Enhancing Map Design for 3-Dimensional Spatial Data Based on Integration of 4IR Geomatics Technologies

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Abstract

Spatial data is an integral product and part of human livelihood as society becomes more spatially enabled. Spatial data in form of maps and location-based services has become an integral part of the public's livelihood in the information society. Maps have been historically created through the traditional cartographic process which targeted customers or audiences with competence in map reading. As such, these maps present geographical phenomenon in complex ways that are not easy to decipher by the novice user, and are of thus limited use. The novice user requires maps that are highly visual and interactive to easily interpret their content and make informed decisions rapidly. The basic data sets that are created by national mapping agencies such as topographic and cadastral maps have not transformed over centuries while society requires value added easy to use map products. The fourth industrial revolution (4IR) brings a wide array of technology for capturing and processing new forms of spatial data which can be integrated in the design of new and innovative map products. This requires transforming of the traditional cartographic process to enable the design of a wider array of products and services. The aim of this study is to explore a map design procedure that utilises 4IR technologies and multiple geo-visualisation aspects through supply chain mapping. Results reflect that changing geo-visualisation techniques within map production improves communication and supply chain mapping can create avenues for the design of a wide array of geospatial products.

Keywords
Map Design, Design Theory, Geo-visualisation, 4IaR Geomatics Technologies and Supply Chains.

1. Introduction
Society is becoming increasingly spatially enabled (Williamson et al. 2011) as geographical information has transformed from once being state owned (ANZLIC 2010) to a public good (Georgiadou et al. 2009) due to the increased diffusion of spatial data and enabling technologies (Çöltekin et al. 2020) that are leading to continuous societal transformation (Kotsev et al. 2020). Government departments use geographical information for directing policy interventions (Craglia and Johnston 2004), decision making (Johnson and Scassa 2023) and the public use location based services (Mayer et al. 2009) to navigate to different places. Spatial enablement has led to increased demand of geographic information that is highly visual and easy to interpret. The public utilizes geographic information on a day to day basis as they navigate the best routes with optimal traffic conditions to their destinations of choice. More and more datasets are being crowdsourced on a large scale such as location and traffic information (Kim et al. 2023) via google maps in order to inform motorists on traffic conditions. Elsewhere crowdsourced data is used in designing digital maps for informal settlements (Soman et al. 2020) and in humanitarian response mapping (Hunt and Specht 2019).

The 4IR has brought forth an explosion in the availability of geographical information collected from multiple devices and remotely from multiple locations. The internet and availability of portable devices allows sharing and access of these data (Ballatore 2014) through different cloud systems and client-server architectures. Geographical Information Systems (GIS) technology for example enable users in remote locations to work concurrently on the same map data and spatial databases (Apollonio et al. 2012).

With the increase in content and richness of spatial information it is now possible to better represent geographical phenomenon in greater detail so that users can better understand the content communicated by maps. While vast information exists to enrich maps, some presentations have not embraced the data that has been made available through the 4IR. Some maps, such as topographical representations continue to provide hard to decipher information to untrained users for example figure 1a. Users cannot learn more from these presentations. This changes when geovisualisation aspects are added for example figure 2b and 2c where the slope and flow directions can be viewed respectively providing users more information.

