Quantitative Measurable Concepts to
Visualize Business Process Improvement

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Business process improvement evaluation enables performance indicators to be used alongside process improvement techniques in order to quantitatively compare measurement information between the as-is and to-be processes. Limitations of the present methods of business process improvement indicate there is scope for looking at the problem in a different way. Business processes are commonly modelled as diagrams which at their fundamental level are complex networks. This suggests the question as to whether complex network analysis (CNA) has anything to contribute to business process improvement. We develop a technique of projecting a business process model onto the sub-space of a complex network and identify the measurable concepts that can be useful in business process improvement. The measurable concepts from CNA are combined with Time and Cost metrics from the simulation technique to visualize and track improvement efforts and satisfy improvement requirements.

Keywords: process modelling, measurable concepts, business process improvement, BPMN, complex network analysis

INTRODUCTION

The need for organizations to maintain good quality service levels, balanced resource utilization, quick response times, adaptation to market changes and customer demands, healthy staff and customer satisfaction, time and cost savings and to continually be at a competitive advantage necessitates the need for continuous process analysis. A business process is analysed both at design time and run time to find design flaws and diagnose support needs respectively (van der Aalst, 2013). Process analysis facilitates the identification of issues within the current (as-is) business process and ensures that they do not reoccur in the proposed (to-be) process. It also identifies bottlenecks, non-value adding activities and generates process alternatives (Boekhoudt, Jonkers and Rougoor, 2000; Irani, Hlupic and Giaglis, 2002). A well-engineered business process employs measures to monitor and guide process performance in a desired direction. Therefore, for an organization to attain maturity in their processes, measurements must be integrated into business improvement objectives (González et al., 2010). Measures can be applied during the design stage of the process development to capture the static properties (complexity, density, cohesion etc.) of the business process. Measures can also be applied at execution stage to quantify the dynamic properties (cycle time, cost etc.) of the business process. Together these can be used to compare the result

of the as-is with the to-be processes to ascertain how much improvement has been achieved within a specific time frame. These measures are presented in Table 1.

TABLE 1
DESIGN AND EXECUTION TIME MEASURES

Design Time Measures	Execution Time Measures
Complexity	Functionality
Quality	Quality
Coupling	Usability
Entropy	Reliability
Density	Effectiveness
Cohesion	Efficiency
Modifiability	Cycle time

(González *et al.*, 2010)

Most of the measures in Table 1 are adapted from software engineering but many of them lack empirical validation (González *et al.*, 2010)(Sánchez-González *et al.*, 2011). There is no standard set of metrics that can be used to measure improvement. Other authors have favored metrics such as quality (Khlif *et al.*, 2009), complexity (Laue, no date), the Quadrangle comprising of Time, Cost, Quality and Flexibility (Dumas *et al.*, 2013). Unfortunately, there is no agreement on appropriate approaches to measure process improvement.

This paper is therefore concerned with the question: What metrics are appropriate for quantitatively measuring process improvement both at design and execution stages? One commonly used but hard to define metric is quality (Sánchez-González *et al.*, 2011), as a measure quality is multidimensional and multifaceted and should be quantified using multiple measures. Internal quality measures (density, coupling, complexity etc.) influence external quality measures (understandability, usability, and modifiability etc.) and the relationships are not straightforward. Internal quality measures can proffer insight into the macroscopic properties such as the strength or quality of the relationship between the activities in the model (White and Corp, 2004). Existing traditional business process analysis techniques cannot assess the structural properties of a business process model (Mendling, 2008; Dumas *et al.*, 2013); therefore, a complex network analysis approach is employed to analyze the structural relationship and behavioral structure of the process activities.

Business processes are commonly modelled as diagrams which at their fundamental level are complex networks of nodes and links. The performance of a process is affected by its network structure in a non-trivial way. For example, in road traffic, alternative routes will result in fewer traffic jams, although the alternative route is not necessary the fastest. Road construction engineers conduct traffic impact simulations for road construction projects, policy setting and traffic organization (Yang, Hao and Luo, 2012). Therefore, metrics which have an influence on process flow such as 'shortest path' in complex network analysis may be useful for assessing more efficient processes.

