used without a qualification certificate of VV&A (Zhang et al., 2012; Figure 1).

VV&A is a significant mean to improve the credibility of simulations, especially during large-scale simulations. It is successfully affirmed in various studies of large-scale simulations to accredit and validate simulations results. Recently, numerous research surveys are published on the application of large-scale simulations. However, these research studies are either extremely broader to specifically discuss VV&A or extremely limited on the use of VV&A in a specific and relatively narrower application domain. Moreover, all these research studies provide an excellent review and details of current verification and validation (V&V) techniques but lack in providing origin and history of the development of these techniques. This research reviews the origin and development of VV&A theory, standards, frameworks, methods, techniques and tools from a specific application to large-scale simulation applications (like multi-agent simulations). This research will also focus on which features and characteristics of VV&A can be utilized to a large-scale simulation problem.

The rest of this paper is organized as follows: Section 2 introduces the details of VV&A. Section 3 reviews the VV&A standards. It explores VV&A frameworks and also discusses which VV&A framework is appropriate for the large-scale simulation platforms. Method and techniques of VV&A are presented in Section 4. This section also discusses about how to apply technology and methods to VV&A processes. Sections 5 and 6 explain tools of a VV&A framework and also suggests appropriate tools for large-scale simulations. Moreover, Section 7 summarizes this research (Figure 2).
2. The research on VV&A theory of simulations

Since the inception of modeling and simulations (M&S), the concept of VV&A in simulation models has been defined using life cycle simulations and model development processes (Borko, 1962).

Sargent (1997) presented a model for the model development process and described the relationship between models and reality (Figure 3). For simulations, Balci stated that V&V should be a constant ongoing process throughout the life cycle simulations. Later, in 1994, he introduced testing function into the verification process of simulation and concluded that VV&T is not a phase or step in the life cycle of a simulation study but a continuous activity throughout the entire life cycle (Figure 4). Furthermore, he provided a more exhaustive taxonomy for the VV&A process and talked about the necessity of verification in the formulation of simulation models (Balci, 1997; Balci and Nance, 1985).

The spectral analysis method was applied to the validation work of the missile simulation. Balci and Sargent (1984) believed that the confidence interval method can also perform the relevant validation work of the simulation. In 1996, the DMSO set up the Military Simulation VV&A TST to draft the Recommended Practice Guide (RPG) 5000.61. In 1996, the DoD issued the Ministry of Defense VV&A recommendations (Department of Defense Instruction [DoDI], 2003; Sanders, 1996). This recommendation guideline divides the VV&A work in the life cycle of simulations into seven main stages: determining VV&A requirements, VV&A plan design, concept model verification, system design verification, system application verification and system acceptance.

IEEE 1278.4 was initiated by the IEEE DIS (Distributed Interactive Simulation) Committee and completed in 1997, which provides VV&A guidelines for DIS emulation users and developers (Interactive and Committee, 1998). In 2004, the International Test Operations Procedure (ITOP) released the first version of the “General Procedure for M&S V&V Information Exchange” (ITOP 01-01-002). In 2007, IEEE 1516.4 practice defines the processes and procedures that should be followed to implement VV&A for federations being developed using the high-level architecture (HLA) using the Federation Development and Execution Process (FEDEP) (Interoperability et al., 2007). The development history of VV&A is presented in Figure 5.

**Figure 3.**
The model development process
Survey on VV&A of large-scale simulations

Figure 4. The life cycle of VV&A
Different scholars and organizations also give relevant definitions and requirements to VV&A. The economist Machlup (1955) provides the first formalized definition of the concept of verification as “Verification in research and analysis may refer to several things that includes correctness of mathematical and logical arguments, the applicability of formulas and equations”. Sornette et al. (2007) defined validation as “the process of determining the degree to which a model is an accurate representation of the real world from the perspective of its intended uses”. This definition is identical to Sargent’s: a model must be validated to ensure some minimal degree of accuracy for a given system or problem entity. The only difference is that the system/problem entity is a physical phenomenon in the real world instead of a generalized process. In previous works (Oberkampf and Barone, 2006; Oberkampf and Barone, 2007), V&V is again defined as “Verification is the assessment of the accuracy of the solution to a computational model. Validation is the assessment of the accuracy of a computational simulation with experimental data”. This concept has widely been accepted by most of the scholars. The DoD defines accreditation in DoDI 5000.61 as “the official certification that a model or simulation is acceptable for use for a specific application” (Sanders, 1996).

Verification ensures that the model works as expected. Verification is a software-level process that does not necessarily require information about the model’s outputs. It is more of a check that the model’s equations are correctly coded and implemented. The ultimate goal of validation is to establish credibility in a model such that the model can also be used to predict problem entity behaviors on unseen and untested cases. Validation is the testing of model outputs against experimental data to see if the model yields accurate outputs. Model accreditation determines if a model satisfies a specified model according to a specified process.

Finally, this section introduces the concepts of VV&A, the evolution process of VV&A and the VV&A process in the simulation life cycle, which can help readers to have a preliminary understanding of VV&A.

3. The research and establishment on VV&A standards of large-scale simulations
Does the establishment of VV&A standards of a large-scale simulation in the life cycle guide the work effectively and orderly? To answer this question, we can observe the following VV&A standards and specifications.

3.1 DoD VV&A RPG
DoD VV&A RPG is a basic framework for the overall guidance of the subordinate Army, Navy and Air Force according to the DoDI 5000.61 recommended guidelines, allowing subordinate organizations to make corresponding adjustments and changes according to their specific circumstances (Glasow et al., 1996; Glasow et al., 2000; Glasow et al., 2005).

![Figure 5. The development history of VV&A](image-url)
3.2 IEEE 1278.4
IEEE 1278.4 was initiated by the IEEE DIS Committee and completed in 1997. IEEE 1278.4 provides VV&A guidelines for DIS emulation users and developers. It meets user requirements by flexibly defining and applying the DIS emulation VV&A basic principles, so different simulation purposes will result in completely different VV&A processes (Interactive and Committee, 1998).

3.3 IEEE 1516.4
IEEE 1516.4 practice defines the processes and procedures that should be followed to implement VV&A for federations being developed using the HLA with FEDEP, which provides implementation-level guidance to VV&A practitioners (Interoperability et al., 2007).

A summary of VV&A standards is presented in Table I. The most essential content of DoD RPG is to put VV&A behavior into the entire development life cycle of M&S. The advantages include easy operating documentation and so on. Whereas, the disadvantage is that the specification is special and cannot be applied independently to a special M&S process. They are more like a tutorial on the management and education of VV&A than scientific achievement. The IEEE 1278.4 protocol is primarily intended for the DIS protocol. IEEE 1516.4 is the VV&A standard of distributed interactive simulation systems based on HLA. IEEE 1278.4 and IEEE 1516.4 are aimed at standards performing the VV&A work for a typical system with special structure, so neither of them is universal.

The research establishment on VV&A standards is the important content in the simulation technology. It is a work of great significance, and it can improve the level of creditability of large-scale simulations and accelerate the standardization, intelligence, integration and automation of the reliability assessment. It can speed up the process of normalization and standardization of modeling and simulation and can satisfy the demands of VV&A standards of large-scale simulations. The next section will focus on the validation framework of VV&A.

4. The research on VV&A framework of large-scale simulations
Heritage techniques for VV&A (Sargent, 2005) cannot easily be transferred for simulations. It needs time and efforts (Terano, 2007; Klügl, 2008; Niazi et al., 2009; Pengfei et al., 2011; Railsback and Grimm, 2011), but these studies do not directly deal with the model verifying process. Validation techniques and their guidelines are addressed in most of the modeling textbooks and have even been instantiated in the form of a validation process for general

<table>
<thead>
<tr>
<th>Standard</th>
<th>DoD RPG</th>
<th>IEEE 1278.4</th>
<th>IEEE 1516.4</th>
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<tr>
<td>Application scenarios</td>
<td>Military project</td>
<td>Distributed interactive simulation</td>
<td>The high-level architecture simulation</td>
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<td>The role of VV&amp;A</td>
<td>Accreditation agent</td>
<td>VV&amp;A agent</td>
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<td>Purpose</td>
<td>Establish VV&amp;A methodology</td>
<td>Guide VV&amp;A operations</td>
<td>Provides VV&amp;A implementation-level guidance</td>
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<tr>
<td>Method</td>
<td>Define the VV&amp;A framework</td>
<td>Define the VV&amp;A framework</td>
<td>Define the VV&amp;A framework</td>
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<td>Kernel ideas</td>
<td>Roles phase</td>
<td>Roles process</td>
<td>Roles responsibilities</td>
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</table>

Table I. Compare the standards of VV&A
agent-based models (Law, 2007; Klügl, 2009). However, such techniques are still too general to provide a concrete, practical methodology for the key validation step. At the same time, agent-based modeling and simulation (ABMS) is an important branch of large-scale simulations (Li and Sun, 2007). It involves multiple agent co-simulations and has diverted researchers’ attention during the past decades. Furthermore, the weak validation and verification of agent-based simulation models make ABMS hard to trust. Each of these agent-based models needs to be validated separately, but how to validate the overall simulation of these combined models remains an unanswered question. It is generally well accepted that it is difficult to validate large-scale simulations sufficiently then to trust their results (Sargent et al., 2000). In many cases, the cost of trying to achieve complete validation is neither practical nor worthwhile (Shannon, 1975). In fact, it has been shown in previous research studies (Weisel et al., 2003; Weisel, 2004) that separately validated models can produce invalid outputs when combined. As per above discussion, it can be concluded that a VV&A simulation verification framework is needed to solve how to verify the simulations.

