International Journal of Information Management 33 (2013) 597–610

Contents lists available at SciVerse ScienceDirect

International Journal of Information Management

journal homepage: www.elsevier.com/locate/ijinfomgt

Modelling information flow for organisations: A review of approaches and future challenges

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ARTICLE INFO

Article history:
Available online 26 February 2013

Keywords:
Information flows
Information systems
Conceptual modelling
Network analysis
Organisational design

ABSTRACT

Modelling is a classic approach to understanding complex problems that can be achieved diagrammatically to visualise concepts, and mathematically to analyse attributes of concepts. An organisation as a communicating entity is a made up of constructs in which people can have access to information and speak to each other. Modelling information flow for organisations is a challenging task that enables analysts and managers to better understand how to: organise and coordinate processes, eliminate redundant information flows and processes, minimise the duplication of information and manage the sharing of intra- and inter-organisational information.

The purpose of this article is to review literature for diagrammatically and mathematically modelling information flow for organisations and to identify problems facing information flow modelling research. The article will focus on research articles to identify: (1) approaches for diagrammatically modelling information flow, (2) approaches for mathematically modelling information flow, and (3) the current state of information flow modelling research. The article concludes by identifying and discussing possible future challenges for information flow modelling research.

Contents

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http://dx.doi.org/10.1016/j.ijinfomgt.2013.01.009

1. Introduction

1.1. Background

Modelling information flow for organisations is a challenging task. This is because an organisation by nature is a 'communicating entity' i.e. it is a made up of constructs in which people can have access to information and speak to each other (Clegg, Kornberger, & Pitsis, 2005). Within an organisation, communication for the flow of information can involve different groups, processes, individuals, communication channels and so on.

1.2. Aim of article

In this article, the state-of-the-art of modelling information flow for organisations is reviewed. The aim of this article is to review the role of existing approaches to modelling information flow for organisations. In order to accomplish this, the article will examine research articles to identify the main approaches and problems of modelling information flow for organisations.

1.3. Information, information flow and organisations

Information is useable data, inferences from data, or data descriptions (Ackoff, 1989; Checkland, 1988). It is used and analysed in four different ways: as a resource, as a commodity, as perception of patterns, and as a constitutive force in society (Braman, 1989). Information is important to the existence of organisations so much so it is likened to oxygen for human life (Al-Hakim, 2008). In profit driven organisations (i.e. businesses), information is a critical factor that determines growth and prosperity (Krovi, Chandra, & Rajagopalan, 2003), and information flow is considered the lifeblood of processes such as product development (Eppinger, 2001). Information flow is defined by the logic of a distributed system made up of agents, and the relationship in the distributed system i.e. information only flows between two separated parts that are connected or related and is defined by a set of structural and behavioural rules (Barwise & Seligman, 1997; Bremer & Cohnitz, 2004; Correa da Silva & Agusti-Cullell, 2008). In organisations, information flows in verbal, written or electronic form (Yazici, 2002), from a sender to a receiver (Westrum, 2004) and is dependent on access to information resources (Atani & Kabore, 2007). Information also moves between: (i) individuals in an organisation or organisations, (ii) organisational departments, (iii) multiple organisations, and (iv) an organisation and its environment (Henczel, 2001).

Information flow is an important part of work flows (Al-Hakim, 2008; Mentzas, Halaris, & Kavadias, 2001) that requires a synergy between humans and computer systems in modern organisations (Burstein & Diller, 2004; Hinton, 2002). Within research, studies focused on information flow have been undertaken in science and engineering branches such as organisational theory, management science, economics, artificial intelligence, ecology, control engineering, sociology, and computer science (Albino, Pontrandolfo, & Scozzi, 2002; Braha & Yaneer, 2007; Ehsani, Makui, & Sadi-Nezhad, 2010).

Within organisational theory and management science, the focus of research has centred on the analysis of information flow. This is because a widely recognised challenge for organisations is how to better understand and manage processes for capturing, storing and retrieving information (Lo Storto, D'Avino, Dondo, & Zezza, 2008). Thematic analysis (Blackburn, 2001), ECCO (Episodic Communication Channels in Organisations) analysis (Zwijze-Koning & De Jong, 2005), functional decomposition (Friesdorf et al., 1994), structured analysis (Feinstein & Morris, 1988; Hansen, Heitger, & McKell, 1978) are examples of methodologies applied for analysing information flow in organisations.

1.4. Information flow modelling

However, the first step in an information flow analysis methodology is the modelling of the current information flow in an organisation (MacIntosh, 1997) to create a 'fingerprint' of the organisation's communication structure (Ciborra, Gasbarri, & Maggiolini, 1978; Ellis, 1979; Michael & Massey, 1997; Yazici, 2002). This activity is typically preceded by the collection of data about organisation processes via data collection techniques such as interviews, surveys and questionnaires (Cerullo, 1979; MacIntosh, 1997; Pingenot, Shanteau, & Sengstacke, 2009; Stapel, Schneider, Lübke, & Flohr, 2007).

Modelling is a classic approach to understanding complex problems. A model is an abstract representation of a reality at a certain level of detail (Michael and Massey, 1997; Ball, Albores, & Macbryde, 2004). Modelling information flow is the process of describing how information is transferred point-to-point along communication channels in an organisation (Black & Brunt, 1999; Hibberd & Evatt, 2004). This is done mathematically (Collins, Bradley, & Yassine, 2010) and diagrammatically (Albino et al., 2002) to aid organisations in ranking information, prioritising information flow and defining how budgets can be managed (Pentland, 2004).

Modelling information flow for organisations is motivated by the need to better understand how to: organise and coordinate processes, eliminate redundant processes, minimise the duplication of information and manage the sharing of intra- and inter-organisational information (Szczerbicki, 1991; Howells, 1995). It is also required to understand communication barriers among departments that results in sub-optimal and inflexible organisational processes (Barua, Ravindran, & Whinston, 1997; Chiu, 2002; Friesdorf et al., 1994; Hansen et al., 1978; Krovi et al., 2003; O'clock & Henderson, 1994; Sander & Brombacher, 2000). This is because models aid analysts to effectively communicate complex design issues (Hansen et al., 1978) and a better understanding of organisational processes is vital to assessing the performance of an organisation (Hsieh & Woo, 2000, Hartley, Shepperd, & Bosanquet, 2002).

It is however important to note that information flow is a partial view of an information model which in itself is a partial view of an organisation (Ou-Yang & Chang, 2000; Collins et al., 2010). Other views required to create a ‘complete picture’ of an organisation include organisational, functional, and process views.

This article reviews the main approaches to mathematically and diagrammatically modelling information flow in organisations. Diagrammatical modelling produces conceptual models for analysing the information needs and problems of an organisation (Ewusi-Mensah, 1982). These conceptual models are constructed to visually represent and aid in the analysis of organisational data, decisions, procedures or transactions (Albino et al., 2002).

Mathematical modelling is carried out to analyse attributes of information flow such as ambiguity, equivocality, redundancy, consistency and uncertainty (Lo Storto et al., 2008). It uncovers statistical properties that underlie organisational structures and functions (Collins et al., 2010) for the creation of models based on economics and computer science, team theory and decentralisation of incentives (Creti, 2001).