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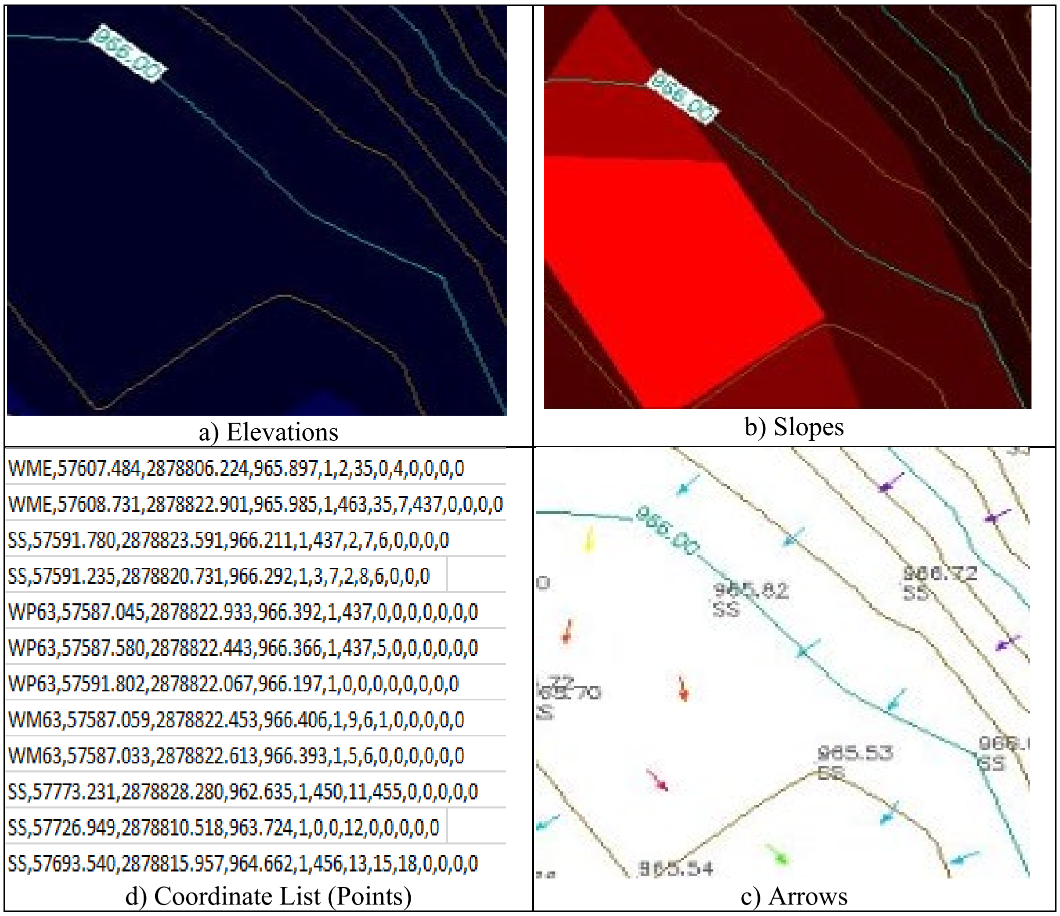

Figure 1. Geo-visualisation examples: a) elevations; b) slopes; c) arrows d) Coordinate list [Data Courtesy – Ricochet (Pty) Ltd, Botswana]

While the discipline of cartography has standards that guide mapping, methods for easier communication to novice users through improved geo-visualisation options should be explored. This is possible when there is integration of multiple spatial data sets including geotagged photographs and crowd-sourced data, text and multimedia (Apollonio et al. 2012) in order to provide more information about the map. This is essential as society continues to become more spatially enabled with general public utilising spatial data.

1.1 Objectives

This paper explores a design procedure to harness multiple data sets collected through 4IR geomatics technologies in providing enriched spatial data sets that better represent geographical reality and provide better understanding of the geographic phenomenon to users based on supply chain principles. The hypotheses for this study are:

H_0: Design theory can be utilized to represent the map production process

H_1: Design theory cannot be utilized to represent the map production process

H_a: Supply Chains management can model the production of spatial data
H_b: Supply Chain management cannot model the production of spatial data

2. Literature Review: 4IR Geomatics Technology

There are various geomatics technologies that are used to collect raw spatial data, transform it through several value addition processes, store it in data warehouses and distribute it to data vendors who deliver it to end users through a supply chain. This concept is referred to as the spatial data supply chain (Kurwakumire et al. 2013). This section discusses these 4IR technologies that enable geomaticians to produce maps, mapping applications and location based services.

With increasing developments in information technology, there are several easy to use and affordable portable devices for spatial data collection. Software tools have also been in incremental upgrading due to further developments in data science and machine learning. Together with the increase in computing power, it is possible to collect vast amounts of data from sensory systems and other platform and process it to create new spatial data sets that are in formats for aiding decision making.

The technology has become highly disruptive and this has resulted in an increase in users of spatial data for both personal and professional reasons. Spatial data has become a daily need of the public whether knowingly or unknowingly.

2.1 Big Data

Sensors have made it possible to collect data in real time and continuously at specific location so that near real time monitoring of a particular phenomenon can be done. Phenomenon normally collected in this way includes temperature, precipitation and ocean tides. With application of machine learning algorithms in mapping it is possible to create dynamic maps that update at provided intervals to reflect the current status of a given phenomenon accurately to within a given time period. Due to the large size of the data sets, they are referred to as big data or specifically big spatial data. Additionally, GIS has been utilized to integrate Big Data from different sources as a Covid-19 response (Zhou et al. 2020) due to increased capabilities for disaster resilience (Sarker et al. 2020).

2.2 Unmanned Aerial Vehicles (UAVs)

UAVs capture aerial photographs of geographical phenomenon. These photographs are a source of information for the cartographic or the map design process (Cartwright 2010).

2.3 Laser Scanners

Laser scanners measure point clouds for recreating surfaces such as buildings which creates indoor and outdoor three-dimensional (3D) representations or virtual models (Fröhlich and Mettenleiter 2004). They are useful in monitoring hazards such as landslides (Bitelli et al. 2004) through comparison of point cloud data based on different time epochs.