In order to apply the complex network analysis approach, business process models are projected onto a sub-space of networks and quantitative measures are obtained relating to their intrinsic structure. We propose that the combination of complex network analysis coupled to simulation approaches can provide quantitative measures of process improvement both at design and execution stages.

The remainder of this paper is structured as follows: Section 2 describes the background to the concepts. Section 3 presents our approach for analyzing and measuring business process models and selection of metrics. The subsequent sections present the simulation technique for performance analysis of a business case study, implementation of the simulation methodology, network projection of the business process models and visualization of the results. Finally, section 6 presents the conclusion and future work.

PREVIOUS METRIC PROPOSALS

The determination of process improvement is focused on the correct choice and combination of metrics. Much work has been devoted to this area and there has been a long succession of attempts at defining the best measures. Rolon et al. define a set of metrics for the evaluation of the complexity of conceptual models of business processes based on the adaptation and extension of the FMESP (Framework for the Modelling and Evaluation of Software Processes). The work was unvalidated and inconclusive. Gonzalez et al (González et al., 2010) examined a number of measures and concluded that there is lack of measurement validation and most authors do not place importance upon validating activities. Others have proposed measures specific to standard languages such as Event-driven Process Chain (EPC), BPMN, YAWL, Petri net, UML AD (Aguilar et al., 2006; Mendling, 2007; Laue, no date).

Bisogno et al. provide a method for detecting process criticalities and identifying the best corrective actions using BPMN and Business Processes Simulation to measure key performance indicators using criteria such as completion rate of process, throughput time, rate of resource utilization and resources service level. The outcome of the study needed further refinement. Given that simulation models can be time consuming and costly, financial costs should have been included as part of the indicators.

Oukharijane et al. proposed an approach that uses existing quality metrics to evaluate the quality of BP models in terms of comprehensibility or understandability and modifiability or flexibility such as: Control Flow Complexity (CFC): Complexity is a measure of simplicity and comprehensibility of the process model.

Cardoso et al. adapted McCabe's cyclomatic number (Mccabe, 1976) as a complexity metric for CFC which takes into account the number of gates, (AND, OR, and XOR etc.) and counts the number of decisions in the flow of control. The number of all possible decisions is increased by every split in the model. Other metrics proposed include: Interface Complexity (IC), Number of Activities (NOA), Number of Activities, Joins and Splits (NOAJS), and Coefficient of Network Complexity (CNC). CNC is the ratio of the total number of links in a process model compared to its total number of nodes.

Vanderfeesten et al. has defined Cross Connectivity (CC) to measure the strength of the arcs between process model nodes and a Coupling metric (CP) which is the number of interlinks between the activities of a process model. The degree of coupling is dependent on the type of gateways (AND, OR, XOR) between activities and the complexity of the connections. Density (D) was defined by Mendling (Mendling, 2006) as the total number of links compared to the maximum number of links. Their approach was validated by developing a BP-Quality tool, but no information was provided about the interpretation and applicability of these metrics.

Consideration of these metrics leads to the conclusion that the use of software metrics is considered a useful approach to measuring business process models during design time and can be used to measure improvements. Some of these metrics (such as the CFC, NOA) can be determined from formula, while others require the use of software tools. Even when the measures were obtained as described above, there is no concrete interpretation in direct relation to the process model.

We are therefore proposing a new approach which is based on a consideration of the underlying network structure of the business processes using complex network approaches.

COMPLEX NETWORK ANALYSIS

A network is a group of nodes and links often referred to as a graph in mathematical literature (Newman, 2010) (Ferdinandy, no date). In this paper, the term network, node and links are used throughout. The pattern of the relationship between these nodes can be identified and measured using network theory (Jamali and Abolhassani, 2007). We project a business process model designed in BPMN onto a directed network. A directed network is preferred (over undirected) as this portrays the directed nature of the connection between most business processes.

