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# A Survey of OR/MS Models on Care Planning for Frail and Elderly Patients

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**Abstract**

*Context*

With an ageing population, there is an increased demand on public health services and on long-term-care facilities. It is not uncommon for frail and elderly patients to spend longer in hospital or require more support within the community, often due to multi-morbidities. Many health services are faced with the complex problem as to how to administer the best care for the frail and elderly whilst best managing limited health resources.

*Objective*

This paper focuses on the literature concerning frail and elderly patient pathways within both hospital and community care settings with the use of Operations Research and Management Science (OR/MS) methods. To cover a wide range of specialities, the following additional subject areas have been included: Geriatrics and Gerontology, Health Policy and Services, Industrial Engineering, and Medical Informatics, to synthesise the work on modelling the application of care for frail and elderly patients. This review paper also analyses trends in the research literature and identifies gaps for future study.

*Methods*

A set of criteria has been established in which a systematic search was performed against to identify literature from 2000 to 2020. In total 62 publications

were identified as applicable and were categorised methodologically and analysed. Common features of the papers including hospital setting, research aims and planning decisions have been identified and discussed.

*Results*

The results from the analysis reveal that this field of study is increasing with over 47% of papers having been published since 2015. The main findings suggest three areas of future research. Firstly, focus should be on modelling pathways holistically, with collaboration from both hospitals and community care settings. Secondly, work should be conducted on patient outcomes of these modelled pathways to highlight the increase in quality of care. Thirdly, there is potential for a wider variety of OR/MS methods to be utilised across the whole pathway. These three areas will reduce pressure on health services which are currently facing rising demands with limited resources.

*Keywords:* OR in Health Services, Elderly, Frail, Care Planning, Literature Review

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## 1. Background

Frail and elderly patients have one of the largest associated healthcare costs compared to any other age group, with many countries worldwide facing a rising ageing population [50, 71]. The United Nations have stated that the ageing population is set to become one of the most significant social transformations of the $21^{st}$ century [73]. These patients can be considered as vulnerable patient groups as their health is likely to deteriorate quickly. For the purpose of this research, a patient is classified as elderly if they are aged 65 and older [60]. A frail patient is classified as one who is at high risk of falling into dependency as a result of a negative event, such as an injury, fall or disability. Most frail patients tend to fall within the elderly age category, however the reverse is not always true. This review considers patients who fall into either of the frail or elderly categories.

For the first time in history, in 2018 the global number of people aged above 65 outnumbered the number of children under the age of five [73]. It is estimated by 2050, 21.3% of the world's population will be aged 60 years or older [72]. It is currently predicted that between a quarter to a half of people over 85 are classed frail [16, 72]. Therefore, it is important for research to focus on the variability in the demand for future services and the planning decisions that will be required to ensure the needs of these patients are fully met. Alongside this, it will allow improvements to be made in both patient care and medical efficiency as well as reducing associated medical costs for health services.

This literature review focuses on care planning decisions for the frail and elderly across the care pathway. A care pathway can be defined as "a complex intervention for the mutual decision making and organisation of care processes for a well-defined group of patients during a well-defined period" [74]. Frail and elderly care often does not follow a different care pathway to the rest of the population, however these patient groups often have longer recovery times with more specific care needs [39]. In order for planning decisions to be successful the review aims to highlight the need for research to focus on the entire pathway for a patient, e.g., 'holistic pathway', where the research is focusing on not a single care location but on the movement of the patient between care locations. Previous research often discusses a single setting scenario, e.g., a hospital ward, however, it may be beneficial to consider the steps prior to a patient's admission and/or discharge that will effect the stay within a single setting.

Due to increasing pressure on health services resulting from frail and elderly patients, this paper specifically focuses on the body of work that has been published so far. To the best of our knowledge, this work provides the first interdisciplinary review of existing Operations Research and Management Science (OR/MS), Geriatrics and Gerontology (GG), Health Policy and Services (HPS), Industrial Engineering (IE) and Medical Informatics (MI) literature in the field of frail and elderly care planning. From January 2000 to December 2020, a total of 62 papers fitting the criteria were identified. A classification scheme has been provided for these papers to help researchers identify similar

research to their own. This review also highlights common themes such as the healthcare settings of these papers, the OR/MS techniques utilised and provides a discussion of potential future research scope.