2.4 Global Navigation Satellite Systems

Global navigation satellite systems (GNSS) enables the measurement of real time locations in three dimensions achieving centimeter accuracy. This is through on integration of satellite signals from different constellations to include GPS, Galileo, Glonass and BieDou in the position determination computations to generate best possible values of the location (Li et al. 2015). GNSS is used in field data collection for designing topographical and cadastral maps.

2.5 Online Mapping Tools & Crowdsourced data

There are several tools proving web maps such as google maps and open street maps. Maps and satellite imagery are free for the public to use. The public can contribute content such as photographs, place names, traffic flows and place ratings to enrich the use of maps by future users.
The web mapping platforms provide base layers for building spatial applications on and also provide navigation, measurement and even in some cases, the generation of contour lines and surface models.

2.6 Pictometry

Photographs supplement vector maps by providing a more visual representation of what exists at a spatial location (Cartwright 2010). Oblique imagery obtained from pictometry are used for generation of 3D city models (Wang et al. 2011) and for damage assessment on buildings after hazards such as earthquakes (Gerke and Kerle 2011). Pictometry is used for street view on google maps. Nowadays, pictometry is used by private institution such as universities and museums to design virtual models of campuses and monuments respectively so that the public can benefit from virtual tours.

2.7 Remote Sensing

Remote sensing is major tool that has been employed in change detection for land use and land cover (Liu and Zhou 2004), informal settlement detection (Kit et al. 2012), urban change (Pham and Yamaguchi, 2011) and precision agriculture (Zhang and Kovac 2012). While the technology has been available for some time, it now benefits from imagery with high spatial and temporal resolutions and increased availability of multispectral images that increase its application areas. Remote sensing is an enabling technology that allows the creation of new maps and that provide different geo-visualisations in a short space of time. Remote sensing technologies include synthetic aperture radar (Krieger et al. 2007) and lidar (Zolkos et al. 2013). Remote Sensing has been highly improved by the incorporation of data science and machine learning algorithms in the processing software. Additionally, satellites are now able to utilise more bands enabling more detailed analysis of phenomenon above, beneath and on the earth's surface. Many countries are increasing managing to launch their own satellites to increase the availability of spatial data. On the other hand, repositories such as Google Earth Engine, (NOAA) and United States Geological Surveys (USGS) earth explorer are still increasingly providing remotely sensed data sets.

2.8 Spatial Data Infrastructures (SDIs)

Spatial data infrastructures provide the mechanism to discover, access, share and exchange geographic information and services from remote locations (Sliwinski 2004). SDIs manifest as integrations of webGIS, distributed geographic information systems and electronic government systems. SDIs are part of the digital infrastructure that is among the critical public infrastructure. Geographic information for problem solving and decision making can be sourced from this infrastructure by organisations in different sectors. SDIs provide cost minimisation through limiting the duplication of primary spatial data collection by promoting reuse of secondary data sets that are hosted within the infrastructure.

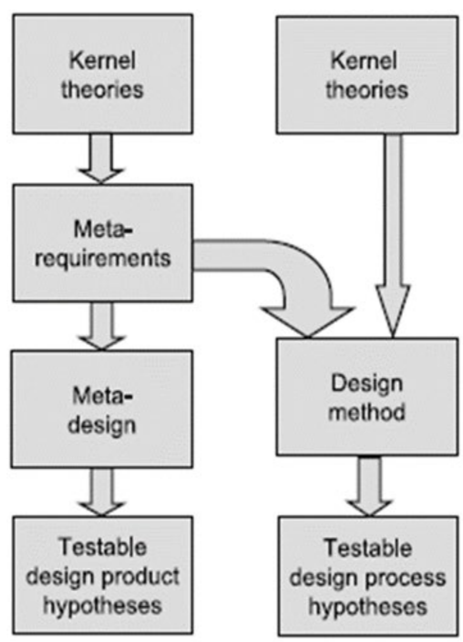

Figure 2. Design Theory (Walls et al. 2004; Baskerville and Pries-Heje, 2010)

4. The Traditional Map Design Process

Cartography is the process of map design for representing geographical phenomenon on and below the earth's surface. The importance of technology in this design process is to provide infrastructure for the production, reproduction and distribution of maps to various end users (Cartwright 2010). The technology comprises hardware, software, data warehouses and the internet (Kurwakumire et al. 2014). From kernel theories, the meta requirements are determined which are used to either select a design method or to design a manufacturing workflow that can be simulated and tested before actual product design is done.