The first formal framework for V&V was proposed by Oberkampf (1994). This framework is proposed for building confidence in CFD (computational fluid dynamics) code predictions that overcomes some of the difficulties of past procedures and delineates, i.e. the causes of uncertainty in CFD predictions. Easterling (2001) provided a conceptual framework for quantifying the uncertainty in model predictions, which is shown in Figure 6. Bayarri et al. (2007) presented the conceptual framework for V&V of physics-based simulations. This framework quantifies multiple sources of error and uncertainty in computer models, combines multiple sources of information and updates validation assessments and acquires new information. Li-Ping and Xiao-Ping (2007) combined fuzzy similarity theory, fuzzy analytic hierarchy process (FAHP) and fuzzy comprehensive evaluation method to propose a comprehensive fuzzy credibility evaluation framework, which is applicable to the effectiveness of crowd simulation in loops. Mehrabadi et al. (2014) proposed the verification, validation, and uncertainty quantification (VV&UQ) framework, i.e. applicable to power electronic systems. This framework is used to gather all of the uncertainties during the simulation and modeling process. It gathers model form uncertainty, model inputs uncertainty and uncertainty due to the numerical approximations

![Figure 6. The first formal framework for V&V](image-url)
for quantitatively assessing the reliability of the model. Drchal et al. (2016) propose a six-step validation framework entitled VALFRAM (validation framework for activity-based models) that allows exploiting historical real-world data to assess the validity of activity-based models. Wang et al. (2016) present a novel rescheduling framework of the crude oil operations based on a continuous-time representation. Abnormal events and uncertainties in the crude oil tank farm area are considered and analyzed in this framework with an objective to improve the robustness of the final crude oil operations plan. In the same year, Barnes et al. (2016) presented a new simulation framework for wireless sensor networks based on QEMU and SystemC that aims at validating the binary code of wireless protocols by checking that the protocol’s implementation complies with its property specifications during the simulation process. Based on our experimental study, we tried to show the correct functionality of our hardware platform model by comparing with real frame exchange traces and the verification of one of the protocol’s properties during the simulation process.

VV&A verification framework not only improves the reliability of general simulation but also plays a significant role in large-scale simulations. The multi-agent simulations are from one of the main forms of large-scale simulations. There are many works about verification and validation of multi-agent simulations (Terano, 2006; Klügl, 2008; Niazi et al., 2009; Pengfei et al., 2011). However, these studies do not directly deal with the model testing process and never ever proposed a model testing framework to conduct validation and verification using the model testing process. In response to these problems, some scholars also proposed some validation frameworks for multi-agent simulation systems. Zoumpoulaki et al. (2010) proposed a framework for designing evacuation simulations that are based on a multi-agent BDI architecture enhanced with the OCEAN model of personality and the OCC model of the emotions. Furthermore, this paper (Gurcan et al., 2011) presents our testing framework in detail and demonstrates its effectiveness by showing its applicability on a realistic agent-based simulation case study. Moreover, they propose a generic framework for the automated execution of these requirements defined at each level. Furthermore, this body of work presents the design of a novel generic framework for the automated model testing of agent-based simulation models.

Table II summarizes few of the validation framework schemes. As per Table II discussions, although these frameworks meet the verification requirements of their simulation systems in combination with different methods, none of them is universal. Therefore, in the face of large-scale simulation, scholars need to develop a suitable simulation framework based on actual application scenarios.

Therefore, establishing a universal verification framework in the life cycle of VV&A will be helpful to apply VV&A methods and techniques to the simulation models. It can obviously improve the credibility of simulations, especially large-scale simulations like multi-intelligent simulations. The following section provides details on VV&A methods and technology. The next section will introduce the main technologies and methods in the VV&A process.

5. The research on VV&A technology and method of large-scale simulations
In every step of VV&A activities, proper VV&A methods and techniques should be selected and used as the specific operation methods. Therefore, it is extremely important and necessary to expand the research on VV&A methods and techniques of large-scale simulations.
5.1 Methodology
Since the late 1960s, foreign countries began to entertain VV&A during the simulation process. Fishman and Kiviat (1967) used the spectral analysis method to evaluate the equivalence between the simulation model and the actual system. In fact, it was the first time when the concept of verification and validation of the simulation model was proposed. Moreover, Sargent (2001) summarizes the verification methods of related simulation models, including Turing test, sensitivity analysis, extreme condition test, statistical test and subjective validity test. Combined with the research of related scholars, this research reviews VV&A methods considering two main aspects, i.e. credibility evaluation method and model validation method.

5.1.1 Credibility evaluation method. Credibility calculation is considered the most important task of VV&A. It can further be divided into two main steps, which are credibility testing method and credibility calculation method (Yu and Xiao, 2018).

5.1.1.1 The first research focuses on the credibility testing method. Based on the whole life cycle trusted process guarantee model, Lv (2016) proposed the Web application software credibility verification model. He proposed a software credibility testing method under the support of the verification model. Furthermore, considering the content structure of the
trusted behavior statement and the structural features and trusted features of REST application software, Liu (2017) proposed a RESTful Web application credibility testing method based on the behavioral declaration. Moreover, Yu and Xiao (2018) also proposed a new method of generating credibility test cases based on the immune algorithm.

5.1.1.2 The next research method is the credibility calculation method. Wright (1972) proposed a graph comparison method for credibility analysis. Balci and Sargent (1984) believe that the confidence interval method can be used to perform the relevant verification work of the simulations. Kheir et al. (1986) proposed using Theil’s inequality to analyze the relevant data of the missile’s simulation system and the actual system in flight experiments. Montgomery and Conard (1980) studied the spectrum analysis method and applied it to the verification of missile simulations. Han (2013) proposed a hybrid metric design method for application software credibility using static hash metrics and dynamic behavior values as evaluation criteria. Xiong et al. (2016) proposed a multi-attribute decision-making modeling method to design a strategy to build a credible indicator tree. This method is based on on-demand driving and using dynamic methods. Zhao et al. (2014) used the factor analysis method to construct a credibility evaluation index system for Web software. The structural entropy method is applied to the weight calculation of the credibility index. Qi et al. (2018) proposed a credible evaluation method based on FAHP. It combines the analytic hierarchy process (AHP) with the fuzzy comprehensive evaluation method. The intention is to overcome the problem that the subjective judgment of human beings as a person in the traditional AHP will have a great impact on the results. The literature (Yang et al., 2003) uses FAHP to calculate the weights of the factors affecting the credibility of the simulation, but the final credibility evaluation results only consider a set of expert scores.

5.1.2 Model validation method. Another important method of credibility research is the model credibility calculation method. It could help in verifying the credibility of a simulation. Several researchers have investigated and examined various validation approaches for different types of simulation models.

Birta and Ozmizrak (1996) proposed a method of a validation knowledge base, captured as a set of relationships between input and output variables of a simulation model. Kleijnen (1999) presented different statistical techniques to be used for simulation model validation based on the available data. Balci recommended that a validation method is the comparison of graphical outputs from simulations with experimental data and testing the degree of statistical agreement between the two (Balci and Sargent, 1982a, 1982b, 1984). Cooley and Solano (2011) describe the use of validation methods in model building. They discussed the stages of simulating an agent-based simulation model and presented six specific validation approaches. Ahn (2007) proposed a novel method for the validation of agent-based evacuation and crowd simulation. They used concepts from the field of human computation. Liu (2001) proposed the principle and fuzzy quantitative evaluation method for establishing the fuzzy comprehensive evaluation system for the credibility evaluation of large-scale simulations. However, the FAHP is not sufficient to determine the weight of each index, which reflects the ambiguity of expert judgment. Peng et al. (2017) believe that a similar degree method can be suitable for evaluating the credibility of a simulation system and an actual system. Tian et al. (2012) proposed that after applying the gray clustering method to the Integrative Avionics System, one can use this method after combining with the AHP for large-scale simulations.