The remainder of the review is structured as follows: Section 2 introduces the methods used to identify the papers and discusses related literature reviews identified through this search. Section 3 analyses and provides a classification of the results. Section 4 discusses gaps within the research, with Section 5 identifying areas for future research. Section 6 provides a conclusion. For the figures which discuss a classification result, a respective table within the Appendix has been included detailing the reference numbers for each paper. Table A7 within the Appendix provides a comprehensive list of the 62 papers including each classification category.

## 2. Methods

### 2.1. Data Sources

To identify major research streams in the literature, a structured search was performed following Webster and Watson's methodology [77]. The search engine, Scopus, was used to identify relevant journal articles and conference proceedings papers, from January 2000 to December 2020 restricting the search to English results.

### 2.2. Inclusion Criteria

Webster and Watson [77] highlighted that a literature search should not be confined to one research methodology, one journal or to one region. To provide a complete search, the search string contained at least one of the following terms found within each column of Table 1: One OR/MS method phrase, one patient flow term and one age category, mentioned in the article title, abstract or given keywords. The Boolean operators: 'AND' and 'OR' were used to concatenate different terms among different categories. Firstly, for each category, the terms within the string were concatenated with an 'OR' command, whilst the overall

categories were connected with an 'AND' command. For terms such as 'Integer program*' an * was used to signify multiple endings, e.g., 'integer program' or 'integer programming'. For phrases with multiple endings with only one character, such as 'Heuristic$', a $ sign was used to indicate this, i.e., 'Heuristic' or 'Heuristics'. This is similar to the methods Hulshof et al. [41] performed within their taxonomy.

Table 1: Final terms for literature searches

| | OR Method | Patient Flow Terms | Classification of People |
|---|---|---|---|
| Agent based model* | Network analysis | Appointment | Elderly |
| Branch and bound | Neural network$ | Capacity allocation | Elderly care |
| Branch and price | Optimi* | Capacity management | Frail* |
| Clustering | Quadratic program* | Capacity planning | Geriatr* |
| Column generation | Queuing | Care access | Home care |
| Computer simulation | Queueing | Care pathway | Long term care |
| Constraint program* | SCA | Clinical pathway | Nurs* care |
| Discrete event simulation | Scatter search | Critical pathway | Old people |
| Discrete optimi* | Scheduling | Demand forecasting | Older people |
| Dynamic program* | Simulation | Demand management | Palliative care |
| Genetic algorithm | SSM | Demand prediction | >65 |
| Goal program* | Strategic Choice Analysis | Flow of care | |
| Heuristics$ | Strategic Options Development and Analysis | Flow of patients | |
| Integer program* | Stochastic analysis | Integrated pathway | |
| Linear program* | Stochastic modelling | Patient flow | |
| Logistics | Stochastic processes | Patient pathway | |
| Markov chain | Stochastic program* | Patient process | |
| Markov decision | SODA | Patient route | |
| Markov model | Soft OR | Patient throughput | |
| Mathematical model | Soft Systems Methodology | Process flow | |
| Mathematical program* | System dynamics | Scheduling | |
| Metaheuristic$ | Tabu search | Whole-system$ | |
| Mixed integer program* | | | |

To allow multiple OR methods to be investigated, the search terms were identified within Hulshof et al. [41] and Palmer et al's. [61] review of OR methods for modelling patient flow and outcomes. Soft OR methods were investigated including systems thinking, problem structuring and Delphi methods, however these did not increase the number of publications. This suggests that soft OR

methods are under-represented within the field and highlights potential future research. To include a range of techniques, overall classification terms were used such as 'Metaheuristic$' as well as common methods encompassed within this technique such as 'Tabu search' and 'Genetic algorithm'.