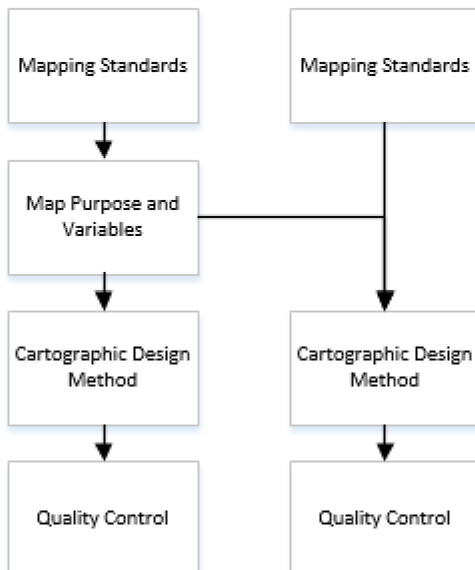

Figure 3. Design Theory applied in Map design

While map production was traditionally limited to national mapping organisations (NMAs), nowadays there are multiple organisations and individuals involved in developing geographic content. The traditional setup recognized the development and supply of inputs such as paper and ink, and then the input spatial data that was utilized by the production unit to create maps. On completion of the maps, they would then be duplicated by the reproduction unit, before the distribution unit made the maps available to different users including government units. This was in essence the map production workflow, that was a government infrastructure. The focus of the mapping was limited though to topographic and orthophotomaps which had limited applications. These production units essentially formed a value chain. The failure of some national mapping agencies to evolve and develop new products to suit different problem solving needs saw the emergence of geographic content developers in the private and non-government sectors to fill the gap and demand that the NMAs were failing to close and meet. This later on extended to volunteered geographic information and crowdsourcing furthermore increasing the amount of updated and rich in content maps available.

On mirroring the design theory depicted in figure 2, figure 3 is developed to mimic the traditional map production process. The map design process has its premise on standards. Standards define the type of symbols, use of color, representation of scale and orientation among other map annotations. The purpose of the map as per the customer's request detects which part of the standards the manufacturer should utilize and what input (raw or semi-processed data) should be sourced from suppliers. This data is then transformed to a final map product through a specific cartographic design method that suits the output desired by the customer. The map product undergoes quality control before it is branded, packaged and delivered. The traditional design process is shown in figures 6 and 7. A typical cartographic workflow is provided by Jolma et al. (2008: 175) which details the intrinsic processes involved in the actual design of different maps that cover a diversity of user needs (see figure 5).

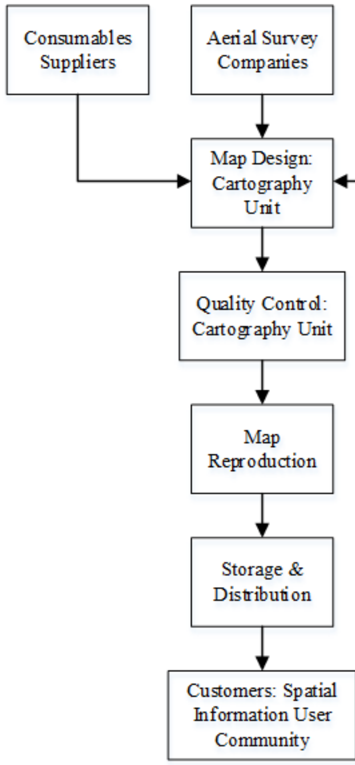

Figure 4. Expansion of Map design process

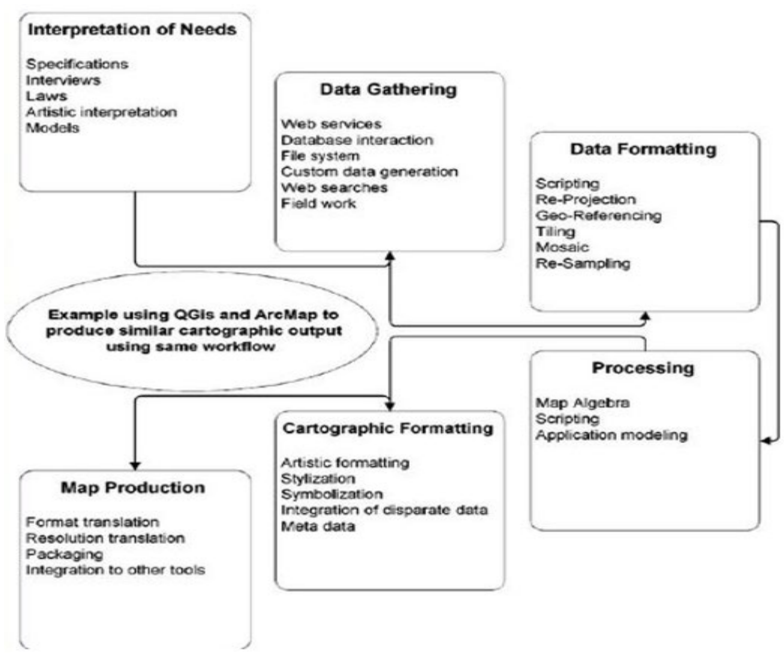

Figure 5. Example Cartographic Workflow - Source: (Jolma et al. 2008: 175)

5. Results and Discussion

Cartography is the art and science of map making. One of the design issues in map making is the ability to generate maps at different scales from one high resolution map (Brewer and Buttenfield 2007). This would ensure quicker map production and reproduction and delivery to end users and improve the effectiveness of the mapping value chain. Automating this process would improve the efficiency of this supply chain based on utilization of technology and generalization algorithms (Brewer and Buttenfield 2007).

