Data Driven Approach to Enhancing Efficiency and Value in Healthcare

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Part VI

Discussion and conclusions

Chapter 8

Discussion

Previous five chapters focussed on solving practical problems in different levels of healthcare management, using data-driven methodologies.

This chapter serves to draw together the discussion of key findings from these studies, as well as contributions and implications of this research for policy and practice in healthcare.

As introduced in Chapter 1, the objective of this research is *the investigation of influence of cross-discipline approach to create value through data-driven methodologies in healthcare*. As noted, this research is drawing upon both theoretical and empirical analysis, with use of Modelling & Simulation; Metaheuristic optimisation; Social Network Analysis; and Data Mining.

This discussion is structured as follows: Section 8.1 revisits the specific aims of this Thesis, and summarises the key findings in reference to the specific objectives; Section 8.2 evaluates the contribution and implications of our findings for policy and practice in healthcare, describes the level of clinical and managerial engagement in each of the projects, and discusses the main issues identified in this research.

8.1 Research Aims: Revisited

This section presents a reminder of the purpose of the study and discusses the main research results and findings.

- ***Analyse activity, capacity and demand of a cancer diagnostic services across a region.***

  Chapter 3 used Modelling & Simulation methods and Data Analytics to study current performance and to model improved and more efficient future states of cancer diagnostic services in the UK. Existing capacity and current activity for all endoscopy units in Wessex was estimated using both open data and information provided by NHS Trusts. Potential maximum capacity using the infrastructure available within the region was also estimated. A five-year projection of future demand for endoscopy services was also performed. This analysis informed hospital manager and commissioners (CCGs) about capacity needed by each hospital.

  This project was developed as part of a programme to increase early detection of cancer and thereby reduce premature mortality in Wessex. The work was commissioned by the NHS Wessex Clinical Network (CN) as part of the Cancer Alliance work, linked to Dorset and Hampshire & Isle of Wight Sustainability and Transformation Partnerships (STPs), and supported by all Clinical Commissioning Groups (CCGs) and Trusts in Wessex as a priority work-stream. This work would be used by the CN to support Health Education England (HEE) in planning regional workforce.

  A combination of Statistics, Data Analytics, and Modelling & Simulation, using Discrete Event Simulation (DES) approach, was used to estimate the future demand based on two scenarios. The fist scenario was based on a national Bowel Cancer Screening Programme (BCSP) using fecal occult blood test (FOBt) for screening and a Colonoscopy after a negative result. Results of the simulation shows that a 4% increase in demand is expected. In the second scenario analysed, the screening programme was a combination of the FOBt and the new BCSP, based on a Flexible Sigmoidoscopy test for all the patients 55 years old. The expected increase in demand with this scenario was 28%. An important variation in working practices and efficiency was observed across the region, with an endoscopy room utilisation that varies from 41% to 94% across the hospitals included in the analysis.

  The analysis showed a potential to improve capacity utilisation within existing resources, increasing the number of endoscopy points per session and the room utilisation. An example of the impact of this interventions is that if all the hospitals adopt a 11 points per session policy, and increase the utilisation rate to 80% then the capacity across the region will increase about 12.5%. If activity goes as planned for the hospitals, then an increase from 3,440 points per week (current activity) to 4,473 points per week (current capacity) is possible with all scheduled activity takes place, and no changes to staffing nor session time required.

Following this project, the development of bespoke analysis and modelling for each provider unit was recommended for the project steering group. Another recommendation was the review of current booking templates across sites to understand the variation from the 12 points national standard, and the time assigned to 1 endoscopy point because some units assign 15 minutes and some assign 20 minutes to the same procedure. Review of session utilisation and start and finish times should be routinely monitored as low utilisation usually falls into three categories: insufficient backfilling of lists, high percentage of patient do not attending, and under booking.

This study was based on a strong relationship with clinicians and NHS managers across the region, and supported by NHS Wessex CN. The impact of the project was high and was the starting point of a collaboration between NHS providers and Trusts, the University of Southampton, and Wessex Academic Health Science Network. Through this project, Modelling & Simulation was accepted as a valid and useful methodology to evaluate cancer diagnostic services in the region. Benefits of the project was not only the final results but the insight generated through this.