1.5. Structure of article

The remainder of this review article is structured as follows. Section 2 will introduce the review method while Sections 3 and 4 will identify key approaches to mathematically and diagrammatically modelling information flow or organisations. Section 5 will identify the main applications of information flow modelling in organisations and capture the current state of research by identifying problems and achievements of information flow modelling research for organisations. Finally in Section 6, possible future research questions and challenges of information flow modelling research for organisations are discussed.

2. Review method

Reviews similar to the area of research covered in this article have focused on aspects such as, the usefulness of design structure matrices for organisational designers (Browning, 2001), the use of network analysis techniques for assessing information flows in organisations (Zwijze-Koning & De Jong, 2005), and the role of information technology in organisations for managing the flow of information (Dewett & Jones, 2001). Also, Aloni (1985) reviewed patterns of information flow by applied scientists in complex organisations.

However, the strategy adopted for this review was twofold: firstly to investigate empirical and theoretical research articles focused on modelling information flow for organisations and secondly, to identify problems of information flow modelling for organisations. As a result, general literature on organisations is beyond the scope of this review.

The approach for this review article, as shown in Fig. 1, consists of two main steps: *selection* and *evaluation*.

The *selection phase* involved making use of a widely accepted online database for literature (SCOPUS accessible via www.scopus.com) to search for and identify peer reviewed articles.

Two literature searches were conducted. For the first literature search, the keywords “information flow”, “model” and “organisation” were combined to search for articles relating to modelling information flow for organisations. 268 articles were returned.

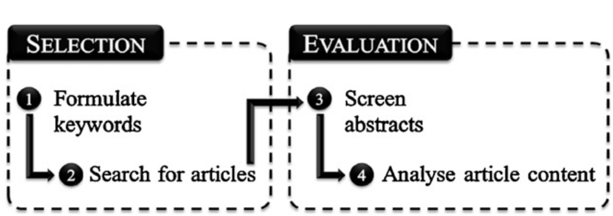

Fig. 1. Review methodology.

As earlier mentioned, modelling of current flows is the first step in information flow analysis, and modelling approaches focus on analysing information flow. Consequently, as part of this review, articles relating to ‘information flow analysis’ were also examined as part of the selection phase to extract: modelling approaches and problems of information flow that require analysts to make use of modelling approaches within these articles.

The second search using a combination of “information flow”, “analysis” and “organisation” was also carried out to identify articles for this review. This search returned a total of 276 articles. Both searches were then repeated using the alternate spelling for organisation (i.e. organization) and these searches produced the same results. Duplicates were then removed; generating 419 unique articles.

During the *evaluation phase*, the abstracts of the articles returned based on the literature searches were then screened to identify related and relevant articles. The screening process identified 99 articles that formed the basis for the review. Identified articles were based on the presence of proposals, discussions or case studies of diagrammatical and/or mathematical modelling for organisations within the contained empirical or theoretical research work. Omitted articles focused on research areas such as brain mapping and circuits in neuroscience, and cross-border flow studies in geography–these articles were considered beyond the scope of this review. Next the successfully screened articles were read and analysed to capture, compare and contrast the three main focuses of the review as summarised in Table 1.

This review article plans to contribute to knowledge by: evaluating the main approaches for modelling information flow and, making recommendations for future research.

3. Diagrammatic modelling

The use of diagrams makes it easier for organisational personnel to relate to and understand organisational requirements (Juric & Kuljis, 1999). It offers a unique opportunity to assess the impact of operations, management and support processes by capturing activities and interactions (Ball et al., 2004). Diagrammatic modelling of information flow for organisations can be grouped under three main approaches: pictorial representations, graph representations and matrix representations as shown in Table 2. Pictorial representations are informal diagrams of organisational *scenarios* achieved mainly through the use of ‘rich pictures’ (Checkland, 1999). Graph representations are more formal diagrams of organisational networks achieved through structured or network analysis. Structured analysis is a methodology proposed for analysing interacting units (i.e. systems analysis) with the goal of realising feasible solutions to problems (Booch, Rumbaugh, & Jacobson, 2005; Bravoco & Yadav, 1985; Chen, 1976; DeMarco, 1979; Doumeingts, 1989; IBMC, 1969; Katzan, 1976; Knowledge Based Systems, 2006; Orr, 1977; Petri & Reisig, 2008; Ross & Schoman, 1977; Staley & Sutcliffe, 1974; Warnier, 1981). This is achieved by describing the problem functionally, procedurally or hierarchically. Network analysis concentrates on relationships (not characteristics) between people (Zwijze-Koning & De Jong, 2005). These relationships uncover communication patterns and aid in understanding attitudes towards organisational tasks and events. However, complex processes in organisations when depicted as graphs, quickly become clustered with boxes and arrows in what Michael and Massey (1997) termed “spaghetti and meatballs”. It is for this reason that matrix based representations for information flow, such as design structure matrices (DSMs) (Al-Hakim, 2008;

Table 1
Review focus and article section allocation.

Review focus	Number of articles used	Article section		
		3	4	5
Approaches for diagrammatically modelling information flow	38	×		
Approaches for mathematically modelling information flow	33		×	
Applications and current state of information flow modelling research	47			×

Browning, 2001, 2002; Christensen et al., 1997, 1999; Eppinger, 2001; Steward, 1981) and pattern matrices (Friesdorf et al., 1994), have been proposed.

Based on these different approaches, studies to apply diagrammatic models, from the literature, can be grouped according to two main categories: integrative analysis that offers visualisations for different perspectives of information flow and perspective analysis that applies, adapts or introduces primitives to model behavioural and structural aspects of information flow.

3.1. Integrative analysis

Feinstein and Morris (1988) critiqued the use of data flow diagrams, Warnier-Orr diagrams, Hierarchy plus Input-Process-Output (HIPO) diagrams and logic charts, for systems analysis. The authors noted that the use of modelling approaches depends on the system to be developed. Driven by the need for an integrated approach to function- and data-orientation, Feinstein and Morris proposed a tree model that makes use of representations for entities and transformation functions to characterise the communication, observation and creation of information within organisations.

Durugbo, Tiwari, and Alcock (2011) reviewed the origin, concept and applications of six function-oriented approaches for modelling information flows: data flow diagrams, Integrated DEFinition method of modelling functionality and information modelling (IDEFØ and IDEF1), Graphes à Résultats et Activités Interreliés (GRAI) grids and nets, Petri nets, Input-Process-Output diagrams and DSMs. The authors also identified the strengths and weaknesses of these approaches and used this insight to suggest considerations for product and service designers with regards to the selection, suitability, and completeness of modelling strategies.

Christensen et al. (1997) used DSMs within an enterprise modelling framework to act as a supplement for an object-oriented modelling framework. The matrices adopt an information-processing view of projects and are derived for an initial quality function deployment (QFD) diagram. To explicate coordination requirements for projects, three matrices are stipulated: QFD matrices (house of complexity) that depict casual interactions as constraints, DSMs (house of uncertainty) that capture informational dependencies as contingencies, and responsibility assignment matrices (house of interdependence) that illustrate participation during information exchanges in the form of communications. Christensen et al. also used IDEFØ notation to model discrete events simulations of information processing and coordination, and used simulation results to make project estimates and to propose changes to project design.