A summary of a few VV&A method schemes is presented in Table III. In conclusion, there are several methods such as AHP, spectrum analysis and others that can also be applied to the simulation verification process. However, each method has its own advantages, disadvantages and scope of applications. It is necessary to select the
appropriate method according to the requirements of different application scenarios and its characteristics. For large-scale simulations, which have the characteristics of complex computation, interactive and autonomous, one can use the gray theory (such as gray prediction method, gray decision method) and the fuzzy mathematics theory to effectively deal with complex logic problems. Furthermore, the AHP can deal with multi-objective decision-making in a simulation. By summarizing the different methods proposed and discussed by various researchers, almost every researcher believes that a single method or theory is difficult to verify the various problems associated with a simulation system without applying for medicine according to indications.

5.2 Technology
Based on these methods, a substantial amount of research has been performed to define a technique for verifying and validating simulation models.
Balci (1994) surveyed current software validation techniques and current simulation model VVT techniques and describes how they can all be applied throughout the life cycle of a simulation study. The technology can be divided into informal, static, dynamic and formal. Moreover, a distinct difference between each classification exists (Figure 7):

- Informal techniques are among the most commonly used techniques. They are called informal because the tools and approaches used rely heavily on human reasoning and subjectivity without stringent mathematical formalism.

- Static techniques are concerned with accuracy assessment on the basis of characteristics of the static model design and source code. Static techniques do not require machine execution of the model, but mental execution may be used (Whitner and Balci, 1989).

- Dynamic techniques require model execution and are intended for evaluating the model based on its execution behavior. Most of the dynamic V&V techniques require model instrumentation.

### V&V Techniques for Simulation Models

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<th>Informal</th>
<th>Static</th>
<th>Dynamic</th>
<th>Formal</th>
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<td>Audit</td>
<td>Cause-Effect Graphing</td>
<td>Acceptance Testing</td>
<td>Induction</td>
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<td>Desk Checking</td>
<td>Control Analysis</td>
<td>Alpha Testing</td>
<td>Inductive Assertions</td>
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<td>Documentation Checking</td>
<td>Calling Structure Analysis</td>
<td>Assertion Checking</td>
<td>Inference</td>
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<td>Face Validation</td>
<td>Concurrent Process Analysis</td>
<td>Beta Testing</td>
<td>Lambda Calculus</td>
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<td>Inspections</td>
<td>Control Flow Analysis</td>
<td>Bottom-Up Testing</td>
<td>Logical Deduction</td>
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<td>Reviews</td>
<td>Static Transition Analysis</td>
<td>Comparison Testing</td>
<td>Predicate Calculus</td>
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<td>Turing Test</td>
<td>Data Analysis</td>
<td>Compliance Testing</td>
<td>Predicate Transformation</td>
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<td>Walkthroughs</td>
<td>Data Dependency Analysis</td>
<td>Authorization Testing</td>
<td>Proof of Correctness</td>
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<td>Data Flow Analysis</td>
<td>Performance Testing</td>
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<td>Fault/Failure Analysis</td>
<td>Security Testing</td>
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<td>Interface Analysis</td>
<td>Standards Testing</td>
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<td>Model Interface Analysis</td>
<td>Debugging</td>
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<td>Semantic Analysis</td>
<td>Execution Testing</td>
<td>Execution Monitoring</td>
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<td>Structural Analysis</td>
<td>Execution Profiling</td>
<td>Execution Tracing</td>
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<td>Symbolic Evaluation</td>
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<td>Fault/Failure Insertion Testing</td>
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<td>Syntax Analysis</td>
<td>Field Testing</td>
<td>Interface Testing</td>
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<td>Traceability Assessment</td>
<td>Functional (Black-Box) Testing</td>
<td>Graphical Comparisons</td>
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<td>Predictive Validation</td>
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<td>Product Testing</td>
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<td>Regression Testing</td>
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<td>Sensitivity Analysis</td>
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<td>Special Input Testing</td>
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<td>Boundary Value Testing</td>
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<td>Equivalence Partitioning Testing</td>
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<td>Extreme Input Testing</td>
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<td>Invalid Input Testing</td>
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<td>Real-Time Input Testing</td>
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<td>Self-Driven Input Testing</td>
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<td>Stress Testing</td>
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<td>Trace-Driven Input Testing</td>
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<td>Statistical Techniques</td>
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<td>Structural (White-Box) Testing</td>
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<td>Submodel/Module Testing</td>
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<td>Symbolic Debugging</td>
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<td>Visualization/Animation</td>
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Figure 7: A taxonomy of techniques for conventional simulation models
Formal techniques are based on mathematical proof of correctness. If attainable, proof of correctness is the most effective means of model V&V. Current state-of-the-art proof of correctness techniques is simply not capable of being applied to even reasonably large-scale simulations.

A taxonomy of more than 77 V&V techniques for conventional simulation models is presented in Figure 7. Detailed descriptions of these techniques can be found in previous works (Balci, 1998; DoD, 1996). Balci (1994) summarized VV&T techniques that are applicable to each of the ten credibility assessment stages described in Table IV. The more of these techniques we apply, the more confidence we may gain in the credibility of a life cycle phase.

Balci (1995) refers to the validation techniques listed in the US DoD VV&A recommendations and combines them with the relevant literature (Balci, 1994; DoD, 1996; Yilmaz and Balci, 1997). As per them, VV&T techniques are classified into six distinct credibility assessment perspectives: informal, static, dynamic, symbolic, constraint and formal. The object-oriented paradigm provides numerous advantages such as maintainability and reusability over the procedural paradigm (Sargent, 1997; Yilmaz and Balci, 1997). These techniques come from the software engineering discipline and are applicable to object-oriented simulation model V&V. They further divided the V&V techniques for object-oriented simulation models into conventional, adaptive and specific.

Based on special scenarios, especially in complex agent environments, some scholars have proposed relevant verification techniques. Railsback and Grimm (2011) have studied about testing agent-based simulation models. In this study, they define 10 important techniques to find and fix software errors: i.e. syntax checking, visual testing, print statements and spot tests with “agent monitors”, stress tests, test procedures, test programs, code analysis and statistical analysis of file output and independent reimplementation of submodels. However, they found the approaches they have proposed are far from the automation of the model testing process; the primary reason is that they do not have an architectural perspective about how these solutions could be integratively constructed and conducted. Moreover, some of their solutions are not generic and completely depend on the NetLogo simulation framework (Sklar, 2007). Louloudi and Klügl (2012) proposed a new technique to validate agent-based simulation models. A novel face validation technique is presented that enables systematic plausibility checks by a human expert immersed into a fine-grained virtual reality environment that is the exact representation of the simulated multi-agent model. Tabak et al. (2010) proposed to use radio frequency identification technology applied for validation of an office simulation model. This technique was proved to be effective by verifying that there were no significant differences between the predicted and observed activity behavior. To better utilize the potential of the system of simulation models and simulators, industrially applicable methods for VV&UQ are crucial. Eek et al. (2015) presented an exploratory case study of VV&UQ techniques applied on models integrated into aircraft system simulators at Saab Aeronautics and in driving simulators at the Swedish National Road and Transport Research Institute (VTI). Results show that a large number of V&V techniques are applied, some of which are promising for further development and used in simulator credibility assessment.