After this study we produced bespoke simulation models for individual NHS Trusts and we started a new project aiming to analyse cancer pathways and to evaluate current cancer diagnostic activity, capacity and demand across five specialities (Gynaecology, Urology, Upper and Lower gastrointestinal, and Lung) at a Wessex wide level.

- ***Predict short-term and long-term demand for knee Arthroplasty at a national level***.

  Chapter 3 also presented a summary of a study focussed on prediction of the burden of revision Knee Arthroplasty across the Spanish National Health Service, both in short-term (2015) and long-term (2030), and their impact on primary KA utilisation. This project was developed using Statistics and Modelling & Simulation techniques.

This study was developed in collaboration with the IMIM (Hospital del Mar Medical Research Institute, Barcelona) and the Agency of Health Quality and Assessment of Catalonia (Agència de Qualitat i Avaluació Sanitàries de Catalunya [AQuAS], Barcelona).

One of the findings was that the variations in the number of revisions depend on both the utilisation rate of primary KA and the survival function applied. Projections of the burden of KA provided a quantitative basis for future policy decision making on the concentration of high-complexity procedures; number of orthopaedic surgeons required to perform these procedures; and the resources needed.

The study was supported by a steering group of clinicians and health service managers. The impact on the healthcare system is unknown as the original outcome was a report commissioned by the National Health Service.

This project was presented in academic conferences, published as a official report, and also published in a peer-reviewed journal (see Appendix A).

This was the first study developed as part of this Thesis, and the methodology here discussed was the starting point for the analysis of activity, capacity and demand presented in Chapter 3.

- ***Improve operational performance and patient experience in a hospital department***.

  Chapter 4 presented the application of System Modelling & Simulation to improve operation performance and patient experience in an endoscopy department in Wessex. This project was developed using a mixed methodology, including process mapping, time motion study, interviews with clinical staff, analysis of data collected in paper-based forms, analysis of hospital Electronic Patient Records (EPR), and literature review for parameter estimation and training. A DES model was developed as part of this project. The model predicts consistently well the endoscopy process and patient Length of Stay (LoS) at the unit.

  Following the analysis of activity, capacity and demand of a cancer diagnostic services described in Chapter 3, a bespoke computer based endoscopy unit model was developed. This project focused on making the best use of resources (staff, endoscopy rooms); bottleneck identification and reduction; non value-added activities reduction; process standardisation; and patient experience improvement.

This simulation model enables Trust teams to review different operational elements (e.g., patient arrival time; endoscopists working hours; staff roles; etc.) and to evaluate the benefits on patient experience and department capacity utilisation.

Some of the challenges identified in this project are the lack of available data to populate simulation models; the complexity to access to this information when available; and the lack of transferability of knowledge and tools between NHS organisations. Aiming to bridge this gap, we are now developing a tool focused on cancer pathways modelling and simulation, data visualisation, and capacity and demand analysis using open source tools and open data.

Final outcomes from the modelling was presented to hospital managers as well as the Clinical Commissioning Group (CCG) manager, and an evaluation of the implementation of the changes recommended over three months was agreed with the Trust.

Feedback from the CCG shared at one of the Wessex CN Steering Group Meeting concluded that the work was of value. Key actions to be undertake by the Hospital as a result of the modelling are given below:

- Reviewing differing operational guidance and patient pathways with a view to identifying any further improvements, whilst affirming protocol.
- A number of utilisation audits have taken place using the modelling to check were and how the trust can improve intra and session utilisation.
- Considering differing skill mix both inside the endoscopy room and the unit itself.
- Patient flow including staggered start times: They currently operate staggered times for the patients, however, are looking to review these as they feel that they have under estimated the amount of urology Two weeks referral (TWR) reserved slots available.
- The modelling highlighted a need to improve patient communication. Different improvements are being implemented.

This study has shown the potential value for further formal studies to quantify and optimise existing endoscopy capacity before major investments in extra capacity, with a potential improvement in both patients and staff experience, accomplishing the same amount of work in less time.

- ***Solve a complex optimisation problem in the healthcare sector***.

  Chapter 5 discussed how Metaheuristic optimisation can be used to solve complex problems associated to scheduling or routing in healthcare. A Genetic Algorithm was implemented to solve a simplified version of the Home Care Healthcare Problem, focusing on the problem of routing healthcare professionals to deliver home healthcare services to the patients.