Gutierrez and Leone (2012) used sequence diagrams to visualise information flow for enterprises. These diagrams contribute to an integrated environment – termed the distributed and executable enterprise modelling (DE^{2}M) environment – for use in analysing business processes.

Rozenkranz and Holten (2010) detailed and discussed the benefits of the variety engineering method as an approach for visualising multiple perspectives of organisational information flows. The method is based on concepts from cybernetics and makes use of design science artefacts for diagnosing relationship problems of activity coordination, actor communications and information channels.

Ou-Yang and Chang (2000) developed a shop floor system design based on an integrative analysis approach that uses diagrammatic representations to show organisation, data, function and control views of systems. Representations used in their

Table 2
Diagrammatic techniques for modelling information flow.

Diagrammatic form	Diagrammatic technique	Description	References
Pictorial	*Rich picture*	Informal representation using a wide range of charts, symbols and text	Burstein and Diller (2004), Raghavan and Roy (2005), Toivanen, Häkkinen, Eerola, Korpela, and Mursu (2004)
Matrix	*Design structure matrix*	Compact representation of dependency, independency, interdependency and conditionality of information flow	Al-Hakim (2008), Browning (2002), Christensen et al. (1999), Collins et al. (2010), Eppinger (2001), Lo Storto et al. (2008)
	Pattern matrix	Compact representation between concurrently and sequentially linked business elements	Friesdorf et al. (1994)
Graph	*Structured analysis*	Formal representation using a set of standard primitives to illustrate information flow via tools such as flow charts (information flow charts, logic charts and event driven process chains), entity relationship diagrams, Warnier-Orr diagrams, Reliability block diagrams, Hierarchy plus Input-Process- Output diagrams, Petri nets, Integrated DEFinition (IDEF) method, Graphes à Résultats et Activités Interreliés (GRAI) grids and nets, and Unified modelling language (UML) use cases, role activity diagrams and collaboration diagrams.	Al-Hakim (2008), Albino et al. (2002), Ball et al. (2004), Blackburn (2001), Braha and Yaneer (2007), Dawood et al. (2002), Feinstein and Morris (1988), Friesdorf et al. (1994), Hansen et al. (1978), Jarke et al. (1997), Kumar and Aggarwal (1989), MacIntosh (1997), Ou-Yang and Chang (2000), Stapel et al. (2007), Raghavan and Roy (2005), Waring and Wainwright (2002), Juric and Kuljis (1999), Pingenot et al. (2009), Booch et al. (2005), Bravoco and Yadav (1985), Chen (1976), DeMarco (1979), Doumeingts (1989), IBMC (1969), Katzan (1976), Knowledge Based Systems (2006), Orr (1977), Petri and Reisig (2008), Ross and Schoman (1977), Staley and Sutcliffe (1974), Warnier (1981).
	Network analysis	Formal representation of nodes and links for organisational networks such as social networks, task networks and information flow sub-networks	Aoyama et al. (2005), Braha and Yaneer (2007), Zwijze-Koning and De Jong (2005), Hatala and Lutta, 2009, Cross et al. (2006)

research include Petri-nets, organisation charts, functional trees, entity-relationship diagrams and extended event process chains.

Raghavan and Roy (2005) proposed a Generalized Stochastic Petri Net modelling approach for analysing stock rationing in cooperative and non-cooperative situations. They also made use of rich pictures to model information flow in supply chain networks (SCNs) as discrete event dynamical systems (DEDS). SCNs link suppliers and customers (Themistocleous, Irani, & Love, 2004) whereas DEDS represent systems that evolve over time as a result of discrete events with complex interactions (Raghavan & Roy, 2005).

Christofferson (1999) proposed a specification information flow model to represent different types and flows of specifications within the construction industry. The model aids builders, supplier and subcontractors in implementing computer applications to organise and manage system specification. Christofferson validated the model through a software prototype containing different databases and connections between buyer information, lot information, custom options, subcontractor and supplier information, schedule details and planning information.

3.2. Perspective analysis

In Ho et al. (2004), rich pictures are used to characterise the flow of logistic information for an airline company. Using insights from the representation, they identified three ways of improving flows: common formats for communication, minimised time of arrival on the ground for airplanes, and minimal time for selecting suppliers. The authors provide a logistics approach that combines online analytical processing, neural network and extensible markup language (XML) technologies, based on these identified improvements. Similar use of rich pictures was applied in Burstein and Diller (2004) and Nikolic, Savic, and Stankovic (2007) for modelling information flow and sharing in large hierarchical organisations and emergency response processes respectively.

Nookabadi and Middle (1996) applied the IDEFØ approach as a structural model for analysing the needs of quality assurance information systems. They proposed a generic model to support decision-making during pre-production, production, and post-production.

Liu and Kumar (2011) used Unified Modelling Language (UML) activity diagrams to model information flow in supply chains. Their work makes use of Event-Condition-Action (ECA) rules to shed light on how supply chain activities can be configured to enhance information sharing. The performance of identified configurations is also evaluated by flow simulation.

Using flowcharts, Ewusi-Mensah (1982) proposed a 'matrix model' for constructing the flow of data and processes within organisations. The goal of the model was to aid organisations in understanding information requirements.

Chiu (2006) proposed an information flow diagram–an adaptation of data flow diagrams–to aid in understanding business process bottlenecks in sequential, deferred, real-time, parallel, wheel, one-to-many, many-to-many and many-to-one-to-many information flows. The transformation of information in these generic cases are explained in terms of information sources, required knowledge, information flows following process completion, operator of activities in a process and transformation media. In a similar approach, Hoitash et al. (2006) used an adapted version of data flow diagrams to assess the level of information flow latency i.e. delays experienced during the flow of information from sources to destinations. They also evaluated entity-relationship diagrams and event driven process chains but considered them unsuitable due to their focus on data and process modelling respectively. Hoitash et al. argued that an awareness of information flow latency enables firms to identify their digitalisation levels, resolve process bottlenecks and improve stakeholder value.

Focusing on the characteristics of information flow during delivery exchanges, Durugbo, Hutabarat, Tiwari, and Alcock (2012) introduced information channel diagrams to visualise interactions, processes, coordination and streamlining during information flow. A methodology based on functional composition is also prescribed for how collected information flow data can be transformed into diagrammatic models. A similar approach was adopted by Stapel et al. (2007) for developing the FLOW notation that offers primitives for modelling the flow of documents in projects and manufacturing processes and by PhamThi and Helfert (2007) for conceptualising the integrated aspects of static, dynamic and organisation that offers notation for organisational classes, roles, transactions and privileges. Also in Al-Hakim (2008), the Information product map and information product UML are proposed as formal representations that focus on the quality of data in an organisation. These diagrammatic models were developed based on data flow diagrams and UML respectively.

In Cross, Laseter, Parker, and Velasquez (2006), social networks are used to visualise information flow as well as the lack of awareness and distribution of technical expertise within communities of practice. Based on insights from these visualisations, interventions to improve the community's effectiveness were proposed using target points where connectivity needed to be increased (or decreased). Sampaio et al. (2012) also used social networks to visualise information flow in a Brazilian telecommunication company. The study examined individual perceptions of organisational roles, interpersonal relationships and sources of knowledge.