We can draw the following conclusions through observing Figure 7 and the Table IV: Informal techniques subjectively do not have stringent mathematical formalism. Most of them are used in formulated problem stages and system and objectives definition stages. Static techniques are mainly concerned with accuracy assessment on the basis of characteristics of the static model design; its main application is model design stage. Dynamic techniques (like sensitivity analysis and statistical techniques) are intended to
Table IV. The VV&T techniques for the credibility assessment stages

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<tr>
<th>Table IV. The VV&amp;T techniques for the credibility assessment stages</th>
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<td><strong>FP VV&amp;T of Sim</strong></td>
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<td>Assertion checking</td>
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<td>Black-box testing</td>
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<td>Bottom-up testing</td>
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<td>Boundary analysis</td>
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<td>Cause–effect graphing</td>
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<td>Consistency checking</td>
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<td>Data flow analysis</td>
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<td>Debugging</td>
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<td>Execution monitoring</td>
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<td>Execution profiling</td>
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<td>Execution tracing</td>
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<td>Face validation</td>
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<td>Graph-based analysis</td>
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<td>Lambda calculus</td>
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<td>Logical deduction</td>
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<td>Partition analysis</td>
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<td>Path analysis</td>
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<td>Predicate transformation</td>
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<tr>
<td>Proof of correctness</td>
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<tr>
<td>Regression testing</td>
</tr>
<tr>
<td>Reviews</td>
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<td>Semantic analysis</td>
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<td>Sensitivity analysis</td>
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<td>Statistical techniques</td>
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<td>Stress testing</td>
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<td>Structural analysis</td>
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<td>Submodel testing</td>
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<td>Symbolic debugging</td>
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<td>Symbolic execution</td>
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<td>Syntax analysis</td>
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<td>Top-down testing</td>
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<td>Visualization</td>
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<td>Walkthroughs</td>
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<td>White-box testing</td>
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</table>

**Notes:** FP VV&T = Formulated Problem VV&T; FA of Sim = Feasibility Assessment of Simulation; S&OD VV&T = System and Objectives Definition; VV&T Model Qual = Model Qualification; CM VV&T = Communicative Model VV&T; PM VV&T = Programmed Model VV&T; ED VV&T = Experiment Design VV&T; EM VV&T = Experimental Model VV&T; Pres. VV&T = Presentation VV&T
evaluate the model based on its execution behavior; Formal techniques are based on mathematical proof of correctness and mainly targeted at programmed model VV&T. Actually, the dynamic technology is absolutely more suitable for facing the more complex behavioral activities in large-scale simulations.

Strengthening the research on VV&A technique and methods of large-scale simulations can not only establish the foundation for the development of VV&A software tools but will also further improve and strengthen VV&A theory. Furthermore, at the same time, it can solve the problem of single-operation methods in VV&A work and can also provide the technical support for performing VV&A work during the life cycle effectively and comprehensively. The preceding section discusses the basic tool used in VV&A process.

6. The development of VV&A validation tools of large-scale simulations
VV&A is of great significance in the simulations. In the actual VV&A activities, it is difficult to implement the complete VV&A principles due to the systematic engineering, which requires a sound program design, effective organization, efficient management, a large number of testing and data processing work (Mazhen et al., 2016). Furthermore, comparing with simple simulations, most of the difficulties that can be found during the assessment of the credibility of large-scale simulations are mainly manifested in the following aspects (Chens et al., 2001):

- Large-scale simulations have a huge scale, including many subsystems, and the evaluation workload is quite large. It is difficult to complete the task by manual work alone (Qin, 2009).
- The large-scale simulations have many evaluation indexes, complex index tree structure and a huge amount of expert evaluation data and need a lot of calculation in the evaluation process. Without special auxiliary tools, it is difficult to ensure the correctness of evaluation calculation (Birta and Ozmizrak, 1996; Zupan et al., 2006).
- There are many evaluation methods for large-scale simulations, and it is difficult to ensure the accuracy of the evaluation results by a single evaluation method. How to select and use statistical methods correctly has become a major problem for the validators of large-scale simulations (Deslandres and Pierreval, 1991; Balci et al., 2000).

These problems can be solved by using VV&A tools to some extent. Therefore, it is of great significance to study the simulation model VV&A tools, which can be shown as follows:

- To improve VV&A automation level of the simulation, the VV&A of the simulation is an extremely complicated task, which involves many links, and these links have a division of labor that works together. However, VV&A tools can not only improve the economy and rapidity of VV&A work and reduce the work intensity of VV&A personnel but also greatly improve the automation degree of VV&A.
- To improve VV&A collaboration of the simulation, the VV&A tool of simulation can support VV&A personnel to cooperate closely with project managers, design developers and model users, to share various resources in the process of modeling, exchanging various information frequently and greatly improve the collaboration degree of imitation VV&A.
- To improve the integration of the VV&A, the use of the VV&A tool integration framework to integrate all kinds of VV&A tools that have been and will be developed can not only save resources and facilitate data sharing but also significantly improve the integration degree of VV&A.
Therefore, the simulation requires a large number of model VV&A tools to assist in the VV&A process. These tools support the VV&A work throughout the life cycle of the model development with different functions at different stages of the VV&A development model. Ma Zhen divided VV&A’s tools into two major types: tools for VV&A activity and function and artificial intelligence. The VV&A activity tools are shown in Figure 8.

Moreover, the simulation model VV&A tool first appeared in the early 1990s, mainly based on the development of VV&A tools in some West developed countries. By the end of the twentieth century, dozens of assistant tools have been developed abroad for one or more stages of the VV&A process (Balci, 1998; Dean, 2004; Zeigler and Sarjoughian, 2002). Some VV&A tools developed abroad and their functions are summarized, as shown in Table V.

Besides, many scholars have also designed VV&A tools for different scenarios. To reduce the workload and save the resource of evaluation, Qin (2010) designs and develops a simulation credibility evaluation assistant tool based on hierarchical evaluation. HIT-CET (Harbin Inst. of Tech. Credibility Evaluation Tool) can effectively assist to finish the evaluation work, improve the work efficiency and reduce the cost of the evaluation. Reid et al. (2012) created the STAT (Simulation Team Assessment Tool) to evaluate key components of all pediatric resuscitations, not only to evaluate specific scenarios. They created a valid, reliable tool for the evaluation of a team’s comprehensive performance during a simulated pediatric resuscitation, which includes medical decision-making,

![Figure 8. The classification of VV&A tools for a simulation model](image)

<table>
<thead>
<tr>
<th>Tool</th>
<th>R and D company</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Activity</td>
<td>Function</td>
</tr>
<tr>
<td>1 Accreditation, Assessment, Assistant</td>
<td>Joint, accreditation support activity</td>
<td>Verification, validation and accreditation</td>
</tr>
<tr>
<td>2 V&amp;V Managers Toolkit</td>
<td>TRADOC</td>
<td>Verification</td>
</tr>
<tr>
<td>3 VVACET</td>
<td>Tecmasters</td>
<td>Management</td>
</tr>
<tr>
<td>4 Analyst-Pro</td>
<td>GoData Software, Inc.</td>
<td>Verification</td>
</tr>
<tr>
<td>5 Caliber-RBT</td>
<td>Technology Builders, Inc.</td>
<td>Validation</td>
</tr>
<tr>
<td>6 Code Wizard</td>
<td>Para Soft</td>
<td>Accreditation</td>
</tr>
<tr>
<td>7 DAVIE</td>
<td>DMSO Data Engineering</td>
<td>Validation</td>
</tr>
<tr>
<td>8 JASA</td>
<td>Joint Accreditation Support</td>
<td>Verification, validation</td>
</tr>
<tr>
<td></td>
<td>Activity</td>
<td>and accreditation</td>
</tr>
<tr>
<td>9 Authoritative Data Source Library PC Version</td>
<td>DMSO</td>
<td>Verification</td>
</tr>
<tr>
<td>10 DAKOTA</td>
<td>Sandia National Laboratory</td>
<td>Verification, validation</td>
</tr>
<tr>
<td>11 Temporal Verification Framework</td>
<td>Arizona Center for Integrative M&amp;S</td>
<td></td>
</tr>
<tr>
<td>12 HLA Lab Works Suite of Tools</td>
<td>Aegis Technologies Group, Inc.</td>
<td>Verification, accreditation</td>
</tr>
<tr>
<td>13 Vertical Sky Solution 3.1</td>
<td>Vertical Sky</td>
<td>Verification</td>
</tr>
</tbody>
</table>

Table V. The part of a foreign VV&A tool for the simulation model
technical skill and human factors. Several tools are also developed proposing different ways of validating multi-agent simulations. Klugl (2008) proposes a process for validating agent-based simulation models which combines face validation, sensitivity analysis, calibration and statistical validation. Niazi et al. (2009) propose a validation and verification tool for agent-based simulation models for a wide variety of models. In this tool, a multi-agent overlay is created on top of the actual simulation model. The agents populating this overlay have a main task to monitor the simulation’s run based on predefined constraints which when violated are logged. Montanola-Sales et al. (2011) present the verification and validation of an agent-based demographic simulation model implemented using a parallel demographic simulation tool (Yades) using white-box validation methods described by Pidd (2004). In this sense, Montanola-Sales et al. divide their model into smaller components and test the correctness of each component.