Rules for Projection

We adopt the idea of "levels of abstraction" to move from a low-level detailed business process model to a high-level network structure where some elements in the process model are removed. We present an algorithm for reducing a process model to its basic structure (projective space) for analysis:

1) Activities become nodes, and information flows (message flows) and material flows become links.
2) Identify the right level of Analysis because business processes can be analyzed at different levels such as (Hassan, 2009):
   a) Individual level: analysis is based on a node and its relations.
   b) Dyad: Relationship formed by a pair of nodes
   c) Triad: Relationship among three nodes
   d) Complete Network: Relationship between all the nodes in the network. This is our preferred level of analysis.

FIGURE 1
MODIFIED QUADRANGLE

(Brand, N., Van der Kolk, 1995)
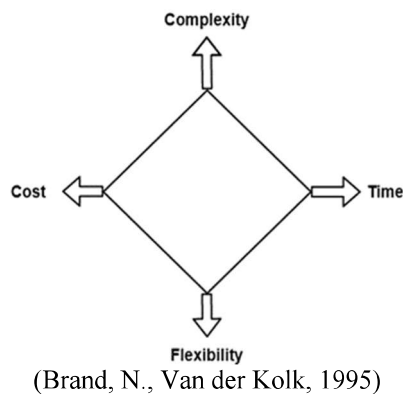
3) Gateways, Pools and Lanes details are not considered because there are no elements in network diagrams to represent these.
4) Notes, pictures, or document links containing extra information are not included.
5) Sub-processes can be modelled as sub-networks but will not be considered in the main network.
6) Decide on the type of relationship that exists between nodes. In our case, we use the directed network
7) Start and end nodes are not included. Databases and other systems are not included.

Complex Network Analysis Metrics

The study of the nature of links in a network can help give insight into the characteristics of the network. These characteristics are assessed using network metrics i.e., the metrics that can be used to quantitatively analyse the structure of a network. Table 2 shows the description of relevant metrics and their interpretation with respect to business process model.

TABLE 2
RELEVANT COMPLEX NETWORK ANALYSIS METRICS

Measures	Description	Relevance/Interpretation
Size	It measures the number of nodes or activities in the model (Laue, no date).	Measures structural complexity.
Diameter	The longest geodesic path in the network.	It can be used as a metric for network size or complexity. The higher the diameter, the higher the complexity.
Density	The ratio of links present in the network and the maximum number of possible links.	It can be used to test the modifiability or flexibility of a business process when changes are made.

Metric Selection – The Quadrangle

Brand and Van der Kolk (Brand, N., Van der Kolk, 1995) describe the effects of process improvement activities on the metrics of time, cost, quality and flexibility charted along four dependent dimensions displayed as a quadrangle. However, quality as previously discussed is a complex multivariate quantity that cannot be easily defined.

In this paper, we replace quality with complexity as shown in Figure 1. Brand and Van der Kolk's model does not have independent quantities and is structured so that an improvement in one dimension could have a negative impact on another. Thus, a reduction in delivery time could increase costs, for instance to hire more people to facilitate a quicker process. This is an expectation of the way that many systems work.

This means that modelling a complex system with dependent parameters is not straightforward which may also be connected in ways which are unpredictable and there may be unforeseen connections at a deep and undiscoverable level.

Consequently, a relative approach is proposed here which in the first instance assumes independence between our four metrics of (Sánchez-González et al., 2011; Dumas et al., 2013):

- Cost: Operational cost especially cost related to human resources required in producing a good or delivering a service,
- Time: Throughput time required to handle a case from start to finish,
- Complexity: The number of components and their relationships,
- Flexibility: The degree to which a model can be effectively and efficiently modified without introducing defects or diminishing quality.