In Browning (2002), the DSM is applied and discussed as a process model for "mapping the genome" of work processes that can be accomplished efficiently and effectively by organisations. The N-square matrix visualises activity sequences and represents dependent, independent, interdependent and conditional information flows among activities.

Similarly, Eppinger (2001) applied DSMs to visualise information flow for General Motors' Powertrain Division and Semiconductor development at Intel. Eppinger discussed how the matrices can be used to optimise information flow through rearranging task sequences, reorganising tasks, reducing information exchanges and managing reworks. Le and Panchal (2011) also applied the DSM approach for collaborative product development, but used the matrices as part of an agent-based model to shed light on the dynamics of participation and product evolution.

Friesdorf et al. (1994) proposed pattern matrices for depicting flows between concurrently and sequentially linked business elements. Symbols used in this representation indicate the frequency of occurrence of information transfer between a source and a destination. Large symbols indicate regular flows whereas small symbols represent occasional flows.

Focusing on the complexity of transmission in organisations in relation to the scale of distribution, Chiu (2002) used social and task networks to understand participation and experiences during design communication. The author concluded that to better understand collaboration, information analysts need to apply process models to describe phenomena and cyclic processes such as consultation, negotiation, decision-making, and reflection. In Batallas and Yassine (2006) social networks were complemented with DSMs for analysing tasks and in Collins et al. (2010), task networks were used for visualising information flow for product development.

Aoyama, Ratick, and Schwarz (2005) also applied an information flow network model–based on social and task networks–to analyse exchanges between suppliers, transportation intermediaries and manufacturers. The model acts as a sub-network of a larger network that also involves a network for goods flow. Aoyama et al. used the information flow sub-network model to depict costs of information transmission and establishing relationships, and performed Monte

Carlo simulations to highlight entangled geographic and functional frictions that influence transport and transaction costs.

3.3. Summary

Generally, diagrammatic modelling kick-starts the analysis of organisational communication (Hibberd & Evatt, 2004; MacIntosh, 1997) and is usually applied and preferred because it is easier for organisational personnel to relate to and understand organisational characteristics. Support for development is also provided through prescribed steps to guide analysts/users. For instance, a data flow diagram can be developed based on two different approaches: explosion (also applied in the Integrated DEFinition (IDEF) methodology) in which each successive model is derived as an explosion from a single activity step in a parent or preceding diagram, and expansion in which a single diagram is iteratively expanded till the entire system has been comprehensively modelled. Similarly, the ICD applies composition to methodically populate models by increasingly adding and connecting primitives for creating a chain of primitives.

These diagrammatic models act as blueprints of organisational structures and have been extensively applied in the standardisation of information by standards organisations such as the International Standard Organisation (ISO), the Industrial Alliance for Interoperability (IAI), Machinery Information Management Open Systems Alliance (MIMOSA) and American National Standards Institute (ANSI) (Abou-Zeid et al., 1995; Dawood, Akinsola, & Hobbs, 2002; Rachuri et al., 2008). However, in an attempt to shed more light on the nature of organisational information flow, analysts also apply mathematical modelling to uncover the mathematical properties that underlie organisational structures and processes (Collins et al., 2010; Durugbo, Hutabarat, Tiwari, & Alcock, 2011).

4. Mathematical modelling

In the literature, approaches for mathematical modelling information flow in organisations can be classified according to two main categories: *flow analysis* that propose quantities and information levels for assessing and improving organisational performance and *organisational analysis* that idealise organisations as different constructs for improving information flow. These approaches as shown in Table 3 make use of mathematical theories based on coordination, probability, complex networks, vectors, fluid flow and so on.

In several works (such as Feinstein and Morris (1988), Hansen et al. (1978), Ding et al. (2005)). In Durugbo, Hutabarat, et al. (2011) and (Durugbo, 2012) mathematical models are complemented or combined with diagrammatical models to create a clearer description of information flow in organisations.

4.1. Flow analysis

The work by Datta and Chaudhuri (1977) concentrated on serial and parallel information flow in operation inventory systems for manufacturing organisations. The term ‘operation inventory system’ was used by Datta and Chaudhuri to describe a chain of manufacturing operations separated by inventories under periodic review of the base stock system of ordering. They developed a mathematical model for deciding on the optimum mix for operation that achieves the greatest efficiency.

Four information flow parameters suggested by Krovi et al. (2003) offer useful quantities for assessing the level of performance of an organisation. Information node density, the first parameter, deals with the complexity of information flow and is computed as the number of intermediate nodes that are present in an information processing channel. Information velocity is the second parameter and deals with the rate of at which information is received at a node. Information viscosity, the third information flow parameter, is concerned with the level of conflict at a node i.e. the presence of contradictory information. The fourth parameter, information volatility describes uncertainty in the content, format or timing of information.

Szczerbicki (1991) modelled internal and external information flow in the functioning of groups and proposed a quantity for evaluating the value of information structures. Based on a simplistic example of an industrial production situation, Szczerbicki demonstrated the use of the model and concluded that rules based on the model can be applied in the development of group decision support systems.

Aoyama et al. (2005) modelled information (and commodity) flow in organisations with independent but linked sub-networks. They focussed on logistics networks that incorporate methodologies for just-in-time manufacturing and inter-period network storage. These logistics networks in modern businesses incorporate web technologies in e-logistics for overcoming factors such as language barriers, and time zone and spatial constraints. Aoyama et al. studied the characteristics of logistics in geographic/virtual spaces and concluded that intermediaries (such as middlemen) can still be important elements in the logistic industry.

Wu, Huberman, Adamic, and Tyler (2004) developed an epidemic model for assessing the spread of information in social organisations. The model concentrates on analysing networks that are scale-free. Wu et al. concluded that the discovery of information hubs in an information network is not sufficient enough to guarantee that information transmitted from a source will spread to a large section of an organisation.

Creti (2001) proposed a model for information that flows horizontally in organisations. These flows, termed ‘side-links’, were applied in the analysis of two forms of organisations: M-form (according to divisions in an organisation) and U-form (according to product-lines in an organisation). Creti treated the flow of information as a variable with unit cost, and concluded that information flow (primarily for demand and external communication) is an important factor that determines the profitability of functional and product-based organisations.

Helbing, Ammoser, and Kühnert (2006) modelled side-links in organisations made up of multiple agents with complex non-linear interactions. The model much like the one proposed by Creti (2001) proposed side links for information flows. But unlike Creti, the model focused on hierarchical, regular area-filling kinds of organisational subdivisions according to triangular, quadratic; and hexagonal configurations. Helbing et al. demonstrated how short-cuts and temporary links in hierarchical organisations can contribute to efficient and effective information flow during crisis or disaster response management.

Ben-Arieh and Pollatscheck (2002) proposed a model for identifying the optimal level of information required to flow in an organisation. The model consists of a productivity function and information processing parameters for assessing the hierarchy of three forms of organisations: homogeneous, semi-homogeneous and non-homogeneous. In the homogeneous organisation all employees, independent of the hierarchical level, possess the same information processing rate. The semi-homogeneous organisation is governed by a common productivity function but different information processing parameters for each hierarchical level. In the non-homogeneous organisation, the levels of hierarchy are governed by a different productivity function and different information processing parameters.