  This problem was modelled as a Travelling Salesman Problem (TSP), using a complete graph $G = (N, A)$, where N is a set of n cities, and A is a set of arcs. Genetic Algorithm was introduced as a tool to solve this problem, focusing on the impact of parameters selection on its performance and execution time. A theoretical case was solved using a benchmarking dataset.

  Several commercial options are currently available to solve this and much more complex problems related with scheduling and routing healthcare professional, nevertheless, we described an alternative approach using only open source tools. Metaheuristic optimization deals with optimization problems using metaheuristic algorithms. This approach can provide a useful solution to tackle complex problem in healthcare, and through this, enhancing efficiency and value.

  Metaheuristic algorithms remains an open field of research for which many questions are still left unanswered, even regarding well-established methods. When analysing the impact of this methodology in real-world problems in healthcare we observed a huge gap, and therefore, more work should be done to demonstrate the potential impact of metaheuristics in the improvement of healthcare services.

- ***Analyse and extract insight from an organisational network***.

  The study presented in Chapter 6 was focussed on the extraction of Organisational email knowledge using Social Network Analysis (SNA) and Data Mining (DM) techniques. A theoretical review of SNA concepts was presented, and also an empirical analysis using information extracted from email datasets.

  Several practical and theoretical implications were identified with this study, and particularly from the case study about mining email networks using SNA and DM. Specifically, practical contributions include the impact of SNA as an effective tool to evaluate and compare different social networks, and to identify important individuals within a particular network.

Different ways to select important individuals were studied, for example, to identify popular individuals; those connected to popular members of the network despite having few connections; or critical members of the network, based on the idea that some individuals play the role of an intermediary in the interactions or in the communication flow through the network. These characteristics were analysed using the concept of *centrality* in SNA.

Popular metrics used to analyse and compare networks as a whole were also discussed in Chapter 2 and implemented in Chapter 6.

Theoretical implications include the review of core network concepts and future directions for an area of network research in knowledge extraction from email networks. SNA studies tend to focusses on a personal (egocentric) network, or on a complete (whole) network. In this Thesis, we presented a methodology to develop and analyse a network formed by the combination of different egocentric networks. We also showed the impact of centrality metric selection in the finding of *important* members of the network, and demonstrated a low correlation between centrality metrics, meaning that they indicate distinctive measures likely to be associated with different outcomes.

As a case study, SNA was applied to identify the properties and structure of the communication network of one of the key Wessex Academic Health Science Network (AHSN) programmes, through the investigation of the project manager's email network, and we demonstrated that SNA can be applied to email datasets without violating important ethical issues (e.g., non required access to email content). Mining email networks was also used to identify specific individuals that could help to spread innovation and information to the whole network. Properties and structure of the communication network formed by combining different egocentric networks were also investigated.

Collecting email network data presents several challenges in terms of reliability, validity, and legal and ethical issues, especially for a whole-network research. Specifically, potential issues include omission of nodes/edges (due to the defined boundary of the network) or retrospective errors, or simply because emails deletion from the servers or because different servers hosting emails using different data structure. Whole-email-network studies require the participants to provide access to their email manager in order to extract specific variables and to download email datasets. If the privacy is not an issue, several options are available to automatise the data collection process.

This study demonstrated that the combined application of SNA and Data Mining is a powerful tool to extract knowledge from data sources already available at the organisation, without extra costs as only open source tools were used for this analysis. The methodology here developed can be used to identify key contacts within a stakeholders networks, but also can be used to identify potential risks of network disruptions or dependency on specific members.

- ***Develop a new healthcare system performance metric***.

  Chapter 7 presented a new healthcare system performance metric based on the Overall Equipment Effectiveness (OEE), a metric developed in the manufacture industry to minimise hidden productivity losses, through the evaluation of three components: availability, performance, and quality.

  Theoretical description of OEE and the *six big losses* was presented in this Chapter, as well as a process for its implementation in a healthcare setting. A case study was presented to evaluate the impact of this system performance metric in a real-world application.

  The evaluation of OEE can be critical for the correct estimation of resources required to attend the expected increase in the demand for healthcare services, to develop a system redesign, as also for the analysis and the continuous improvement of the system performance. The application of this new indicator can be used by practitioners in the evaluation and improvement of healthcare service performance, through the identification of key areas were to focusses on.