These metrics are deployed independently but used relatively for both the as-is and to-be models. By measuring the difference in volume from the as-is to the to-be models, we can say that an overall decrease in the volume of the phase space quadrangle is a measure of the improvement of the system. An interdependency of parameters is not an issue because it is the relative change in volume that counts not the absolute volume. It is not necessary in this model to account for the possible interconnections between parameters to determine if an improvement has been obtained. The only need is to look for an overall decrease in volume of the phase space as a measure of efficiency.

In order to accommodate this, each axis is treated independently and the negative polarities of the Cost-axis and Flexibility–axis are ignored, for instance a decrease in cost would mean the point plot of the graph will move inward instead of moving outward (contrary to the behavior of the negative X-axis). The flexibility dimension also has reverse polarity and scale because an increase in flexibility is an improvement. This is illustrated in Figure 2.

Thus, if the measured outputs are used, regardless of their dependence or independence it can be inferred that a reduction in phase space volume is a measure of improved efficiency. The intention here is not to model how the system works but how to measure improvements in the system and for that we do not need to know how one dimension might impact on another. Of course, changing one parameter may affect

the others but that is an internal consideration of the particular process. All that need be said in this model is that if changes are made and a reduction is visible then the process has been improved.

With regards to the scale used for each independent metric, it is noted that Time is measured in seconds and the scale is marked at intervals of 500. But this relative to the business process. It could be measured in minutes or hours depending on the process. Cost is measured in thousands but again the scale is relative to the particular process. Complexity is 1:5 and Flexibility is 1:5. The unit for time is seconds, cost is dollars, flexibility and complexity are measures generated by complex network analysis and since they are units of phase space rather than real quantities, they do not have any correspondence to real space units and can be considered numerical only. The scale is generated by the max and min values coming from the complex network analysis metrics. However, scale is not important since we are only dealing with relative quantities. The goal is not to compare the metrics to each other, (so scale normalization will not be required) the goal is to compare the volume of the overall metric in the quadrangle of the as-is model to that of the to-be model. The relative volume measure means that absolute scale values are not significant for our optimization process.

FIGURE 2
SCALED REVERSED-Y QUADRANGLE
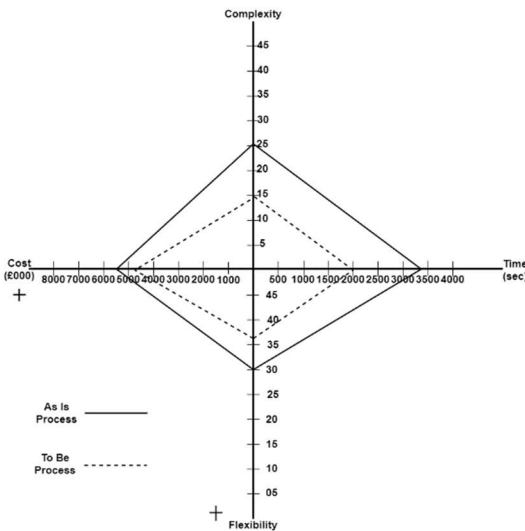
The 4 metrics are determined by measures taken from domains of simulation analysis and Complex Network Analysis and these are related to the metrics as shown in Table 3.

TABLE 3
METRIC CLASSIFICATION

No	Metric	Domain	Measure used
1	Time	Simulation	Cycle Time
2	Cost	Simulation	Cost
3	Complexity	Logical Complexity	Control Flow Complexity (CFC)
		Structural Complexity	Size (s) and Diameter (d)
4	Flexibility	Structural Flexibility	Inverse of Density (D)

1. Simulation domain: Quantitative measures that can be derived from simulation such as cycle time and cost.
2. Logical domain: This considers the control flow aspect of the model by calculating the Control Flow Complexity (CFC) to measure the logical complexity of the process model.
3. Structural domain: This entails a complex network-oriented approach to analyze the structural properties and measure the structural complexity and flexibility of the process model. The structural complexity is defined as the average of the size and diameter of the network while the flexibility is defined as the inverse of the network density. The size, diameter and density of the metrics can be obtained by using the appropriate complex network analysis and visualization software tool [25].