Patient flow terms were identified through multiple sources (Table 1). Firstly, Palmer et al.'s [61] review on patient flow within community care allowed demand and capacity terms such as "demand management" and "capacity allocation" to be incorporated. Secondly, De Luc et al. [19] found 17 phrases which encompassed pathways of patients with the most prominent terms within the literature: "integrated care pathway" and "critical pathway". These terms all loosely follow the same three main stages: the development process to design the pathway; the application and use of the pathway; and the ongoing review of the pathway to learn from the practical experience and to continuously apply improvements [19, 47].

To ensure a variety of journal sets were used, the search focused on five categories in the Clarivate Journal Citation Report (JCR). The five categories were as follows: Geriatrics and Gerontology (GG), Health Policy and Services (HPS), Industrial Engineering (IE), Medical Informatics (MI) and Operations Research and Management Sciences (OR/MS). The rationale to select these five journal categories was because they contain journals in which OR/MS methods are applied to healthcare. A number of upcoming journals were also incorporated as they do not belong to a JCR category and these were appropriately assigned to one of the five categories. These journals were as follows: Health Systems, IISE Transactions on Healthcare Systems Engineering (formally known as IIE Transactions on Healthcare Systems Engineering), Operations Research for Health Care and Proceedings of the Winter Simulation Conference. A brief description of each journal category is as follows with the four additional journals added to the most appropriate JCR category:

- Geriatrics and Gerontology (GG) - Captures a subgroup of medical journals which focus on clinical problems in the treatment of elderly patients

(e.g., Age and Ageing).

- Health Policy and Services (HPS) - Captures journals covering policy and service improvements within healthcare systems (e.g., Health Care Management Science and Journal of Health, Organisation and Management).

- Industrial Engineering (IE) - Includes papers that focus on systems that integrate people, materials and equipment to provide a service (e.g., International Journal of Simulation Modelling and IISE Transactions on Healthcare Systems Engineering).

- Medical Informatics (MI) - Captures papers which focus on healthcare information in clinical studies and medical research (e.g., Health Information Management Journal).

- Operations Research and Management Sciences (OR/MS) - Includes papers focusing on advanced analytical methods to solve complex problems(, e.g., Journal of Operations Management, Health Systems, Operations Research for Health Care and Proceedings of the Winter Simulation Conference).

*2.3. Study Selection and Data Extraction*

The initial search resulted in 437 papers being identified and these underwent analysis by abstract to determine the papers which met the inclusion criteria. A publication was excluded if the abstract was not relevant to frail and elderly patients and their planning of care. These exclusions reduced the number of papers to 39. As advised within Webster and Watson's paper [77], a forward and backward search was conducted after the initial analysis to ensure related papers that had not met all the key search criteria were included. In total 65 publications were found to be relevant, including three literature reviews. The three reviews are discussed separately within Section 2.5, with the remainder of this paper focusing on the other 62 papers. A visual representation of this process has been included within the Appendix (Figure 12).

## 2.4. Study Protocol

To classify and analyse the papers the following protocol was set up to ensure the objectives of the literature review were met. Firstly, a general classification is provided demonstrating the characteristics of the papers including geographical location, JCR category and publication year. Secondly, the papers' medical context is established with discussion around the care locations and diseases suffered by the frail and elderly. Finally, the research aims, the planning decisions and the types of OR/MS methods utilised within the papers is discussed.

## 2.5. Previous Literature Reviews

This subsection aims to provide a brief overview of the three literature reviews identified through the Scopus search. Then, there will be discussion around how our review aims to fill the gaps in the literature not covered by these reviews.

Firstly, Berntsen et al. [11] used their research to provide evidence for a patient pathway for the frail and elderly to be generated using Digi-PIP (digitally support person-centered, integrated and proactive care) methods. Through a systematic search ten papers were identified as focusing on Digi-PIP care on population health, patient experience and cost-effectiveness. The results showed that despite belief that a Digi-PIP approach was the key to sustainable care, research has not been able to provide sufficient evidence.