  It is apparent that the successful calculation of OEE depends on the ability to collect data. If the data collected are unreliable, the OEE value may not reflect real resources or system utilisation. Additional sources of capacity losses could be included in a future analysis if detailed data is collected and available at endoscopy units, example of these are: number of patients that did not attend an scheduled appointment; last-minute cancellations (patients & clinical staff); reduction in capacity because training sessions; capacity loss as a result of rescheduled patients; Endoscopy room turnover time (i.e., time between patient exit and entry of subsequent patient into endoscopy treatment room); equipment failures; and delayed arrival of patients and clinical staff.

A key concept in this approach is the division of performance in three categories: availability efficiency; performance efficiency; and quality efficiency, highlighting that a low performance can be result of a low availability instead of a poor performance.

We described an empirical work designed to test and evaluate the relevant importance and applicability of each of the components of this performance indicator in different healthcare services. This can serve as a practical tool for planning or evaluating improvement initiatives.

- ***Investigate the relations, similarities and differences between machine learning, metaheuristics, modelling & simulation, and data analytics***.

  Relations, similarities and differences between Machine Learning, Metaheuristics, Modelling & Simulation, and Data Analytics was discussed in Chapter 2 but also along the different studies presented in this Thesis. All these methods and techniques were evaluated as part of data-driven methodologies and used with an applied-focuses to solve healthcare problems.

  A variety of techniques from Modelling & Simulation were studied and used to analyse current performance and to model improved and more efficient future states of healthcare systems, with a focus on analysis of capacity, demand, activity and queues both at hospital and population levels. Metaheuristic algorithms were studied and a Genetic Algorithm was used to solve a Routing Home Healthcare problem. Social Network Analysis and Data Mining was used to visualise and analyse email networks.

  A key component in these approaches is the importance of a correct definition of the problem to focus on. Another finding of the review is the important role of data selection, extraction, pre-processing, and conversion in application-oriented projects.

  A new theoretical framework for the implementation of Machine Learning applications was proposed in Section 2.2.2. Section 2.3.2 includes a review of DES, and impact of data in a DES project. Additional steps to the *standard* DES process were proposed here.

Table 8.1: Summary of models developed in this Thesis.

Study	Clinical engagement	Managerial engagement	Impact	Methodology	Reused?	Issues	Applied?
CRC model	high	high	high	DA, DES, Statistics	no	Data access, initial engagement with hospital managers	yes
KA model	high	low	unknown	DA, DES, Statistics	no	Difficult to find benchmarks (prosthesis surveillance)	yes
Endoscopy model	medium	high	high	DA, DES, Statistics	yes	Data collection, clinical engagement	yes
Email SNA	N/A	high	low	DA, SNA, DM, DV	no	Email privacy	yes
Genetic Algorithm	N/A	N/A	null	Metaheuristics	no	Algorithm implementation	no
Performance metric	medium	medium	unknown	DA, DV	no	Low initial acceptance level	yes

A new framework to conduct studies focused on mining email networks was proposed in Section 6.4. This theoretical framework was named *Email Social Network Analysis - Knowledge Discovery in Database process (ESNA-KDD)*. It guided the study described in Chapter 6.

8.2 Summary of contribution and implications of the Thesis

This section summarises the contribution and implications of our findings for policy and practice in healthcare, and describes the level of clinical and managerial engagement in each project. This section also presents a discussion of the main issues identified in this research.

Table 8.1 shows different models developed in this Thesis. Level of clinical and managerial engagement was classified in low, medium or high. Level of impact on the healthcare system was also classified in low, medium and high. Main data-driven methodology used in each project is also presented. A variable related with the reuse of the model or methodology summarises if the model has been reused or not. Main issues are also described. Finally, a summary of the application to a real-world problem is presented.

The first model presented in this Thesis is the Colorectal Cancer Diagnostic model, developed as part of the analysis of capacity, demand, activity and queues described in

Section 3.1. This model had an high impact on healthcare system in Wessex, mainly because high clinical and managerial engagement. A wide range of methodologies were used, but Data Analytics, DES, and Statistics can be named as the main methods used to solve this problem. Despite the fact that this model has a high potential to be applied in a different setting, it has not been reused. The main issue identified in this study was the lack of data, and low initial support from hospital managers, who initially did not see this project as a useful tool to support decision making.