As implied above, we consider complexity from two facets namely, logical complexity and the structural complexity. This is because the logical complexity only takes into consideration the decision nodes within the process model but does not give any information about the structural complexity. The logical complexity is determined by the control flow complexity (CFC) of the model, which is the sum of all the split AND, XOR and OR gateways. The structural complexity is determined by the average of the size and diameter of the network abstraction of the model.

The formulae for the CFC:

$$CFC(BP) = \sum_{AND-split} CFC\ (C) + \sum_{OR-Split} CFC\ (C) + \sum_{XOR-Split} CFC\ (C) \tag{1}$$

Where
   AND-split = + n,
   XOR-Split = + n,
   OR-Split = 2^{n-1}

We define the formulae for the structural complexity as:

$$SC = (s + d)/2, \tag{2}$$

We define the formulae for the overall complexity as:

$$C = \frac{cfc+(s+d)/2}{2}, \tag{3}$$

Where
   cfc = control flow complexity,
   s = size,
   d = diameter.

We now turn to demonstrate an application of this method and present the simulation of the business case study in order to obtain measures in the time and cost dimensions.

BUSINESS PROCESS SIMULATION

Simulation technique allows performance analysis to be carried out on a process model which helps to detect flaws, bottlenecks and human resource planning (Van der Aalst, Weske and Hofstede, 2003). We use the simulation modelling for reengineering collaboration in higher education methodology (Vukšić, V.B., Bach and KatarinaTomičić-Pupek, 2014).

Simulation Methodology

The business case study used is the clearing process of a UK University, the details of the process are available in our previous paper (Fakorede, Davies and Newell, 2019). The simulation modelling for reengineering collaboration in higher education methodology is implemented as follows:

Step One: Initiation

Using the Simulation mode provided by Bizagi, the model was configured (see Table 4) based on the information obtained from admission staff and author's real experience.

Step Two: Analysis

The number of simulation instances was 500 representing 500 applicants. The Bizagi time analysis and resource analysis levels are configured as shown in the Tables 5 and 6 while simulation result is shown in Tables 7 and 8.

Step Three: Re-engineering

The 'as-is' process model was analysed, and some issues were identified and addressed in our previous work (Fakorede, Davies and Newell, 2019) this led to the creation of the to-be process model. When the university offers an applicant a place, this is accompanied by an offer letter emailed to the applicant and an upload of all offers to UCAS. A notification is sent to the student to either confirm or reject the offer. A tracking activity also runs in parallel to the offer decision notification from the applicant, ensuring that applicants can only select one offer at a time. Once the University downloads the offer confirmations, these can be processed and invitation for enrolment is sent to the applicant. As a result of the above modification, the activity "Contact Applicant" as shown in Figure 3 would no longer be necessary because if an applicant does not confirm an offer, they must have accepted an offer elsewhere or no longer interested.

FIGURE 3
REMOVED 'CONTACT APPLICANT'
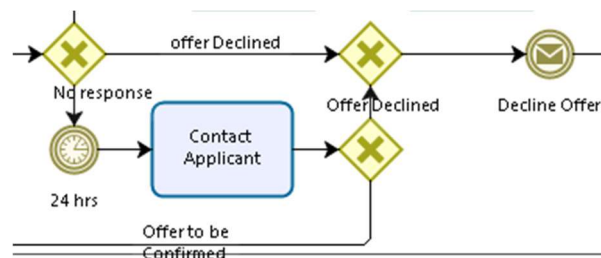
Step Four: Implementation:

The same simulation parameters used for the simulation of the 'As Is' process are used for the 'To Be' process. Table 9 shows the outcome of the simulation of both the 'As Is' and 'To Be' processes in the time and cost dimensions only.

Step Five: Evaluation

An inefficient use of resources was identified in the 'contact applicant' activity and removed, this has had positive impact on cost and time saving. The time analysis for the as-is process in table 8 shows that the average time expended in contacting applicants is 57 mins (1070.92 seconds), this time is saved in the to-be process. Similarly, the resources analysis for the as-is process (Table 9) shows a total cost of £12,033.67 while the resource analysis for the to-be process shows a total cost of £7,251.33, a saving of £4,782.34. From Table 9, there is an improvement in the 'To Be' clearing process in the time and cost dimensions.