It is important to note the expansion of the spatial information user community. The public is not always interested in the base data sets created by NMAs. Some cannot even read or interpret topographic maps. The general public needs maps that are highly communicative and easy to use. These are the aspects to be considered in the design process. Cartographers have failed to for example design easy to use tourist and metro-route maps. Even though there is a standard way that has been adopted for these maps, there are not always easy to use and tourists struggle especially when language is a barrier at help desks in tourist destinations. This means that maps are not presenting a universal language and there is still a complexity barrier to be removed or reduced through some of simplification through either improving the mapping language or geovisualisation techniques applied in the design process. Furthermore, it is important to market products and teach the public about using these maps so that there is basic knowledge about map use.

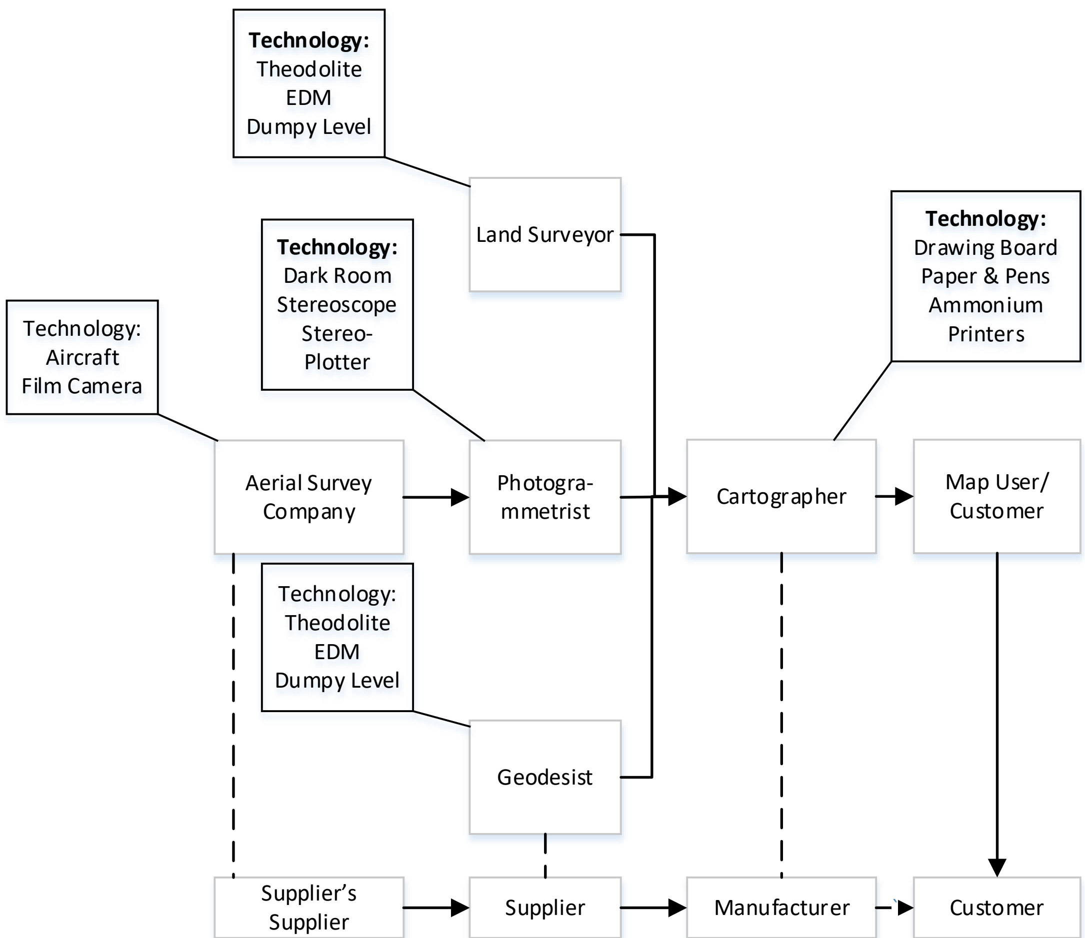

Figure 6. Traditional map design process

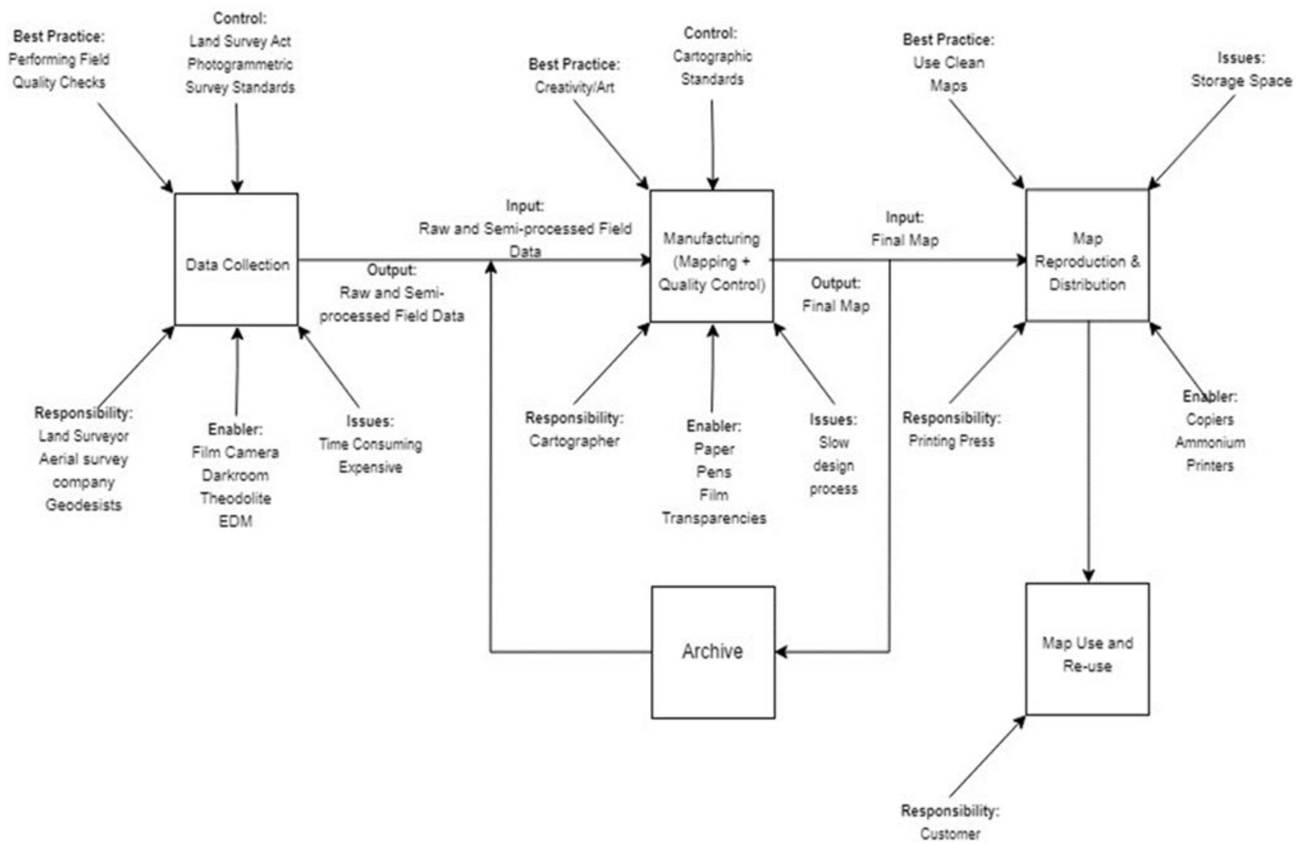

Figure 7. Extended traditional map design process

Interpreting the content of a traditional cartographic map product has been largely due to the reader's ability to decipher the symbols from the legend and translate the information being communicated by the map (Buziek 2000) which is not ideal for novice map users. This presents a major setback to the value of maps to users. The challenge can be mitigated by adding several layers of geo-visualisation through interactive and non-interactive cartographic animations (Buziek 2000) that communicate better the map content. However, technology critics offer the opinion that computer assisted cartography is susceptible to the design of misleading maps due to opening the map design field to those without professional cartographic expertise (Morunonier 1991). However, (Morunonier 1991) supports the use of multiple cartographic or geovisualisation views as opposed to single views in order to better communicate geographical information. The single view is based on the perception of the cartographer on how geographic reality should be represented (Cartwright 2010).

5.1 Graphical Results

In the traditional map design process (see figure 6) there is utilization of tradition land surveying, photogrammetric and cartographic approaches in designing maps. The major purpose of the production line is on producing topographic maps and ortho-photographs. There is limited consideration of other services that are required by the spatial information user community. The major suppliers of input or raw field data are surveyors, photogrammetrists and geodesists who source field data using surveying equipment. The cartographer who is the manufacturer, collects this input data in semi processed format and manipulates it to generate maps which are made available to the users or customers. Traditionally the major users were the national mapping agency itself, government departments, airports, police and the military.