VV&A work of large-scale simulations is a complicated process. It is more difficult and inefficient to carry out VV&A work completely relying on the human. Therefore, it is necessary to develop VV&A tools of large-scale simulations to make the management more systematic, professional and automatic with an intention of improving the efficiency of VV&A work. This section summarizes the current VV&A tools and explains the importance and necessity of VV&A tools in the simulations. The following section will introduce the main content of this article and the plan for the next step.

7. Summary
VV&A is the most important method to assess the credibility of the simulation system. This paper presents a review of 114 papers on VV&A research of simulation and elaborates the application of VV&A in the simulation system by reviewing VV&A concept, VV&A standard, VV&A framework, VV&A technology, methods, VV&A tool, etc. The primary motivation is to present an in-depth theoretical review and analysis for the application of VV&A in large-scale simulations. We focused on the related research of VV&A in large-scale simulation; the standards of VV&A have defined the processes and procedures. The framework which facilitates the full application of techniques and methods to simulation. Moreover, we also examined the tools that can improve automation level and operation efficiency of VV&A in simulations.

Crowd network is the main mode of the modern service industry and future economy society (Chai et al., 2017; Sun and Zhang, 2017), which has the characteristics of large-scaled, open-style, self-organized and ecological intelligent network (Nan et al., 2017). Compared with traditional large-scale simulations, crowd science simulations have several obvious challenges as follows:

- Dynamic is the first challenge. Member attributes and states of crowd science simulations may vary at any time in an uncertain mode. Members are more loosely coupled, but member behaviors and intention variations may lead to a change of group states and intentions in extending scopes.
- Diversification is performed as a key feature; for example, time advance strategy may base on changes of slow variables, events and clock or hybrid mode. Moreover, as members are multiform and multi-disciplinary, transactions are uncertain and various, disturbances have several sources and subscriptions exist in a different layer and aspects, disturbances injection strategy and matching strategy are all needed to take diversification into consideration.
- The scale of crowd science simulation may need to achieve millions or even more trillions to uncover or verify principals and regularities of crowd science.
In a nutshell, crowd science simulation is a new development of large-scale simulations. To better improve the credibility of the crowded network and solve the challenges it creates, it is very essential, urgent and imperative to make standards and frameworks on VV&A working of crowd science simulations. Moreover, this research can help researchers to provide support of a recommendation for formulating VV&A in large-scale simulations.

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Further reading


Survey on VV&A of large-scale simulations


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Exploring the relationships between gamification and motivational needs in technology design

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Abstract

Purpose – Drawing upon the motivational affordance theory, this paper aims to investigate how gamification design and human motivational needs are associated in extant literature.

Design/methodology/approach – The authors conducted a literature analysis of 60 journal articles that studied motivational influences of gamification in information technology design. Content analysis was used to identify game design features and motivation variables studied in prior literature, and correspondence analysis was used to show the co-occurrence of game design features and basic motivational needs.

Findings – The results showed that four types of game design features and eight basic motivational needs are studied in this pool of literature. Correspondence analysis indicates some interesting associations between game design features and basic human needs.

Research limitations/implications – This research used a motivational affordance perspective to interpret the impact of game design features and suggested directions for future investigations. It is limited due to its sample size and considered as an exploratory study.

Practical implications – This research provided suggestions for technology designers that game design features vary in their motivational influence, and therefore, game design features should be used accordingly to meet users' motivational needs.

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Erratum: It has been brought to the attention of the publisher that Jian Tang and Ping Zhang (2018) “Exploring the relationships between gamification and motivational needs in technology design”, published in the International Journal of Crowd Science, https://doi.org/10.1108/IJCS-09-2018-0025 is not the final version of the manuscript and was published due to a production error. Emerald and its typesetters sincerely apologize to the authors for any inconvenience caused. The final version of the manuscript has now been published in its place and contains revised figures and expands upon several sections.
Originality/value – This research is one of initial studies which explored the association between game design features and basic motivational needs. The findings of this study provide the groundwork for guidelines and strategies to facilitate motivational design in information technology.

Keywords Gamification, Human-computer interaction, Basic human needs, Motivational affordances

Paper type Research paper

1. Introduction

Motivation refers to what gives behavior its energy and direction (Ryan and Deci, 2000). In information technology design, a motivational perspective has become increasingly popular and uncovered the drive for technology use (Zhang, 2008a). To understand the underlying mechanism of user behavior in technology interaction, researchers who are interested in the motivational perspective have raised questions such as “why do people initiate, continue, stop, or avoid using technology,” “why do such behaviors vary in intensity” and “how can our understandings of people’s behaviors and their intensity help us design desirable technology that people want to use.” (Zhang, 2008a). Therefore, knowing how to effectively motivate users to adopt and continue using information technology has become a critical issue for researchers and practitioners. In recent years, gamification design, an approach that integrates non-game activities with play to afford similar experiences as games do (Huotari and Hamari, 2017), has been used to engage users in many serious contexts, such as information systems (Liu et al., 2017), marketing (Huotari and Hamari, 2017), education (Hanus and Fox, 2015) and health care (Hamari and Koivisto, 2015b).

Despite an increasing attention from researchers and practitioners, researchers have identified inconsistent impact of using gamification design when influencing user psychological states (Morschheuser et al., 2017). Prior research has presented conflicting findings regarding the effects of gamification design. For instance, quantified measurements such as points, leaderboards and levels are found to have positive effects on user participation (Halan et al., 2010), though researchers are also concerned that these game elements may only increase participants’ extrinsic motivation in the short-term period, with diminishing effects in the long run (Lee et al., 2013). Mekler et al. (2017) found that goal metrics such as points, levels and leaderboards mostly function as external incentives. Research has even found that badges and leaderboards had negative impacts on motivation and student performance in an educational project (Hanus and Fox, 2015). Leaderboards may demotivate low-ranked participants and lead to possible negative effects on overall outcomes (Ipeirotis and Gabrilovich, 2015; Massung et al., 2013; Preist et al., 2014).

One possible reason for such contradictory finding is that many studies do not isolate the effects of individual game elements, and it is therefore impossible to assess to what extent each game element explained the variance of user motivation and performance (Morschheuser et al., 2017; Peng et al., 2012). More importantly, findings from prior studies showed that it is still unclear to what extent the extant literature on gamification takes on a motivational perspective and what are motivational mechanisms of game design elements. In particular, it is still uncertain how to interpret the motivational effects of gamification design and what the motivational paths of game design features are. Given that gamification has become such a trendy approach in technology design, understanding the motivational path of gamification design would make future gamification design more effective and efficient.

As a first step toward that understanding, we conducted a literature analysis of published papers that focus on gamification and motivation that relates to technology design or evaluation. Specifically, we draw upon the motivational affordances theory to...
understand the motivational influences of gamification design. This analysis focuses on game design features and their potential relationships with basic human needs. Our investigation is guided by two research questions:

RQ1. To what extent game design features are linked to basic human needs?

RQ2. What are the potentials of gamification design to motivate users through satisfying their basic needs?

2. Related work

2.1 Gamification

Gamification is a design approach that introduces game elements into non-game contexts to attract participants and create gameful experiences (Hamari et al., 2014). Researchers in information systems (IS) field have shown a long interest in gamification design, though not always using the term “gamification.” IS researchers have investigated the impact of games, play design, rewards and scores (Broer and Poeppelbuss, 2013). These prior attempts showcased the importance of gameful design and its profound effects on technology use (Schlagenhaufer and Amberg, 2015) and identified the potentiality of using gamification design to make repetitive tasks more fun and enjoyable (Flatla et al., 2011).

Among few conceptualizations of gamification, Liu et al. (2017) suggested that gamification design could be categorized into two broad categories, gamification objects and gamification mechanics. Gamification objects refer to visual or non-visual digital objects that form building blocks of gamification systems. Examples of gamification objects include graphics, audio clips, avatars, virtual items, artificial characters, storylines, badges and leaderboards. Gamification mechanics is a higher level of design that is built with game artifacts with play patterns and dynamics, such as level system, point system, quests, competition, and collaboration, in-game economy and social networking systems. These two conceptual levels of gamification design informed a structured view of gamification design, and the framework proposed by Liu et al. (2017) takes a further step to illustrate the motivational influences of these two categories of gamification design. Gamification objects are fundamental components of gamification design and have been investigated in many prior studies (Mekler. et al., 2017; Landers and Armstrong, 2017). To figure out the motivational mechanism of gamification design, it is important to understand the association between gamification objects and their motivational effects. In this research, we attempted to investigate the impact of gamification design at the level of gamification objects, which is at times referred to as game design features. Therefore, in the following paper, terms gamification objects and game design features will be used interchangeably.