Data availability is a well known constrain in the implementation of healthcare Operational Research (OR), and it has been broadly discussed in the literature [21, 200, 24]. Findings related with a limited success in achieving a sufficient level of stakeholders acceptance in the first stages of this project is coherent with a previous study in Sachdeva et al. [183], where the authors proposed a methodology based on Mixed-Mode Modelling (combining hard- and soft- OR methodologies) to enhance the implementation of healthcare OR and to achieve greater acceptance of results for organisational change.

An alternative approach to tackle this traditional separation between producers of research evidence in academia and the users of that evidence, based on the Research-in-Residence model is presented in Marshall et al. [135], where the authors presented examples of this model, and discussed its potential to engage both academics and practitioners in the promotion of evidence-informed service improvement.

The impact of the model of Knee Arthroplasty (KA) described in Section 3.2 and Appendix A is unknown as this study was commissioned by the Spanish National Health Service to be published as a national report. Clinical engagement was high during the development of the study, with a low support from hospital managers, mainly because the configuration of the project steering group. Main data-driven methodologies were Data Analytics, DES, and Statistics. This model has not been reused, and it has a high potential to be used in the projections of primary and revision KA in a different setting. This model was applied to a real-world problem, and the main issues were related with lack of local datasets to estimate knee prosthesis surveillance. A small number of international report was found and used as benchmark in this project.

Similar research carried out in 2007 by Kurtz et al. [122] showed that by 2030, the demand for primary total knee arthroplasty was projected to grow by 673% in the United States, while the demand for knee revisions was expected to double by 2015. The study also included the analysis of hip arthroplasties. Similar results are presented in Patel et al. [164], in a comparative analysis between the projections for U.S. ([122]) and the analysis of data for England and Wales. Culliford et al. [41] presents a different approach to estimate the future rate of primary total hip and knee replacement in the UK to 2035, using projected changes in population demographics and obesity.

The DES model described in Chapter 4 has a high impact on healthcare services, and has been reused in different studies across the UK. Clinical engagement was medium, and a high support from hospital managers was observed. Main methodologies used are Data Analytics, Statistics, and DES. The main issue identified in this project was related with access to Electronic Health Records to populate the simulation model. Lack of clinical engagement was also an initial constraint for the study.

A previous study in Patel et al. [165] analysed inefficiencies in a Gastrointestinal Endoscopy department, and applied a Lean-Principle redesign. The authors concluded that although the healthcare system often is criticised for being inefficient and costly, efforts to redesign delivery processes often are hampered by a lack of training in effective methodology and financial constraints.

Kaushal et al. [108] also analysed efficiency in an endoscopy unit. In the study, the authors identified the pre-procedure/recovery area before patients are wheeled to the endoscopy room for the procedure as the bottleneck, and proposed a solution based on a dynamic room allocation strategy (i.e., transporting patients into endoscopy rooms as soon as possible once room turnover was completed). The authors also proposed a change for the first case of the day each morning: those patients were taken directly to the endoscopy room and bypassed the pre-procedure area altogether. This strategy was also evaluated as part of our research, but despite benefits from a work-flow efficiency perspective, it could not be implemented due to concern about regulatory, legal, and ethical issues related with obtaining informed consent in the procedure room. Informed consent for GI endoscopy is discussed in Atiq et al. [8].

In Day et al. [46], a research using a methodology similar to that presented in this Thesis, observed a patients length of stay equivalent to our results, and evaluated the impact of the simulation of 45- and 40- minute appointment times, increasing procedure volume by 30.5% and 52%, and a decreased patient time spent in the endoscopy unit. These results are consistent with the results of our research.

The SNA discussed in Chapter 6 had a low direct impact on healthcare services, as the study was applied to the analysis of emails of researchers and a project manager from an organisation non directly related with health care provision but with the spread of research and innovation through the healthcare sector. No clinical support was required for this study, and the engagement from managers was high. The main methodologies used were SNA, Data Analytics, Statistics, and Data Visualisation.

This study was applied to a real-world problem, the model has not been reused, but the potential for this is high. Main issues were those related with email privacy regulations. This study identified several practical and theoretical implications, specifically, practical contributions include the impact of SNA as a tool to identify *important* members of a network and clusters or communities of stakeholders. Another contribution is the discussion about how rich information is hidden within email communications and to how to extract, analyse and visualise it.