Figure 7 expands the design process through adding issues, resources and control mechanisms to provide a more detailed picture of the mapping process. For example, raw data collection is a responsibility of land surveyors, aerial survey companies and geodesists and there exists legislation that governs the collection of the data. The data is collected using technology such as theodolites and field camera, with the measure issue being lengthy field procedures.

Again, for this step are best practices such as the utilization of field quality checks. At the end of the diagram it can be noted that the map products are in analogue format and hence reproduction is through photocopying. This brings a problem of storage space in fireproof rooms. In this way, the study has managed to expand the map design process suggested in figures 3 and 4 as a demonstration of concept.

5.2 Proposed Improvements

The design process presented in figure 4 is further expanded in figure 8. Figure 8 also takes note of the issues in the supply chains presented as figures 6 and 7. In the new scenario, which is more realistic, there are multiple data collectors to include private data warehouses, and crowdsourcing applications. This digital data is received to various cartographic mapping workflows that include web-mapping applications. Vast amounts of geographic information are produced and stored in the geo-portal. Client or user systems are linked remotely to the geoportal through web-based applications utilizing client server technology and the spatial information community can down the products from various cloud systems, servers and data warehouses available.

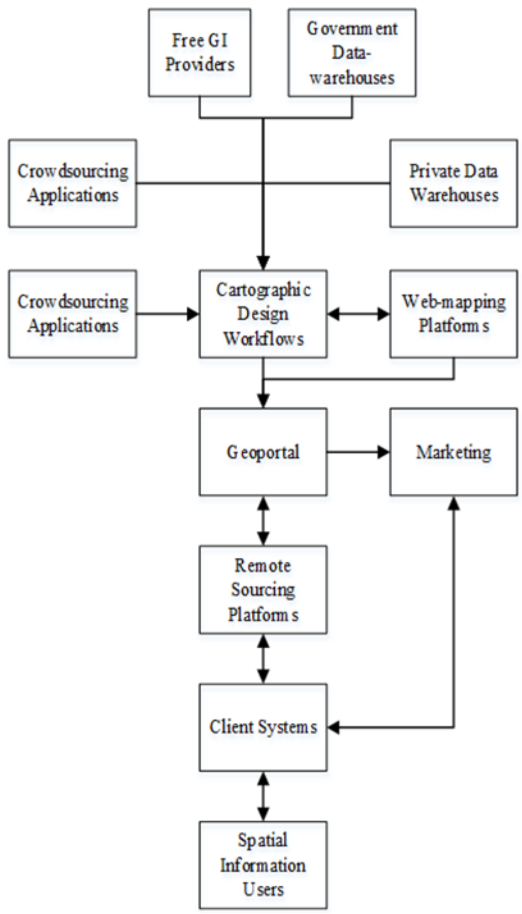

Figure 8. Improved cartographic design process

Figure further expands the content of figure 8 to demonstrate how large the supply chain expands to together with its potential to provide more products and services.