2.2 Motivational affordance theory

Several researchers attempted to undertake the perspective of motivational affordances to investigate the effects of gamification design, and the term “gamification affordance” is used to indicate the motivational effect of individual game elements (Morschheuser et al., 2017). However, according to the motivational affordance theory (MAT) (Zhang, 2008a), motivational affordances indicate the action possibilities supported by information technology to satisfy basic needs. So gamification affordances should not be equivalent to specific game elements, which, however, only represent object features that are implemented in gamified technology design. Meanwhile, we admit the importance of using the notion of motivational affordances to interpret the effects of gamification design.

Technology design
Motivational affordances refer to the action possibilities perceived by users of an information and communication technology (ICT) to satisfy their internal motives (Zhang, 2008a; Zhang, 2008b). MAT posits that technology can be designed in a way that affords possibilities to satisfy basic human needs. MAT is rooted in motivational theories, which speculate the sources and roles of motivation on behavior. There are two types of sources of motivation: external events and internal motives (Reeve, 2005). External events are environmental incentives that have the capacity to energize and direct behavior, such as learning to earn monetary rewards (Ryan and Deci, 2000). On the other hand, an internal motive is an internal process that energizes and directs behaviors, such as learning for the sake of enjoying it (Ryan and Deci, 2000). Internal motives serve the organism by generating wants, desires and strivings that motivate whatever behaviors are necessary for the sake of well-being and growth.

Human basic needs, including physiological needs, psychological needs, social needs, cognitions and emotions, should be considered to enhance motivational aspect of technology design (Zhang, 2008b). Physiological needs relate to the working mechanism of biological systems, which is inherently associated with the strivings of human nature and healthy development. Psychological needs are generated from one’s desire to pursue interaction with the environment, creating practices that promote psychological vitality, well-being and growth. Examples of such needs include autonomy, competence and relatedness. Social needs relate to one’s socialization history, reflecting the activated emotional response to a need-relevant incentives, such as desire for power. Cognitions refer to mental events such as beliefs, expectations and the self-concept. Cognitive sources of motivation revolve around a person’s ways of thinking. Emotions are short-lived, subjective phenomena that orchestrate how we react adaptively to the important events in our lives. Based on these typical categories of sources of motivation, eight basic needs were identified to represent the fundamental drive of human behavior and were argued to be granted substantial research attention in information technology design (Zhang, 2008b; Zhang, 2008a). Table I summarizes the eight basic human needs identified in the MAT.

According to the MAT (Zhang, 2008a), motivational affordances indicate action possibilities supported by information technology to satisfy basic needs. It is important to note that motivational affordances are not equivalent to specific design objects and actually indicate some relational attributes between design objects and human motivational needs. The extant literature shows a gap regarding how game design features are associated with

<table>
<thead>
<tr>
<th>Basic needs</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomy</td>
<td>Need for choice in initiating and regulating one’s behavior</td>
</tr>
<tr>
<td>Self</td>
<td>Need for defining/creating self and self-image, relating the self to society and discovering and developing personal potentials</td>
</tr>
<tr>
<td>Competence</td>
<td>Need to master challenges that are developmentally appropriate</td>
</tr>
<tr>
<td>Achievement</td>
<td>Desire to do well relative to a standard of excellence that encompasses competitions with a task, with the self and against others</td>
</tr>
<tr>
<td>Leadership</td>
<td>Desire to make physical or social world to conform to one’s image/plan; desire to impact or control over others or the world</td>
</tr>
<tr>
<td>Followership</td>
<td>Desire to be influenced by others, to follow others</td>
</tr>
<tr>
<td>Relatedness</td>
<td>Desire to belong</td>
</tr>
<tr>
<td>Affect and emotion</td>
<td>Induced affective states arising as reactions to important stimuli; favorable reacts to stimuli as a natural selection process; sustain desired emotions via cognitive process</td>
</tr>
</tbody>
</table>

Table I. Basic human needs
human motivation, and the lens of motivation affordances provides a niche to interpret the effects of gamification design.

3. Research methodology

3.1 Paper selection

To gain an understanding of how extant literature addresses the motivational impact of gamification design in the context of technology design, we conducted a review of gamification studies reported in English that have a motivational component, an information technology aspect and a design approach or empirical evaluations and may have broad applications in various domains. There are several steps leading to the pool of papers to be selected for this study.

In Step 1, we conducted a literature search with the phrase “gamifi* AND motiv*” in six databases in November 2017. To ensure the relevance of search results, we limited the fields of search to title, abstract and keywords. The search returned the following results: web of Science 765 hits, Scopus 1,120 hits, Science Direct 98 hits, ProQuest 71 hits and JSTOR 5 hits. As the Association of Information Systems e-library does not allow users to set search fields to include title, abstract and keywords altogether, we did the same phrase search in the full-text, which yielded 320 hits.

In Step 2, non-English journals or articles, trade magazine articles, conference proceeding papers and editorial, short demo, opinion or pop educational papers were removed to ensure that the selected articles report complete research and have sufficient details.

In Step 3, additional selection criteria were applied to the papers from Step 2 so that the collection of selected articles met the research purpose. An article was removed if it fit one or more following conditions:

- has no ICT component (a paper should be about designing or evaluating an ICT-based gamification or gamification using ICT);
- is not about gamification (might just have a mere mentioning of it);
- is not about the design or evaluation (with real subjects, and not just preliminary empirical study) of a gamification system/application;
- is a design paper without empirical evaluation or theory-driven design guidelines;
- is a conceptual paper with no specific design or evaluation of a gamification system/application;
- is a review or synthesis of gamification studies or development;
- is a pure qualitative study (e.g., focus group, case study and interview); and
- is impossible to identify motivational states or drives of participants (e.g. young children 30-50 months old and second-year primary school students).

3.2 Paper analysis

After removing papers that did not meet the filtering criteria, only 60 empirical studies were kept for the following literature analysis. Gamification designs share essential features that make non-game activities “gameful.” Based on the structured view of gamification design (Liu et al., 2017), gamification mechanics are a level of design that build on a series of gamification objects, which represents more fundamental design blocks in a gamified technology. To understand the fundamental building blocks of gamification in ICT design, we try to identify specific game design features and attempt to classify them into categories that may have practical meanings and functions.
We also analyzed motivational related variables, constructs and themes to assess to what extent the extant literature undertakes a basic needs perspective to understand motivational influences of gamification design. Only a few of the 60 articles addressed the eight basic needs directly, either as core research variables or themes. For example, competence is directly studied as a variable in Nelson et al. (2016); needs for competence, relatedness and autonomy have been directly studied by Tan and Hew (2016).

For the majority of the 60 papers, basic needs were not the foci of the studies. Yet, each of these studies would consider some motivational variables (see paper selection criteria). A careful examination of the wordings of the measures for motivational variables may reveal that some basic needs are being touched upon, even if not consciously, thoroughly or rigorously. For example, in Suh et al. (2017), the measurements for four facets of flow experience and three facets of aesthetic experience touch upon the following five basic needs: autonomy, self, competence, achievement, and affect and emotion. Therefore, two researchers recorded motivation-related variables studied in the collected and then used Table I as a guiding codebook to identify basic needs from each of the 60 papers. Two researchers independently coded basic needs, using motivational affordances theory as a guide framework. The initial inter-rater agreement was 83 per cent, and after discussions, the agreement reached 100 per cent.

4. Results
In this section, we present descriptive and direct observations from the literature analysis of the 60 papers. The 60 papers were published in 36 different journals. Among these journals, Computer in Human Behavior published 16 papers, Computers and Education published 6, four journals published 2 papers each and the rest of the 30 journals published 1 article each. The publication years range from 2013 to 2018, with 1 paper in each of 2013 and 2018, 5 in 2014, 14 in 2015, 17 in 2016 and 22 in 2017. The frequency distribution shows a sharp increase in the number of publications on this topic in recent years.

The collected articles have addressed a variety of application domains. The most studied application domain is education and learning (33), followed by marketing and e-commerce (9) and health care (7). Other domains include knowledge management, crowdsourcing, human resource management, social media, manufacturing, tourism and citizen science. The broad distribution of domains shows that researchers from various disciplines showed interest in implementing gamification design in technology design to enhance user motivation.

4.1 Findings on game design features
Specific gamification objects were found in each of the 60 articles. Two researchers independently reviewed the articles and recorded original terms used in the literature. Overall, 147 game design features were identified in this literature collection. Table II shows the frequencies of commonly studied game design features. Badges/trophies, leaderboards and points are the three top game features that have been studied in this pool of literature, followed by levels, avatar and virtual item.