Freeman et al. [26] focused on patients aged over 65 and the factors affecting the transition from long-term care facilities (LTCFs) to the community. LTCFs were distinguished as care institutions that provided 24-hour nursing care, personal care or other services, whereas community was defined as home care programs, retirement homes, assisted living facilities or patient's own home, where 24-hour care is not provided. They identified 36 articles and recommended that further understanding was needed due to the complexity of the discharge process with more evidence in the factors and barriers that influence the discharge. The authors concluded that it was unclear of the combination of multidisciplinary team members and institutional factors that best support discharge planning.

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The third and final review identified was Gaugler et al.'s [30] paper on the research focusing on admission predictors of community care specifically within nursing homes in the U.S. The review identified 77 papers which encompassed 12 data sources. After analysing different methods, such as logistic regression and Cox regression models, on a variety of different care factors, including gender and medical condition, their results identified a number of predictors, e.g., cognitive impairment. The work highlights the opportunity for future research to develop tools using the strongest predictors to estimate nursing home admissions, potentially adapting and applying these methods to predict demand for nursing homes and other long-term care facilities.

The three reviews either focused on specific locations within the pathway; [26] with the movement from LTCFs to the community, [30] with nursing home care or they focused on analysing specific OR/MS methods [11]. Whilst these reviews provide beneficial contributions to their areas, we aim to consolidate literature on a wider scale. Instead of analysing one OR/MS technique, [11], 44 different OR/MS methods have been incorporated into the search criteria to cover a wider range of methods. There has also been expansion across different patient groups and treatment settings, (e.g., nursing homes and palliative care), to ensure each aspect of the pathway and its care planning can be investigated. As multiple settings were analysed, this allowed further investigation into how different settings were applying different OR/MS methods. Additionally, there was analysis on how different settings are working collaboratively to ensure successful care planning. This review will serve as a guide on how to conduct further research on the future challenges in frail and elderly care planning.

## 3. Results

After highlighting the focus of previous literature reviews, it was identified that there was a need for the research on OR/MS methods for frail and elderly care planning to be summarised. This would then allow for gaps within the present literature to be determined and a research agenda to be developed en-

abling these gaps to be filled. The following results analysed the findings of the initial, forward and backward searches and classified the literature by general, medical and methodological contents. Each section provides summary statistics discussing the results. Research gaps and discussion of results will take place in Sections 4 and 6, respectively.

*3.1. General Classification*

Table 2 highlights the divide between the location of the research conducted, with the majority of papers being published within Europe and North America. Kerpershoek et al.'s [46] study focused on eight different European countries analysing access to dementia care and is denoted as 'Multi-national' within Table 2. It is worth highlighting that no other papers were found to be multi-national.

Table 2: Country of sampled data and Journal of published research

| Country | UK | Canada | USA | Italy | Australia | France | Hong Kong | Ireland | |
|---------|-----|--------|-----|-------|-----------|--------|-----------|---------|---|
| GG | 2 | 1 | 2 | 2 | 2 | 0 | 0 | 0 | |
| HPS | 6 | 3 | 3 | 1 | 0 | 1 | 0 | 0 | |
| IE | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | |
| MI | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | |
| OR/MS | 5 | 3 | 3 | 0 | 0 | 1 | 1 | 1 | |
| Other | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | |
| Total | 18 | 10 | 10 | 6 | 3 | 3 | 2 | 2 | |
| Country | China | Japan | Netherlands | Norway | Poland | Sweden | Spain | Multi-national | Total |
| GG | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 12 |
| HPS | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 16 |
| IE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| MI | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| OR/MS | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 15 |
| Other | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 10 |
| Total | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 62 |

English only papers were analysed which may explain why mainly European and North American publications met the inclusion criteria. Further categorisation shows there was a disparity within these continents and the work within this field that is being published. Table 2 also displays the JCR categories for each country.