Braha and Yaneer (2007) analysed the topology of information flow networks within the context of large-scale product development. The model makes use of statistical properties inherent in

Table 3
Mathematical techniques for modelling information flow.

Mathematical technique	Focus of technique	Scientific field	References
Complex self-organisation network model	Analyse the trails left by information agents for: observation and recovery, and system normalisation	*Probability theory* *Network theory*	Costa et al. (2007)
Control network model – 'control net'	Analyse offices with regards to information processing	*Graph analysis* *Probability theory*	Ellis (1979)
Control network model – 'information tree'	Analyse the sequence of organisational procedures with regards to optimal control	*Vector analysis*	Feinstein and Morris (1988)
Control network model – 'spanning tree'	Analyse reliability and availability of flows	*Graph analysis* *Probability theory*	Kumar and Aggarwal (1989)
Decision network model	Analyse the organisational structure for uncertainty and complexity of networks	*Fuzzy possibility theory*	Ehsani et al. (2010)
Feedback control model	Analyse delays of information flows and feedback	*Control theory* *Network theory*	Caldwell (2008)
Epidemic model of a scale-free network	Analyse information generation and transmissibility in social organisations	*Network theory*	Wu et al. (2004)
Influence model	Analyse dynamics of individuals and their interactions	*Markov models*	Pentland (2004)
Information coordination model	Analyse coordination between decision units	*Nash equilibrium*	Barua et al. (1997) and Barua and Ravindran (1996)
Information-decision network model	Analyse and improve organisational decision support	*Interaction matrices*	Hansen et al. (1978)
Information object visualisation	Analyse flow time and human resource time performance.	*Markov models*	Strong (1997)
Supply chain model	Analyse information sharing in supply chains	*Stochastic dynamic programming*	Gavirneni (2002)
Intra-organisational collaboration and task-oriented user participation network models	Analyse information flow during organisational collaboration and user participation	*Network theory*	Durugbo, Hutabarat, et al. (2011) and Durugbo (2012)
Inter-organisational resource flow model	Analyse patterns of information flow between organisations	*Network theory*	Galaskiewicz and Marsden (1978)
Logistics network model	Analyse relationships based on geographical spaces	*Graph analysis* *Economic model*	Aoyama et al. (2005)
Management fundamentals framework	Analyse relationship flows for improved management performance	*Probability theory*	Lin and Cheng (2007)
Network model of a company	Analyse coordination of hierarchical networks	*Network theory* *Graph analysis* *Organisational theory*	Almendral et al. (2003), López et al. (2002)
Parameter-based framework	Analyse relationships within organisations and environmental factors	*Fluid flow*	Krovi et al. (2003)
Flow evaluation model	Analyse the functioning of groups for enhancing decision making	*Probability theory*	Szczerbicki (1991)
Production network model	Analyse firm relationships and process characterisation	*Nash equilibrium* *Economic model*	Creti (2001)
Production operations model	Analyse coordination in terms of uncertainty, variability and equivocality	*Coordination theory*	Albino et al. (2002)
	Analyse and simulate relationships and flow patterns in new product development	*Organisational theory* *Probability theory*	Braha and Yaneer (2007)
	Analyse inventories in an organisation in terms of parallel and serial flow, and production stages	*Probability theory*	Datta and Chaudhuri (1977)
Optimal level of information	Analyse organisational hierarchies with regards to productivity and information processing	*Probability theory*	Ben-Arieh and Pollatscheck (2002)
	Analyse organisational hierarchy for side-links and information control	*Graph analysis* *Organisational theory*	Helbing et al. (2006)
Organisation network model	Analyse flow patterns and relationships	*Network theory* *Organisational theory*	Merrill et al. (2008)

complex networks to identify parallels in social, biological, and technological networks. Braha and Yaneer concluded that properties within a firm (intra-organisational) can be expanded and applied in improving interactions involving multiple organisations (inter-organisational).

Kumar and Aggarwal (1989) proposed an approach that utilises spanning trees as a measure for determining the overall reliability of networks. They identified spanning trees as a minimal set of links required to maintain network connectivity. Kumar and Aggarwal applied Petri nets and matrix multiplication in deriving a list of spanning trees for a network that could be used to compute the 'overall reliability' of information flow networks.

In the study by Almendral, López, and Sanjuán (2003) and López, Mendes, and Sanjuán (2002), the traditional hierarchical topologies of organisations were analysed to examine organisational efficiency in terms of: group sizes and information propagation. In both studies the concept of coordination degree was introduced as a quantity that measures the ability of individuals in an organisation to exchange information.

Focusing on coordination theory, Albino et al. (2002) analysed the production operations in an organisation. The model proposes a 'coordination index' derived from uncertainty (or complexity), variability and equivocality in an organisation's information system. In the context of their argument, Albino et al. defined information systems as manual or computer-supported communication and decision- making processes.

Motivated by game theory, Barua and Ravindran (1996) proposed a stylized model of information sharing and focused on information complementarity and coordination between two firms. The model associates costs with increasing levels of information precision. Barua et al. (1997) also developed an information coordination model for analysing the exchange of usable intra- and inter-organisational information between decision units (individuals or groups that are assigned tasks). The model is based on the idea of cheap talk (communication within the context of game theory that costs nothing and is non-obligatory) as a mechanism for partially coordinating inter-organisational activities.

In Gavirneni (2002) information flows in supply chains is modelled. The study applied stochastic dynamic programming to illustrate how by reorganising supply chain operation, coordinated and shared information can lead to reduced supply chain costs.

Costa, Rodrigues, and Travieso (2007) developed a mathematical model of information for complex networks made up of human-made structures. The model analyses trails left by information flow for identifying contamination sources, strategies for immunization and optimal routing paths.

Caldwell (2008) developed a 'feedback control' model that analyses the delay between the time information is sent from a source and received at a destination. The model introduces a task time quantity for assessing the use of information and communication technologies (ICTs) for supporting human-human communication and for improving task coordination.

Strong (1997) proposed a flow model using information objects i.e. groups of related information, and exception handling activities that change object state and make decisions. Markov process models are used to capture the flow of information objects and conditional probabilities assigned to activities to offer indications of information quality. Strong also proposed time variables to compute flow time and human resource time performance.

Pentland (2004) developed an 'influence model' using the coupled hidden Markov modelling approach to characterise the dynamics of individuals and their interactions with others. Global behaviour is assessed using the eigenstructure analysis of an 'influence matrix' that sheds light on how individuals influence group dynamics.

4.2. Organisational analysis

Drawing on graph theory principles, Hansen et al. (1978) developed a technique for analysing organisations when idealised as information-decision networks. The aim of the technique was to propose a 'reachability matrix' for determining if two units are reachable from each other.

Ehsani et al. (2010) modelled organisations as distributed decision networks. The model contained definitions for decision information, informational dependence of decision makers and informational complexity of the network. Ehsani et al. used the model to assess the structure of organisations in terms of the network complexity and uncertainty, and concluded that relations in a distributed decision network contribute to organisational efficiency.