The analysis revealed a list of game features as shown in Table II, yet it is notable that not all these features influence cognitive, sensory or function experiences of users in the same way. Upon careful examination of these features, the following four types of features are emerged:
<table>
<thead>
<tr>
<th>Features</th>
<th>Papers</th>
<th>Frequency</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Badges/trophies</td>
<td>(Aydin, 2018; Alabbasi, 2017; Bittner and Shipper, 2014; Borras-Gene et al., 2016; Ding et al., 2017; Hakulinen et al., 2015; Hamari and Koivisto, 2015a; Su and Cheng, 2015; Koivisto and Hamari, 2014; Malas and Hamtini, 2016; Cheong et al., 2014; Hamari, 2013; Auvinen et al., 2015; Wang et al., 2016; Sailer et al., 2017; Albuquerque et al., 2017; Halloluwa et al., 2016; Hew et al., 2016; Frost et al., 2015; Kwon et al., 2015; Hamari and Koivisto, 2015b; Fajiculay et al., 2017; Buckley and Doyle, 2017; Sigala, 2015b; Gonzalez et al., 2016; Browne et al., 2014; Aydin, 2015; Suh et al., 2017)</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Leaderboards</td>
<td>(Zarzycka-Piskorz, 2016; Aydin, 2018; Yang et al., 2017; Alabbasi, 2017; Bittner and Shipper, 2014; Hamzah et al., 2015a, Landers and Armstrong, 2017; Rodrigues et al., 2017; Su and Cheng, 2015; Malas and Hamtini, 2016; Mekler et al., 2017; Wang et al., 2016; Sailer et al., 2017; Albuquerque et al., 2017; Nebel et al., 2016; Tan and Hew, 2016; Iaremenko, 2017; Chen et al., 2016; Buckley and Doyle, 2017; Gonzalez et al., 2016; Fotaris et al., 2016; Aydin, 2015; Suh et al., 2017; Suh and Wagner, 2017)</td>
<td>24</td>
<td>16</td>
</tr>
<tr>
<td>Points</td>
<td>(Nebel et al., 2017; Aydin, 2018; Alabbasi, 2017; Bittner and Shipper, 2014; Prestopnik and Tang, 2015; Hamari and Koivisto, 2015a; Rodrigues et al., 2017; Koivisto and Hamari, 2014; Song et al., 2017; Boendermaker et al., 2015; Albuquerque et al., 2017; Su, 2016; Morillas Barrio et al., 2016; Chen et al., 2016; Buckley and Doyle, 2017; Gonzalez et al., 2016; Fotaris et al., 2016; Suh et al., 2017)</td>
<td>19</td>
<td>13</td>
</tr>
<tr>
<td>Levels</td>
<td>(Hamari and Koivisto, 2015a, Koivisto and Hamari, 2014; Malas and Hamtini, 2016; Luu and Narayan, 2017; Boendermaker et al., 2015; Nebel et al., 2016; Browne et al., 2014; Suh and Wagner, 2017; Suh et al., 2017)</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Avatar</td>
<td>(Rodrigues et al., 2017; Rodrigues et al., 2016b, Kaczmarek et al., 2017; Rodrigues et al., 2016a, Sailer et al., 2017; Albuquerque et al., 2017; Su, 2016; Buckley and Doyle, 2017)</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Storyline</td>
<td>(Prestopnik and Tang, 2015; Boendermaker et al., 2015; Sailer et al., 2017; Pitura and Chmielarz, 2017; Su, 2016)</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Virtual item</td>
<td>(Santhanam et al., 2016; Su, 2017; Snow et al., 2015; Sigala, 2015b, Aydin, 2015)</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Progress</td>
<td>(Siemens et al., 2015; Nelson et al., 2016; Buckley and Doyle, 2017; Fotaris et al., 2016)</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Rewards</td>
<td>(Hamzah et al., 2015a, Kim and Ahn, 2017; Tan and Hew, 2016; Suh et al., 2017)</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Character</td>
<td>(Su, 2017; Kaczmarek et al., 2017; Su, 2016)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Feedback</td>
<td>(Zarzycka-Piskorz, 2016; Alabbasi, 2017; Gonzalez et al., 2016)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Role-play</td>
<td>(Su, 2017; Luu and Narayan, 2017; Su, 2016)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Team</td>
<td>(Rodrigues et al., 2016b, Rodrigues et al., 2016a, Sailer et al., 2017)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Missions</td>
<td>(Su and Cheng, 2015; Luu and Narayan, 2017)</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Countdown</td>
<td>(Su, 2016; Gonzalez et al., 2016)</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Challenges</td>
<td>(Adukaite et al., 2017; Gonzalez et al., 2016)</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Combat</td>
<td>(Kaczmarek et al., 2017; Buckley and Doyle, 2017)</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Others</td>
<td>(Ding et al., 2017; Pe-Than et al., 2014; Santhanam et al., 2016; Rodrigues et al., 2017; Boendermaker et al., 2015; Sailer et al., 2017; Chen et al., 2016; Buckley and Doyle, 2017; Browne et al., 2014; Aydin, 2015, Hamzah et al., 2015b)</td>
<td>19</td>
<td>13</td>
</tr>
</tbody>
</table>

**Table II.** Game design features and frequencies

**Note:** Game design features that only appeared once were categorized as “others”, such as applause, music, and animated contents.
(1) **Type 1**: It indicates performance status by providing quantitative measurements. Examples include badges, points, scores, difficulty levels, prizes, status bars, etc.

(2) **Type 2**: It engages players deeper into the essence and meaningfulness of the games. Examples include storylines, mission, character building, avatars, profile, role-play, etc.

(3) **Type 3**: It indicates social significance and influence. Examples include leaderboards, collaborative, social points, social media sharing, likes, group forming, team building, team scores, sharing badges, etc.

(4) **Type 4**: It enhances the quality of experience but non-functional, thus not essential. Examples include animation, music, sound, voice, graphics, appearance customization, etc.

Therefore, game design features of each article were coded into one or more of the four types. The descriptive analysis shows that Type 1 is the most studied feature and covered in 53 papers, followed by Type 3, which is studied by 40 papers. Type 2 is studied by 31 papers, and Type 4 is studied by 4 papers. The results also show that a single paper is usually investigated more than one type of game design features. Among the 60 papers, 2 papers covered all four types in their studies, 18 papers covered three types, 26 papers covered two types and only 14 papers focused on one type of game design features. The most studied Type 1 feature is badge/trophies. Other examples of Type 1 features are level, score, point, trophy, prize, virtual currency, title, activity count, performance graph, progress bar, status bar, positive feedback, time limit, reward and percentage. The most studied Type 2 feature is avatar. Other Type 2 features are character, avatar, story line, virtual items, challenge, mission, profile, quest, goal and walk-away option. For Type 3, the most popular feature is leaderboard. Other examples include collaborative competition, social point, social network, social media sharing, team, teammate and virtual room for socializing. There are only four papers on Type 4 with the following features: animation, music, applause, sound, voice, graphics, visualization and customization (for color, music and appearance).

### 4.2 Findings on basic needs

Basic needs are identified from variables, constructs or core themes discussed by the authors of collected literature. Collectively, the 60 papers touched upon all the eight basic needs in Table I, which shows that basic needs are either intentionally or unconsciously discussed and used by researchers when interpreting the impact of gamification design. However, our results also show that some needs, such as affect and emotion, were covered more extensively than others. Specifically, affect and emotion was studied by 37 papers, followed by competence (32 papers), relatedness (28 papers), achievement (25 papers), autonomy (17 papers), leadership (6 papers), followership (6 papers) and self (5 papers). A further examination of these frequencies indicate that most papers covered more than one basic needs. For instance, Pe-Than et al. (2014) and Kwon et al. (2015) covered six basic needs. Five papers covered five basic needs in their research (Sailer et al., 2017; Hamari and Koivisto, 2015a; Sigala, 2015a; Frost et al., 2015; Siemens et al., 2015). Furthermore, 10 papers covered four basic needs, 12 papers studied three basic needs, 14 papers investigated two basic needs and 15 papers focused on one basic needs. Two papers, however, did not examine any basic needs. The frequencies show that a majority of extant literature studied some aspects of basic human needs.
4.3 Correspondence analysis

The descriptive analysis in previous sections provides an overview of game design features and basic needs identified in the collected literature. Correspondence analysis is a method applied to reveal additional insights in qualitative analysis results (Hoffman and Franke, 1986). It is an exploratory technique that displays contingency tables as points in dual, low-dimensional vector spaces (Greenacre, 1984) and provides a direct visualization of relationships among categorical variables (Glynn, 2012; Remenyi, 1992). The maximum number of dimensions needs to represent the raw data table is equal to one less than the smaller of the number of rows or columns of contingency table (Hair et al., 2006). Inertia (eigenvalues) is used to assess the degree of explained variable in correspondence analysis, and usually a rule of thumb is that dimensions with inertia greater than 0.20 should be included in the analysis (Hair et al., 2006). Correspondence analysis is especially helpful to analyze contingency tables with multilevel category variables and therefore is an appropriate technique to present associations between categories of qualitative analysis codes. In this research, we conducted correspondence analysis to provide additional insights in the relationships between game design features and basic needs. It is important to note that the goal of correspondence analysis is not to validate significant relationships among categorical variables but to illustrate the co-occurrences among the variables.