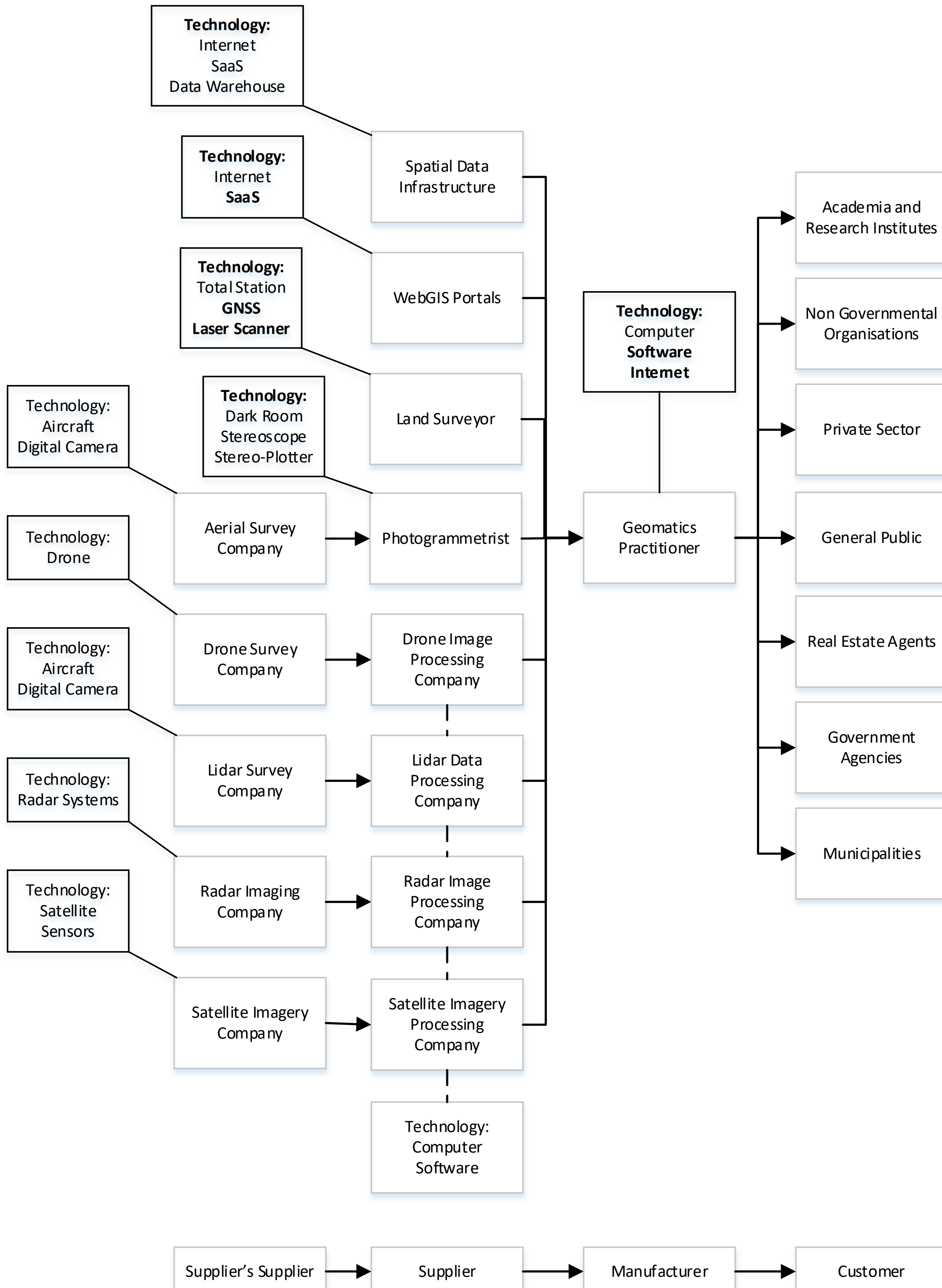

Figure 9. 4IR map design process

5.3 Validation

Society is now more spatially enabled. There is need to further promote use of spatial data through creation of value added geographical information products by national mapping agencies to increase the spectrum of information that is available at nominal cost since spatial data is partly a public good. National Mapping Agencies have been mostly concentrating on basic country data sets such as topographical maps, cadastral layers and photogrammetric images (ANZLIC, 2010). There is need for products which combine multiple data sets and geo-visualisation aspects such a 3D virtual reality for easier interpretation. This is the purpose of the supply chain mapping in figures 6 to 9 to where the status quo of the cartographic process is visualised and a futuristic model that can serve the needs of the wider spatial information community designed,

The supply chain model proposed in Figure 8 and 9 details a design model for value added geographical information products for national mapping agencies. The supply chain comprises of multiple stakeholders including suppliers, the manufacturer, and customers. There is use of multiple 4IR geomatics technologies to collect raw spatial data. This data is transformed to multiple value added products with different geo-visualisation styles and stored in data warehouses and disseminated to users on demand using software as a service (SaaS). This enhanced supply chain is much broader than the traditional map design process in Figure 6 and 7.

6. Conclusion

Often products that have been created for a niche of specialist are often restricted regarding development of alternatives, variations and new products. This has been largely the situation with geographic information or geospatial products and services where surveyors, geodesists and geographers among other few specialists have been custodians of the data. Present day, the majority of the public worldwide uses maps or some form of location based service such as google maps, WhatsApp location, navigation applications among others. While the design theory has not more tailored for the manufacturing industry, this study demonstrates that, it can also be utilized in the cartographic industry where geospatial products and services are manufactured hence accepting the hypothesis H_0. Additionally, the study has demonstrated the use of supply chain mapping in modelling processes involved towards producing an information based product or service, that is nowadays mostly in digital format, hence accepting H_a.

The aim of this study was to provide insight to a map design procedure that incorporates multiple 4IR technologies and geo-visualisation aspects. This was achieved through application of supply chains to the design process. The geographic information supply chain needs to be agile to respond to changing customer needs and new options that arise due to improvement of technology in the 4th industrial revolution. This design however, introduces possible challenges. The greatest negative consequence to increased availability of map data is information overload. This increased availability of geographic information can be taken advantage by providing different geo-visualisation options for users to enrich the quality of information that users view. It is the role of the geomatics practitioners to structure the product design processes in a manner that provide multiple product and service options that are easy to use.

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Biography
Edward Kurwakumire is a Lecturer in Geomatics at Tshwane University of Technology for 11 years. His research areas, include geospatial supply chains and land administration systems. His research work involves primarily designing supply chains for different applications in the geographic information industry.

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