In the work by Lin and Cheng (2007) an organisation is idealised as 'a kind of special system' made up of connected parts that relate to its environment by means of 'relationship flows'. These relationship flows include information flows, matter flows, energy flows, fund flows and personnel flows. Lin and Cheng also suggested that these flows are fundamental to the existence and survival of organisations and the role of management science is to optimise the flows so as to improve organisational performance. Likewise, Galaskiewicz and Marsden (1978) modelled the interorganisational network for resource flow. The main resources considered were money, information and support. Based on this insight, Galaskiewicz and Marsden identified three main patterns for information flow: symmetry in which bidirectional information flow within a channel, exchange in which bidirectionality is supported through the use of different channels, and multiplexity in which information flows unidirectionally in multiple channels.

Feinstein and Morris (1988) focused on the 'state' of information in an organisation and developed an information tree model to assist organisational personnel in understanding the effects of introducing new information systems. The information tree model views complex organisations as information processing systems that are made up of people, equipment, activities, and procedures, that receive/transmit information as inputs/outputs.

Organisations modelled as complex information processing entities are also the basis for the work by Merrill et al. (2008). The information processing entities contain internal structures and processes that change subject to environmental effects. However, unlike the approach by Feinstein and Morris (1988) the work by Merrill et al. concentrated on analysing networks for organisations in terms of internal structures and processes. The result of the network analysis is a report that contains network measurements to complement information flow diagrams.

Ellis (1979) proposed a mathematical model–an information control net, for describing information flow in offices. In the model, offices are idealised as complex, highly, interactive processing information systems. The purpose of the information control net was to rigorously describe organisational activities, test underlying diagrammatic descriptions for flaws and inconsistencies, and suggest possible office restructuring permutations.

In Durugbo, Hutabarat, et al. (2011) and Durugbo (2012) an organisation as a complex network is mathematically modelled using a hypergraph that is connected, partitioned and non-overlapping. These graphs contain social and activity networks for facilitating collaboration and user participation. Indicators for assessing communication, decision-making, teamwork and coordination are also proposed.

4.3. Summary

In general, mathematical models of information flow shed more light on the nature of organisational information flow by offering measures and indicators of information spread and connectivity according to the unit of analysis–organisational units or information flow. The tendency in most cases has therefore been to make use of characteristics being studied (such as uncertainty of information or organisational inventory) to determine the focus of information flow (Jarke, Jeusfeld, Peters, & Pohl, 1997). However, research in mathematical models for information flow in organisations is still in its 'primary state' (Ehsani et al., 2010). This can be attributed to the highly complex and inefficient nature of mathematical models and the need for new organisation theories.

5. Current state and applications of information flow modelling research

Research in information flow modelling, as shown in Fig. 2, has so far been based on three levels of availability and use of information: macro, meso, and micro levels (Benson-Rea and Rawlinson, 2003). At the macro level, information flow is focused on the environment external to a system and current research has focused on defining organisational networks, clarifying the focus of information flow and improving the synchronisation of information (O'clock & Henderson, 1994; Zwijze-Koning & De Jong, 2005). For

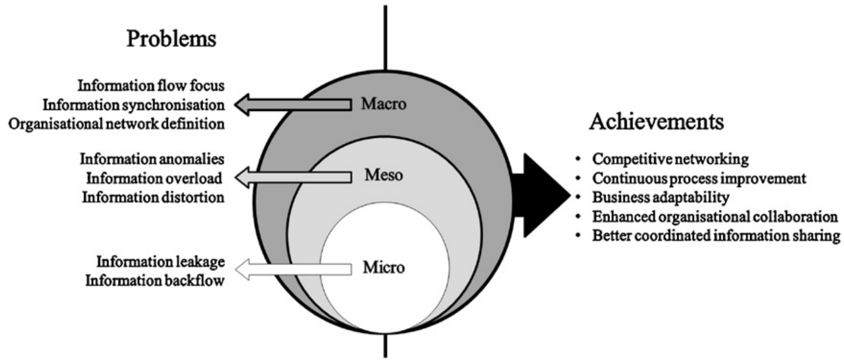

Fig. 2. Current state of information flow modelling research.

the meso level, information flow centres on organisational factors such as cultural and economic factors, and the extant literature is driven by information anomalies, information overload and information distortion often termed the 'bull whip effect' (Ben-Arieh & Pollatscheck, 2002; Childerhouse et al., 2003; Cordella, 2006; Regan, 1970; Stapel et al., 2007; Wamba & Boeck, 2008). The micro level considers the information flow based on interpersonal interactions and is challenged by problems of information leakage and information backflow (Boersma, Loke, Petkova, Sander, & Brombacher, 2005; Kristiansen, 2002; Russell, Wolfson, & Yu, 1996).

This section identifies the current state of research from the viewpoint of work carried out for information flow analysis with regards to applications for information flow simulation, optimisation and management, as summarised in Table 4.

5.1. Information flow simulation

The simulation of information flow in organisations is an important application of mathematical and diagrammatical models (Aoyama et al., 2005; Braha & Yaneer, 2007) used to assess and visualise information flow (as a variable) over a period of time (Christensen et al., 1999). Simulations have supported the deployment of organisational networks by: easing the use of ICTs, making information readily accessible and providing common interfaces for users (customers and staff). Simulation techniques have also contributed to business adaptability by offering useful means for analysing the impact of information systems on organisational performance in terms of: task variety (transaction processing, decision making and communication), organisational levels (user, groups and inter-organisational) and value (organisational philosophy and managerial flexibility) (Jarke et al., 1997).

Typically, simulations begin with diagrammatic representations of information flows. The dynamic properties of these flows are then pre-defined by an underlying mathematical model (Ball et al., 2004). Furthermore, data used in the development of simulation models can be collected from diagrammatical models such as DSMs (Lo Storto et al., 2008) and Petri-nets (Jarke et al., 1997). The three main techniques applied for flow simulation identified in literature are: agent-based, system-dynamics and discrete-event simulation.

Agent based simulation is suited to situations where the main unit of analysis is an agent such as a user, customer or company, that interacts with other agents and its environment (Garcia, 2005, Garcia-Flores et al., 2000). This type of simulation analyses information flow at: micro-levels to understand the behaviour of agents, and macro-levels to work out commonalities in interactions involving agents. An organisation in an agent-based simulation is modelled as a combination of interacting agents with different goals, incentives, processing capabilities and access level to information (Ehsani et al., 2010; Creti, 2001).

Systems dynamics, on the other hand, is a classical technique for simulation that models system/variable interactions (Jarke et al., 1997). It is less common in its use and has been applied in the analysis of supply chains (Ball et al., 2004), process life cycle (Lo Storto et al., 2008) or more abstract levels in an organisation.

Finally, *discrete event simulation* imitates systems that evolve over time based on discrete events with complex interactions (Christensen et al., 1997, 1999; Raghavan & Roy, 2005). It applies queuing techniques and is suited to modelling at detailed process levels in organisations (Ball et al., 2004). Queuing techniques analyse queues that are accumulated due to process variability.