The final column in Table 2 shows the quantity of papers published within each of the JCR categories as discussed within Section 2. Within the backward and forward searches there were ten papers which did not have ISSNs related to the five JCR categories (Figure 1), so these papers have been attributed to the 'Other' category. HPS and OR/MS were the leading journal categories with sixteen and fifteen papers respectively.

Figure 1: Number of publications broken down by journal categories
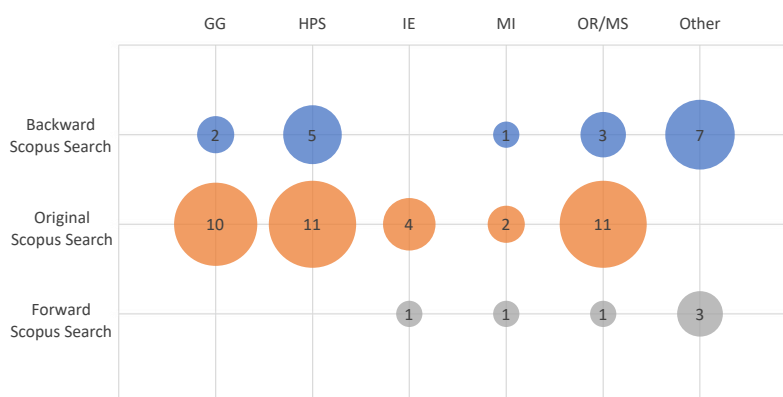


Although there were only four and five papers within the MI and IE categories respectively, it is important to include these within the analysis as they are under-represented areas and provide a different journal focus on patient pathways and their application.

To show the general trend of the research in this field, Figure displays the quantity of papers published every three years. Between 2000 and 2014, the number of papers published remained fairly stable with an upward trend from 2015. Within the last three years, 27% of papers were published, highlighting that this area is becoming more widely researched.

Figure 2: Graph of publication year
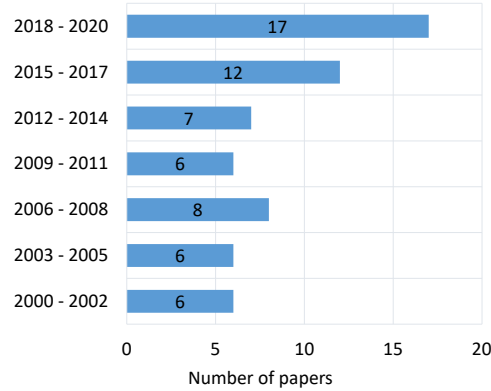


*3.2. Medical Context*

This subsection will analyse the medical context of the papers broken down into the medical setting and the condition area. The medical setting of a patient is the location where their care takes place, e.g., hospital ward or nursing home. The condition area focuses on the medical condition of the patient in the study and whether this was long-term such as dementia or acute, e.g., heart attack. Successful care planning should consider the entire pathway of a patient across multiple settings. It is often necessary to consider the next steps a patient will take to ensure appropriate resources and available capacity to avoid delays in discharge. It is also important to know the condition type of the patient as this will likely affect their discharge destination or the time required to stay within the care setting.

*3.2.1. Medical Setting*

The medical setting of the paper was important to understand how care settings can work together for the planning of care for frail and elderly patients. The research focused on three main areas:

- Single Hospital

- Multiple Hospitals

- Community Care

The community care grouping encompassed: Home care, long-term care, nursing care and hospice care, to meet the wide range of healthcare services that does not take place in a hospital setting. Figure 3 shows a Venn diagram which breaks down the publications into the type of care settings. The numbers reveal there was a clear focus on both community care and single hospital settings.