TABLE 4
PROCESS VALIDATION CONFIGURATION

No	Process	Element
1	UCAS	500 tokens
2	Applicant	Applicant Reject Uni Offer 50% Applicant applies to Uni on UCAS TRACK 50%
3	Triage Team	No Place Available 5% Transfer Call to Department 95%
4	Department	Refuse Offer 5% Place Offer 95%
5	Department	No Response 10% Declined Offer 10% Confirmed Offer 80%
6	Department	Declined Offer 20% Confirmed Offer 80%

TABLE 5
TIME ANALYSIS CONFIGURATION

No	Activity	Processing Time (min)	Waiting Time (min)
1	Triage Call	3	3
2	Chat with Applicant	3	3
3	Place Offer	3	0
4	Download Data	1	0
5	Refuse Offer	0	0
6	Processing Offer	3	0
7	Contact Applicant	3	0
8	Upload offer Conf. to UCAS	1	0
9	Send Enrolment Invitation to Applicant	1	0

TABLE 6
RESOURCE CONFIGURATION

No	Resource	Quantity	Cost/hr	Total Hrs/day
1	Triage Team	4	10	34
2	Academics	4	20	34

TABLE 7
RESOURCE UTILIZATION

Resource	Utilization	Total unit cost	Total cost
Triage Team	90.91%	4000	4000
Academics	91.29%	8033.666667	8033.666667

TABLE 8
TIME ANALYSIS RESULT

Name	Type	Time (m)
University	Process	5856
Place Offer	Task	1344
Download Date from UCAS	Task	708
Refuse Offer	Task	0
Triage Call	Task	1500
Chat with Applicant	Task	1431
Send Enrolment Invitation	Task	163
Decline Offer	Inter. event	
Contact Applicant	Task	57
Process Offer	Task	489
Upload offer conf. to UCAS	Task	163

TABLE 9
SIMULATION RESULTS OF BOTH PROCESSES

Metric	AS IS	TO BE	Diff.	% Diff.
Time	57 mins	0	57 mins	100%
Cost	£12,034	£7,251	£4, 782	49.59%
Complexity	N/A	N/A	N/A	N/A
Flexibility	N/A	N/A	N/A	N/A

FIGURE 5
TO-BE DOWNSCALED NETWORK
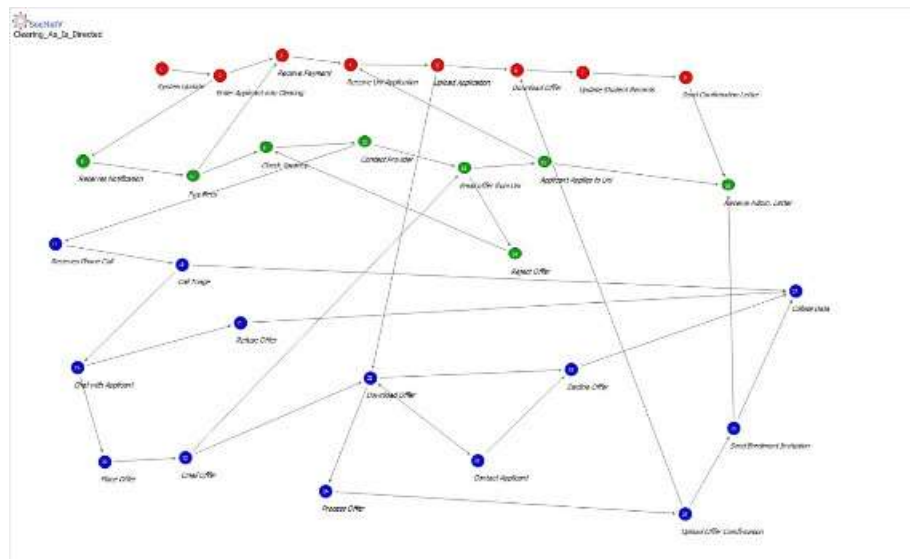
COMPLEXITY & FLEXIBILITY

Complexity as earlier defined is the aggregation of logical complexity and structural complexity. Logical complexity (i.e., Control Flow Complexity) is measured by counting the number of decisions in