5.2. Information flow optimisation

Although, optimisation for improved *efficiency* has long been the dominant goal of organisational research, in recent years, optimisation for *flexibility* and *adaptability* are gradually becoming important factors of organisational processes (Jarke et al., 1997).

Optimised information flow for organisations can be achieved through: rearranging task sequences, re-examining task organisation, minimising information exchanges and managing unpredictable rework (Eppinger, 2001; Browning, 2001). Optimised

Table 4
Applications of information flow modelling techniques.

Modelling application	Description	Reference
Simulation	Making use of agents, system dynamics and discrete events to gain a better understanding of interactions	Raghavan and Roy (2005), Jarke et al. (1997), Christensen et al. (1999), Lo Storto et al. (2008), Aoyama et al. (2005), Burstein and Diller (2004)
Optimisation	Utilising formulations and constructs to realise improvements for efficiency, flexibility and adaptability	Jarke et al. (1997), Eppinger (2001), Christensen et al. (1999), Braha and Yaneer (2007)
Management	*Information system mapping* – visualising layers, relationship and communication channels within an organisation	Howells (1995), Owens and Wilson (1997), Stapel et al. (2007), Mash et al. (2008)
	Control policies – defining rules and standards for enabling organisational communications and interaction	Braman (1989), Smith et al. (2004)
	Restructuring organisations – exploiting constructs and formulas for automating, reorganising and streamlining flows	Eppinger (2001), Stapel et al. (2007), Ellis (1979)

organisations can also be achieved by minimising uncertainty in decomposed organisational processes (Christensen et al., 1999).

Information flow simulation and optimisation concentrate on analysing task information criteria and corporate memory (Jarke et al., 1997). Task information criteria include short-term local effects that relate to processes such as cost, timeliness, correctness and completeness. Corporate memory relates to long-term effects of accumulated, condensed and transferred information as well as feedback loops in organisations.

5.3. Information flow management

Information flow modelling can be applied for managing information flow in terms of: mapping information systems, creating information control policies and restructuring organisations. Models of information flow offer a useful avenue for mapping an organisation's information systems by enabling analysts and managers to visualise and assess the nature of face-to-face interactions (Howells, 1995), the level of documentation (Stapel et al., 2007) and the use of ICTs (Owens & Wilson, 1997) also known as telematics (De Boer & Walbeek, 1999). The way these individual components function in the organisation is determined by information flow networks that are hierarchical or established by formal and informal relationships depending on the level of trust in the organisation (Mash et al., 2008).

In organisations, information control policies govern the use of data and information internally and externally (Braman, 1989; Hartley et al., 2002). This is because the development of information policies is usually determined by levels of trust and available rules/standards and may require a large number participants and scenarios (Smith, Stoker, & Maloney, 2004).

Information policies may be cultural, economical social or political (Braman, 1989). For instance an economically motivated information policy could define information flow during trade negotiations. Information policies are also required for planning organisation network aspects that range from network design to data privacy (O'clock & Henderson, 1994).

In terms of *restructuring organisations*, modelling approaches can be applied to identify problems of information flow (Eppinger, 2001) so as to improve vertical information flows (between units at different hierarchical levels in an organisation) and horizontal information flows (between units at the same hierarchical level in an organisation) (Creti, 2001). Ellis (1979) suggested three main strategies for restructuring organisation as a result of modelling information flow: automation, reorganisation and streamlining. Automation involves replacing manual activities with automated ones whereas reorganisation concentrates on global flows to restructure activities and flows. Streamlining centres on analysing local flows for the elimination of inefficient and redundant processes. These restructuring strategies are designed to improve organisational performance by reducing communication overheads and making predictions about organisational changes.

Although authors such as MacIntosh (1997) have noted that information flow is vital to the carrying out of processes, others such as Aoyama et al. (2005) have observed that processes and information flow usually take place asynchronously. What this means is that a business process such as "shipment of goods" could be undertaken continuously while the exchange of information may be confined to intervals dissimilar to those of a business process. In addition, unsynchronised information flow causes miscommunication between personnel that leads to product and process errors (Pingenot et al., 2009), and delays in communications (Caldwell, 2008). The problem therefore centres on how to synchronise: information flow and processes, as well as the flow of internal, external and internal-external information.

6. Future challenges for information flow research

Research in information flow modelling for organisations, as summarised in Fig. 2, has so far has been beneficial for organisations in five main ways: competitive networking that enables organisations to leverage ICTs for achieving organisational objectives (Malecki, 2002), continuous process improvement and business adaptability through the use of flow management systems (Aoyama et al., 2005; Ball et al., 2004; Berente et al., 2009; MacIntosh, 1997; Ou-Yang & Chang, 2000), enhanced organisational collaboration based on insights into organisational cultures (Doherty & Doig, 2003; Waring & Wainwright, 2002), organisational layouts (Chiu, 2002; Ciborra et al., 1978), and improved information sharing (Childerhouse et al., 2003; Liu & Kumar, 2011; Rachuri et al., 2008; Zhang et al., 2004).

It is however important to note that since information is a valuable resource for organisations (Kehoe et al., 1992; Szczerbicki, 1991), it is therefore necessary to continuously reexamine and analyse how information spreads (or flows) in an organisation. This subsection identifies challenges for future information flow modelling research. Each area is discussed in terms of the implications for organisations and possible research themes.

6.1. Novel organisational networks

Organisational networks facilitate information spread and connectivity within organisations. Typically, these networks are modelled as graphs that contain a set of points (called nodes or vertices) that are associated by lines (called links or edges) (Almendral et al., 2003; Braha & Yaneer, 2007; Hsieh & Woo, 2000). Points represent communication entities such as individuals or locations for carrying out work, whereas lines represent relationships or communication channels. The effectiveness and efficiency of these types of networks are an important factor in the survival of organisations (O'clock and Henderson, 1994).

Information flow modelling studies have applied diagrams and formulae to analyse constructs for scale-free (Wu et al., 2004), hierarchical (López et al., 2002) and random (Costa et al., 2007) networks. The analyses of these networks are primarily due to the creation and emphasis on organisational arrangements and topologies designed to tap knowledge within an organisation. Reviewed articles within information flow research suggest that these organisational networks focus mainly on the arrangement and characteristics of organisational entities. Supply chains are also examples of organisational networks for creating value and managing life cycles.

Current research could therefore be critiqued for failing to identify innovation networks and topologies capable of tapping knowledge from external sources. This is because network analysis research so far has predominantly focused on the analysis of network data and on social relationships with few studies on organisational networks (Zwijze-Koning & De Jong, 2005).There is also a need to characterise physiological elements in organisational networks, to analyse human-to-human (or ergonomics-based) interactions, and to analyse features such as safety, usability, skill levels, and cost-effectiveness.

Possible areas for future research could propose more ergonomically focused networks and explore inter-organisational networks for tapping knowledge from external sources. Other possible areas for research could analyse and model information flow for organisations taking into account external networks that influence the structure and functions of organisations such as customer-, competitor- and market-based networks.

6.2. Design space exploration

Traditionally, efficiency of organisations analysed as information systems was the main goal of information flow research. However, the idealisation of organisations as networks has also exposed the need for factors such as flexibility and adaptability.