Table III summarizes the co-occurrence between game design features and basic needs. For example, autonomy and Type 2 are co-studied 16 times. Leadership or followership is never co-studied with Type 4 in the 60 selected papers.

We conducted the correspondence analysis with package ca from R for windows 3.4.3 (R Development Core Team, 2012). According to the results from the correspondence analysis, the first dimension explained 76 per cent of the variance, and the second dimension explained 17 per cent. These two dimensions explained 93 per cent of the variance, so the perceptual map (Figure 1) is drawn along these two dimensions.

Figure 1 shows four types of game design features in four quadrants, which are distinctive from one another and are surrounded by the eight basic needs. The distance between game design feature codes (GType1-4) and eight basic needs shows their co-occurrence associations. When they are closer, it means they are more likely to co-occur with each other in the collected articles. Type 1 and Type 2 are closer with each other than the other two types of game design features, indicating that these game design features are frequently studied together. Type 1 co-occurred more with autonomy, leadership and achievement. Type 2 is closely associated with affect and emotion and competence. Type 3 of game design features, which allows social interaction and awareness, co-occur more with relatedness and followership needs. Type 4 of game design features, which make the game design fancier but not with additional functions, co-occur more with the need of self needs.

<table>
<thead>
<tr>
<th>Basic needs</th>
<th>GType1</th>
<th>GType2</th>
<th>GType3</th>
<th>GType4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomy</td>
<td>16</td>
<td>9</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Self</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Competence</td>
<td>28</td>
<td>18</td>
<td>22</td>
<td>2</td>
</tr>
<tr>
<td>Achievement</td>
<td>23</td>
<td>13</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Leadership</td>
<td>6</td>
<td>2</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Followership</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Relatedness</td>
<td>25</td>
<td>13</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td>Affect and emotion</td>
<td>32</td>
<td>20</td>
<td>24</td>
<td>4</td>
</tr>
</tbody>
</table>

Table III. Co-Occurrence between game feature types and basic needs
As Type 4 of game design features appeared in only four papers and therefore distant from most of the basic needs, it would be interesting to see the correspondence analysis result with Type 4 being excluded. In this correspondence analysis, the first dimension explained 69 per cent of the variance, and the second dimension explained 30 per cent. The perceptual map (Figure 2) is drawn along these two dimensions. A general observation is that most associations between game feature types and basic needs remain similar to those in Figure 1, but Figure 2 reveals some additional findings. Without Type 4, Type 2 of game design features are close to competence, affect and emotion and self needs. Leadership and followership needs are more closely associated with Type 1 of game design features. Certain needs that are highly conceptually related, such as leadership and followership, competence and achievement and autonomy and self, are not necessarily co-studied as frequently as with other needs.

5. Discussions
It is notable that authors of each of the selected papers have their own research agendas and objectives, and these are not necessarily aligned with a motivational perspective or targeting
on satisfying basic human needs. Therefore, these articles and their authors are not being criticized here for any limitations *per se*. That being said, the answer to *RQ1* is that the literature did not have an extensive focus between game design features and basic human needs. However, we should also admit that even though prior research did not directly investigate the impact of gamification design from the perspective of basic human needs, our identification of distribution of basic needs indicates that the motivational design perspective is widely used by researchers to understand the influences of gamification design.

To answer *RQ2*, in this section, we examine additional issues and several potentials to investigate gamification from a motivational perspective. The ultimate goal is to increase dialogues and investigations among gamification researchers and practitioners on what they might consider to make their work more engaging and interesting to participants.

### 5.1 Are the eight basic needs appropriate in the context of gamification?

There are various ways of investigating basic human needs. For example, the self-determination theory (SDT) focuses on three basic needs: competence, autonomy and relatedness (Ryan and Deci, 2000). In this study, we used Zhang’s (2008a) eight basic needs to map out the gamification studies. The result is promising to show that these eight needs can be a more comprehensive representation of basic human needs in the context of gamification. In particular, each of the eight needs seems to be appropriate and is touched upon by the 60 papers collectively. This may open the door to examine further the theoretical bases for gamification research that go beyond the popular SDT.

### 5.2 Could a gamification study cover more basic needs?

The answer is yes. The highest number of needs being touched upon in one paper is six in our pool of literature. Furthermore, as shown in Table III, except Type 4 that is limited by the number of papers selected, all the other three types of game design features have been co-studied with all eight basic needs. Researchers would need to be conscious about the existence of basic needs when investigating the motivational influences of game design features. It is also very challenging to pinpoint associations between specific design features with individual basic needs. Therefore, further research should carefully review and develop the potential theoretical relationships among game design features and basic human needs.

### 5.3 What can happen in a study if researchers are conscious about basic needs?

To be mindful about basic human need might lead to a set of interesting discoveries in research. Satisfying basic needs alone could have its own right and benefit. It would be interesting to find out what happens once basic needs are satisfied. Many of the studies in the literature focus on learning outcomes, task performance and positive attitudes when participants are engaged in gamification. These outcomes might be directly caused by the satisfaction (or lack of) of the basic needs.

### 5.4 Could motivational affordance theory prescribe gamification design?

None of the 60 papers directly used MAT as their theoretical bases or design principles. Yet, given the fitting of the eight basic needs from MAT, one would speculate that applying the motivational affordances perspective may yield gamified technology that satisfies users’ various needs. One potential future research is to build on this literature analysis to examine whether incorporating certain MAT design principles (that correspond to basic needs covered in a study) to the study’s design may make a positive difference. Another potential
future research is to expand MAT to address additional factors. One example of such effort is "situated motivational affordances," which describes opportunities to satisfy motivational needs provided by the relation between the features of an artifact and the abilities of a subject in a given situation (when and how) (Deterding, 2011).

6. Limitations and conclusion
Several limitations should be noted before interpreting our analysis results. First, the pool of papers is not as large as we hoped to cover. Additional papers with other types of research methods might provide additional insight. Second, theoretical foundations of the collected articles were not discussed in this research, so this research is limited in terms of analyzing these papers from the authors' theoretical perspectives. Third, this study did not go into more details in each of the selected papers to uncover to what extent some of the basic needs are satisfied or not. This is understandable because not all selected papers focused on basic needs and their satisfaction. It would, however, be very interesting to know what factors (game design features, task characteristics, situations, etc.) might satisfy which basic needs and what are the outcomes of such satisfaction. Last, gamification design is an approach that can be operationalized at different levels of abstraction. This paper focused on the level of gamification objects and analyzed associations between game design features and human basic needs from the lens of motivational affordances. We hope that these limitations can turn into future research directions and efforts. Gamification research is a promising design approach that, when designed mindfully, can tap into satisfying basic human needs and thus attract more engagement and use by intended users. This study provides a glimpse of the literature from a motivational perspective and indicates that such a premise is feasible and deserves more attention from researchers and practitioners.

References


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Number 1
1 Editorial board
2 Research on map matching algorithm based on priority rule for low sampling frequency vehicle navigation data
   Zhishuo Liu, Yao Dongxin, Zhao Kuan and Wang Chun Fang
14 Dynamic prediction of cardiovascular disease using improved LSTM
   Kuang Junwei, Hangzhou Yang, Liu Junjiang and Yan Zhijun
26 Alignment of business in robotic process automation
   Ning Zhang and Bo Liu
36 Intelligent transaction: definition, modes, and research directions
   Leiju Qiu, Yang Zhao, Qian Liu, Baowen Sun and Xiaolin Wu
49 Crowdsourcing for search engines: perspectives and challenges
   Mohammad Moradi
63 A survey on VV&A of large-scale simulations
   Yanan Wang, Jianqiang Li, Sun Hongbo, Yuan Li, Faheem Akhtar and Azhar Imran
87 Exploring the relationships between gamification and motivational needs in technology design
   Jian Tang and Ping Zhang