the flow of control in the process model. A low CFC indicates that the process model is easy to understand. Splits in the model add to the CFC number as follows: OR-split with n will add 2^{n-1} to the CFC metric, AND-split will add 1 to the CFC metric and XOR-split with n outgoings will add n to the CFC metric of the model (Laue, no date)[29].

$$CFC(BP) = \sum_{AND-split} CFC\ (C) + \sum_{OR-Split} CFC\ (C) + \sum_{XOR-Split} CFC\ (C)$$

Where

$\quad\quad$ AND-split $= + n,$
$\quad\quad$ XOR-Split $= + n,$
$\quad\quad$ OR-Split $= 2^{n-1}$

There are 6 OR-splits, 0 AND-splits and 0 XOR-splits in the as-is clearing model, so applying the formulae, we have $\mathbf{2^{6-1} = 32}$. While in the to-be there are 4 OR-splits, 1 AND-splits and 0 XOR-splits, so applying the formulae, we have $\mathbf{(2^{4-1}) + 1 = 9}$, implying that there has been an improvement in the logical complexity.

The structural complexity and flexibility measures are obtained from the network projections of both the as-is and to-be clearing processes. Next, we apply the projection rules to reduce the business process models to their network structures.

Network Projection of the Process

The Social Network Visualizer (SocNetV) tool (*Social Network Visualizer*, no date) was used to create the network projections as well as to perform the analysis. The network projections are shown in Figures 4 and 5. The colored nodes simply show the nodes in the same BPMN lane.

FIGURE 4
AS-IS DOWNSACLED NETWORK
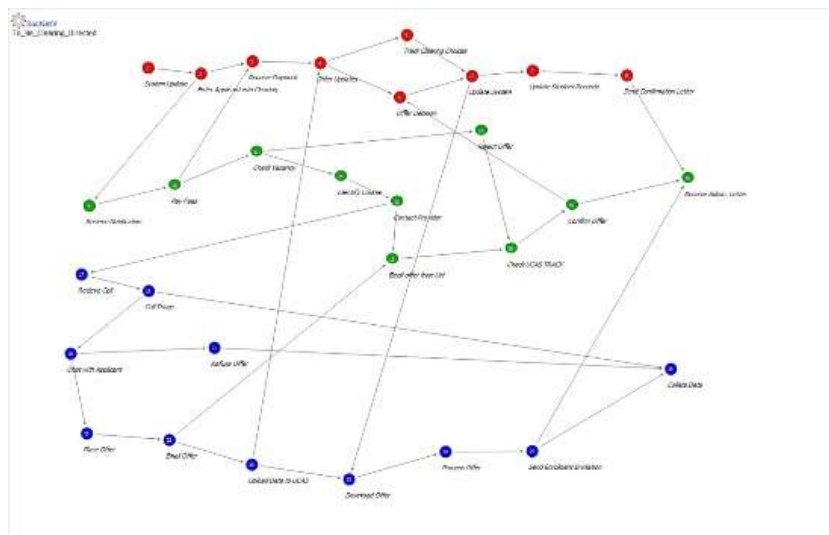
The results obtained from the analysis is shown in Table 10.