A new framework for email mining was also proposed, combining theories from SNA and DM. Theoretical implications include the review of the core network concepts and future directions for an area of network research in knowledge extraction from email networks. SNA studies tend to focusses on a personal (egocentric) network, or on a complete (whole) network. In this study, we presented a methodology to develop and to analyse a network formed by the combination of different egocentric networks. We also showed the impact of the centrality metric selection in the finding of *important* members of the network, and we demonstrated a low correlation between centrality metrics, meaning that they indicate distinctive measures likely to be associated with different outcomes.

Correlations between SNA centrality measures reported in Section 6.3.3 are consistent with the results presented in Valente et al. [215], where the author studied the correlation between centrality measures for 62 sociometric networks in different settings.

Genetic Algorithm described in Chapter 5 did not required clinical or managerial support as this was a theoretical study. The model, based on Metaheuristic optimisation, was implemented using a benchmarking dataset, and no direct impact on healthcare services was expected. The algorithm has not been reused and the potential for this is high.

Finally, the study presented in Chapter 7 was applied to a real-world healthcare related problem. Level of support from clinicians and managers was medium and the real impact on healthcare organisations still unknown. Main methodology was Data Analytics and Data Visualisation. The metric has not been used in other organisation and the potential for reuse is medium. Main constrain for the study was a low initial acceptance level from healthcare staff, mainly because this concept was originally developed in the manufacture industry.

A previous study in Gellad et al. [72] proposed a conceptual framework for GI endoscopy efficiency for assessing the quality of medical care through an analysis of structure, process, and outcomes. The study also summarised four characteristics of ideal efficiency measures: (1) measures should have relevance to key stakeholders; (2) scientifically sound; (3) measures should not require excessive cost or burden to obtain; and (4) measures should lead to measurable change in a system.

Chapter 9

Conclusions

In the last chapter I reviewed the specific aims of this research, and I discussed key findings in reference to the specific objectives of the Thesis; I presented an evaluation of contribution and implications of the research for policy and practice in healthcare; I also described the level of clinical and managerial engagement in each of the studies; and finally, I discussed the main issues identified through this research.

In this chapter, I will present the general conclusions and recommendations for further research.

9.1 Conclusions

This Thesis has investigated the impact of Machine Learning, Metaheuristics, Modelling & Simulation, Data Analytics and Data Visualisation in increasing efficiency and value in healthcare, analysing strategies to expand the impact of those data-driven approaches.

The research was based on solving practical problems for particular context in different levels of healthcare management, with the research drawing both theoretical and empirical analysis.

My primary purpose was **to demonstrate that multidisciplinary knowledge and cross-discipline approach is required to create value through data-driven methodologies in healthcare** based on the experience acquired after several years working with healthcare organisations.

The techniques employed, have played a pivotal role in furthering the improvement of healthcare organisations using mix data-driven methodologies - an area of research which appears to be gathering considerable momentum. Furthermore, this Thesis has demonstrated the value of these approaches, contributing insights into the growing need to improve the efficiency and sustainability of healthcare systems everywhere.

As we argue in this Thesis, academia has shown a rapid increase of attention to healthcare operations management in recent years. I believe that this field will continue to develop in the future. This Thesis illustrates that data-driven methodologies contributes to more rational, integrated decision making in healthcare and that it can provide strong benefits in reorganising healthcare more efficiently. I am convinced that healthcare managers, clinicians and decision makers are increasingly aware of these benefits. Their belief in the practical need for integrated solutions is a key driven to turn theory into practice and to make the contributions of the academic community achieve real societal value.

9.2 Recommendations for further research

This final section discusses the opportunities for further work afforded by the conducted research. Each area of interest is introduced by chapter, and a basic outline of the proposed extensions is given.

- **Chapter 2**.

  As a basic step, the background information provided in Chapter 2 could be extended to include both greater aspects of the data-driven approaches studied in this Thesis (as discussed in Section 1.5), but also additional methodologies applied to healthcare. It would be also of great interest to extend the investigation of the gap between demand and supply of this methods. As discussed in Chapter 1.5, conclusions here presented are based on my experience, so additional research in the generation of multidisciplinary knowledge and application of cross-discipline approaches to create value in healthcare is also recommended.

- **Chapter 3**.