Articles within information flow modelling research suggest that so far, current studies have focused on idealising organisations as networks and information systems as captured by Section 4. This focus assists subject matter experts (such as business managers and system engineers) to improve organisation performance by concentrating on specific communication variables such as ambiguity, equivocality, redundancy, consistency and uncertainty as highlighted in Section 1. Exploring the space within which organisations are designed is an area of research that could aid in the development of unique and more effective:

- structures for improving organisational functions and behaviour, and
- characteristics for analysing the performance of an organisation.

Different idealisations such as 'organisations as clouds' could assist analysts and managers to explore, refine and improve layers within an organisation viz. face-to-face interactions, paper documentation, and ICTs.

6.3. Organisation contribution

An area of research that could offer new directions for information flow research involves the analysis of contributions towards an organisation within the context of information flow. The contributions towards an organisation could be analysed from various perspectives such as individuals, processes, departments and hierarchical levels. Reviewed literature suggests that current approaches to modelling information flow in organisations focus on communication variables for coordination of processes, and cooperation/collaboration among personnel.

Possible future research could therefore explore 'contribution networks' as well as attributes and characteristics of contributions towards an organisation. These studies could further enhance information sharing by introducing an addition layer for evaluating flows within working teams and from external sources.

6.4. Studying industry needs

As highlighted earlier, information flow presents a partial view of information which in itself is a partial view of an organisation. The need to reduce the gaps among various models applied by organisations is a long standing challenge for modelling research pursued to shorten the time to model and develop systems (Ou-Yang & Chang, 2000). IDEFO, HIPO, GRAI, UML and SysML are examples of modelling languages that attempt to provide comprehensive tools for software and systems development. Most of these modelling languages concentrate on organisations in traditional manufacturing sectors and organisations involved in software development.

However, organisations exist for a wide range of purposes that include commerce, politics and charity. Across these organisations, organisational culture and operating policies may also vary depending on industry (domain and sector) needs. Consequently, current information flow analysis methodologies and modelling approaches could be improved by more empirical research within and across organisations to study industry needs. Useful criteria that could guide this area of research may focus on research questions and characteristics of information flow such as 'Who analyses information flow in industry?', 'Who needs the analysis of information flow as part of their day-to-day activity?' and 'What would the managers of information flow want to better understand?' These questions could aid analysts and managers to create and apply diagrammatic primitives and mathematical formulae that reflect current industry needs.

6.5. Critiquing information flow

The proliferation and widespread use of ICTs in modern society has made it possible for individuals to communicate via multiple channels such as electronic mails (emails), phone calls, web conferencing, and text messages. In an organisation, some communication channels, though present, may be redundant or infrequently used for long durations. In spite of this, the presence of multiple communication channels could offer assurances and flexibility in intra- and inter-organisational information exchanges. Ineffective processes on the hand are a major problem for organisations that impact on resources, time and quality of operations (Creti, 2001; Helbing et al., 2006; Howells, 1995; Szczerbicki, 1991). Consequently, whereas redundant processes contribute to inefficiency in organisational functions, redundant communication channels contribute to assurances in information flow.

The application of modelling for simulation and optimisation is therefore required to critique information exchanges and analyse communication channels in organisations. Possible areas for studies could concentrate on proposing models for simulating information flow based on flow relevance, channel significance and organisational needs. Other areas could critique and propose formulations for optimising the use, the level of use, and the appropriateness of ICTs.

7. Conclusions

Organisations, as communicating entities, require people to communicate and exchange information. Businesses as profit-driven organisations are also characterised by work dynamics in terms of work status, practices, roles and responsibilities as well as the social dynamics of person-to-person interactions. Based on these constructs, permutations relating to the flow of information can involve single or multiple transfers of information from one person to another and the broadcast of information from single or multiple sources to multiple sources. During business exchanges and interaction, information may be conveyed to merely confirm, enhance or update a previous message. Flows may also contain messages that are formal or informal in nature and content. Along these lines, the flow of information plays a vital role in the existence of organisations and in the survival and competitiveness of businesses. Modelling information flow is therefore an important design task for organisations required to represent communication and analyse communication variables.

In this review article, an attempt has been made to identify approaches to modelling information flow for organisations. The article highlighted the purpose, approaches and applications of diagrammatical and mathematical information flow modelling for organisations. This review article also highlighted how combinations of diagrammatical and mathematical modelling can be applied to simulate and optimise short- and long term information flows, and to manage information systems via information system maps, control policies and restructuring schemes. It is however important to note that the creation of an all-encompassing information model is an exercise that is unnecessary and impractical for design. For a start, such a model may be too complicated for use due to the various aspects which the model will have to consider. There is also the semantic challenge of keys, symbols and representations for such encompassing model which could further complicate and confound the use of the model.

This article makes three key contributions. First, the article provides a critical assessment of how pictorial, graph and matrix representations are applied to create integrated and viewpoint depictions of processes and interactions. Second, the article evaluates mathematical models that make use of mathematical theories, for flow and organisational examination. These theories are based on concepts such as coordination, economics, graphs, probabilities, networks, vectors, and fluid flow. Third, the article offers insights into how macro, meso, and micro levels of information flow models can be leveraged for improved organisational structure and behaviour. Problems of information flow modelling highlighted in this review consist of difficulties in defining organisational networks, information flow focus and information synchronisation. Other problems centre on information anomalies, overload, distortion, leakage, and backflow. Reviewed literature also suggested that information flow modelling in organisations has been beneficial for five main reasons: continuous process improvement, business adaptability, organisational collaboration, improved information sharing and competitive networking of organisations.

Generally, organisations analysed as 'information processors' has been traditionally applied to depict internal structures and processes. This contrasts with the re-emerging 'organisation as a network' idealisation in which patterns of relations and involvement are analysed for organisations. Another important benefit of the network model approach is the emphasis on identifying networks and topologies capable of tapping knowledge from external sources. Added to this is the growing significance of networks and networking technologies in modern society for collaboration and social interactions. Widely used in businesses, these networking technologies support rapid access and sharing of information and include the internet, electronic mails, smart phones, tablet personal computers, 3rd and 4th generation mobile telecommunications, social networking, and 3D virtual worlds. This increases the significance of person-to-person interactions for successful operations and creates new requirements for modelling information flow. Consequently, there is a need for researchers to critique information flow models not only in terms of their ability to support perceptual (for thorough grasp of meaning) and conceptual (for hypotheses development) reasoning; but also in terms of their relevance and appropriateness for analysing current organisational structure and behaviour within different industry sectors.

With this is mind, five main challenges for future information flow modelling research were highlighted and discussed. There is a need for modelling approaches to analyse novel organisational networks and for analysing contributions within organisations. There is also a need for new design paradigms that explore the design space for organisations and for effective structures and characteristics for analysing and improving organisational performance. Other possible future areas of research could be motivated by studying industry needs and critiquing the flow of information.

Acknowledgment

The author would like to extend their sincere thanks to the Engineering and Physical Sciences Research Council (EPSRC), for its support via the Cranfield Innovative Manufacturing Research Centre (CIMRC), towards the work carried out in the preparation of this article.

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