<div align="center">

TABLE 10
DATA FROM DIRECTED NETWORK ANALYSIS

</div>

Process Model	No of Nodes	Density	Diameter
As Is Process	29	0.051	10
To Be Process	30	0.046	12

Applying the formula for the overall complexity:

$$C = \frac{cfc + (s + d)/2}{2}$$

$$C_{as\text{-}is} = \frac{32+(29+10)/2}{2} = 25.75, \quad C_{to\text{-}be} = \frac{9+(30+12)/2}{2} = 15$$

$$F_{as\text{-}is} = 1/D = 1/0.051 = 19.60, \quad F_{to\text{-}be} = 1/D = 1/0.046 = 21.74$$

The calculations above show that the to-be process model is less complex than the as-is process model and there is an increased flexibility in the to-be process model. Overall, there is a visible improvement in the to-be process model as displayed in Table 11 and visualized Figure 6.

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TABLE 11
EVALUATION OUTCOME

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Metric	AS IS	TO BE	Diff.	% Diff.
Time	1071s	0	1071s	100%
Cost	£12, 034	£7, 251	£4, 782	49.59%
Complexity	25.75	15	10.75	52.76%
Flexibility	19.60	21.74	2.14	10.35%

CONCLUSION AND FUTURE WORK

Our aim was to identify measurable concepts that could provide quantitative metrics and visualized process improvement both at design and execution stages. We employed a hybrid approach by using complex network analysis techniques to determine process improvement at the design stage and simulation techniques at the execution stage. Both techniques were applied to an as-is and to-be UK HEI clearing process to measure improvement. A custom-made scaled Reversed-Y Quadrangle was used to track and visualize improvements in four dimensions.

FIGURE 6
REVERSED-Y QUADRANGLE FOR THE PROCESSES
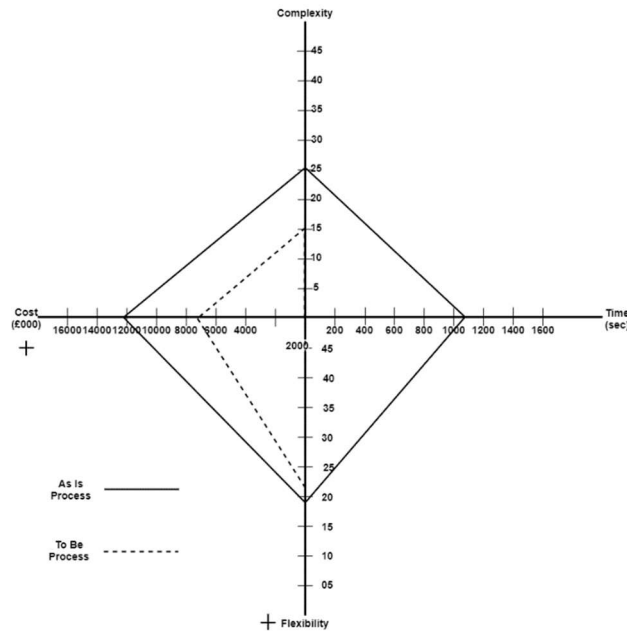
While it may be easy to predict the outcome of the simulation in terms of cost and time, the structural properties of the process models can be obscure. We have demonstrated that complex network analysis (CNA) techniques can contribute towards improving and measuring business processes. In terms of complexity, the to-be process is less logically complex than the as-is process according to the CFC analysis. This is beneficial because there is less decision making in the process resulting in a decrease in delays and throughput time. However, in terms of structural complexity the as-is process is favoured over the to-be process. This is a result of the to-be process having a higher structural diameter which translates into less efficient information transport between the nodes. Since a more distributed system requires more attention to be placed on information access, relevant improvement heuristics (such as integration between the UCAS and University systems and/or introduction of a document management system) could be introduced to enhance the efficiency of the process. In terms of the overall complexity the to-be clearing process is significantly less complex than the as-is clearing process.

The density metric indicates the number of connections in a network. It is a measure of flexibility, the higher the density the lower the flexibility. From Figure 6 we can see the to-be process is more flexible and efficient than the as-is process.

Further work will see an investigation into the applicability of other types of networks such as undirected and weighted directed networks, and if applicable, further projections can be considered. Future work will explore the interpretation and relevance of complex network analysis metrics to business process models to provide further insight into its macrostructure.

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