  Studies presented in Chapter 3 are related with activity, capacity and demand analysis at a population level, and both could be taken forward for future research. These include:

- *Modelling the colorectal cancer diagnostic services pathway (Section 3.1)* - the methodology used in this study could be also used to evaluate different clinical pathways. As discussed in Section 8.1, as results of this research, we are currently extending the project to the analysis of additional cancer pathways and to evaluate current cancer diagnostic services across five specialities (Gynaecology, Urology, Upper and Lower gastrointestinal, and Lung) at a Wessex-region level.
- *Predicting the burden of revision knee arthroplasty (Section 3.2)* - this study could be applied to a different population to estimate future demand for primary and revision knee replacement surgeries. This methodology could also be reused to investigate future demand for a different intervention (e.g., hip or ankle replacement). Evaluation of impact of different technologies (represented by the surveillance functions) in the prediction of future demand could be also investigated.

- **Chapter 4**.

  As mentioned in Section 4.4, this study has several limitations (e.g., observer variance, seasonal factors, and the *observer effect*). Training lists, and nurse endoscopist lists, where fewer points are assigned; other staff functions as unit-related functions; and non-clinical activities are not included in the analysis. I believe that the next logical step is, therefore, the clinical verification of these findings.

  There are several directions to further research. An analysis focussed on the patient time being scoped, versus patient time in the room/total list time, could be useful in order to analyse the importance of the turnaround time, and delays (patients, clinicians, and equipment). We can introduce additional variables into the analysis, for example costs, to evaluate the impact of the cost-effectiveness analysis of the proposed interventions. We can also, re-use the simulation model to evaluate future changes using a multi-criteria decision analysis approach.

  As noted, some of this proposed future research are currently being investigated since the project delivery. As a result of this study, system modelling is now being undertaken across other endoscopy units in the region, and the simulation model here developed is being re-used. A framework to generalise the proposed methodology was also developed and this is currently being tested across different hospitals to be used as a toolkit to evaluate and improve the process for all cancer diagnostic services across the Wessex region in Southern England, UK.

As discussed in Section 8.1, this study has shown the potential value for further studies to quantify and optimise existing capacity in healthcare organisations, but also showed us the complexity of undertaking this type of project with NHS organisations. Additional research related with *lean-simulation* is also suggested.

- **Chapter 5**.

  This study was solely applied to a simplified version of the problem of routing healthcare professionals to deliver home healthcare services to the patients. And as discussed in Section 5.4, a Genetic Algorithm was implemented and applied to a benchmark dataset extracted from TSLIB [175]. Several potential extensions are identified:

  – Additional investigation of the Genetic Algorithms, evaluating new genetic encoding, fitness function, and genetic operators.
  – Experimentation with other problem structure and solution space to investigate the relation between them and parameter selection.
  – Evaluation and implementation of other metaheuristics (see Section 2.1.4).
  – Application to additional optimisation goals including for example, multi home care professionals, staff scheduling, work-load balance, time windows for the patient visit, and patient preferences.

- **Chapter 6**.

  As discussed in Section 6.5, we identified several practical and theoretical implications in our study and particularly from the case study about mining email networks using SNA.

  Practical contributions include the impact of SNA as a tool to identify *important* members of a network and clusters or communities of stakeholders. Another contribution is the discussion about how rich information is hidden within email communications and to how to extract, analyse and visualise it. A new framework for email mining was proposed, combining theories from SNA and data mining. Therefore, further investigation of this proposed framework in a new setting could be explored.

  Theoretical implications include the review of the core network concepts and future directions for an area of network research in knowledge extraction from email networks. SNA studies tend to focusses on a personal (egocentric) network, or on a complete (whole) network. We presented a methodology to visualise and to analyse a network formed by the combination of different egocentric networks. We also showed the impact of the centrality metric selection in the finding of important members of the network, and demonstrated a low correlation between centrality metrics, meaning that they indicate distinctive measures likely to be associated with different outcomes. Additional research on this topics is also recommended.

Future research could also consider the analysis of dynamic network, to investigate the evolution of email networks in time. Other potential future research is a meta-network (i.e., multi-mode, multi-link, multi-level networks), through the integration of different data sources, for example: online social networks; emails; and network surveys.

- **Chapter 7**.

  Finally, Chapter 7 introduced a new healthcare system performance metric based on the Overall Equipment Effectiveness (OEE) metric, originally developed in manufacture industry. A case study based on an endoscopy unit was also discussed. Further research could be related with the test and evaluation of this metric in a different healthcare service.