Figure 3: Number of publications within each care setting
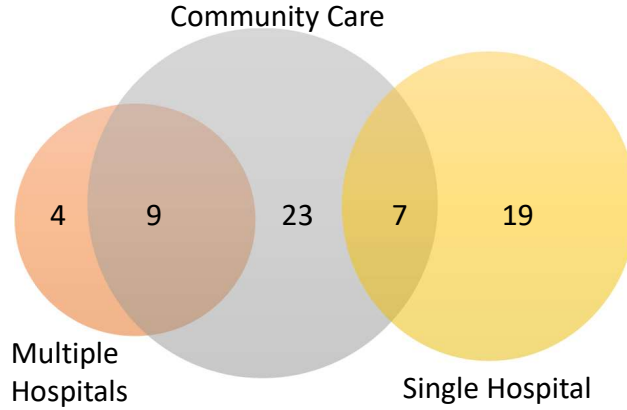


In total, there were 16 papers (26%), which use care planning in a holistic manner. These papers were particularly interesting as they focused on the cross over between community care and either single or multiple hospitals. Papers [18, 42, 43, 51, 56, 62, 63, 75, 86] focused on the intersection between community care and multiple hospitals whilst papers [23, 27, 28, 31, 32, 37, 69] focused on single hospitals and community care.

A brief overview of Patrick [62] and Taylor et al. [69] is provided as these works are examples of community care with multiple hospitals and single hospital settings.

Patrick [62] developed a Markov decision model that determined the required bed numbers in long-term care facilities in order to keep demand below a given threshold. Patrick also developed a simulation model to incorporate both hospital and community care demand to predict impact of policy implementa-

tions. These models have aided future capacity planning by comparing current practice against proposed alternative models.

The work conducted by Taylor et al. [69] involved modelling the time geriatric patients spent in hospital and in community care. The authors generated a stochastic compartmental Markov model with three hospital components: acute care; rehabilitative and long stay; two community components and an absorbing state. They were able to successfully provide short-term estimates and a better understanding of future bed usage within geriatric hospital settings.

*3.2.2. Illness/Disease Focused Papers*

There were eight papers which focused on a specific illness/disease often suffered by the frail and elderly. These illnesses were as follows: dementia [13], falls [25], gastrointestinal [1], heart failure [8, 48, 66] and hip fractures [10, 76]. Seven of the eight papers focused on a single hospital setting and the remaining paper focused on community care [13]. There were a further eight papers which focused on an inpatient department: an emergency department [62, 64, 65, 70] or a geriatric ward [15, 24, 33, 55]. Interestingly, none of these 16 papers used care planning across multiple settings. The recovery times for frail and elderly patients is usually longer than the general population. Often, they will require further care within the community once they are ready to be discharged. If there is insufficient resources or lack of availability within the community, then these patients may have to remain in hospital, causing bed blocking.

*3.2.3. Community Care Focused Papers*

There were 23 papers which had community care as the only setting. Six of these papers concentrated on the overlap and movement between settings in community [9, 29, 49, 57, 78, 83]. Lin et al. [52] focused on day care whilst [22, 34, 35, 82] studied home care. The remaining papers focused on either nursing care [5, 12, 58] or long-term/aged related care facilities [4, 6, 13, 20, 21, 45, 46, 68, 81]. This shows that within the grouping of community care there were a wide range of different settings being analysed.

For frail and elderly care mapping to be successful, the journey of a patient should be documented, which will depend on the type of illness they are suffering from. Therefore it is important for more research to be conducted into specific illnesses and healthcare settings. Monitoring the journey of a patient from admittance through to discharge, may become a valuable tool in order to predict long-term demands and capacity planning.

### 3.2.4. Condition Area

A classification which has been commonly used within healthcare literature reviews is the condition area of the patient [7, 85]. These condition areas are often categorised as either: acute or chronic.

- Acute - Medical conditions that are brought on unexpectedly, e.g., heart failure, or patients undergoing or recovering from a surgical procedure, e.g., femur fracture.

- Chronic - Medical conditions that are prolonged and rarely cured, e.g., dementia.

Often chronic conditions can develop and cause an acute condition, and likewise, if untreated an acute condition can often become chronic. It is therefore important for research to be focused within both strands of conditions, especially when considering frail and elderly patients. These patients often have many chronic conditions which require long-term care, however they can easily become more serious conditions requiring immediate care.

Figure 4 displays the quantity of papers in each condition category.

Figure 4: Condition categories of publications
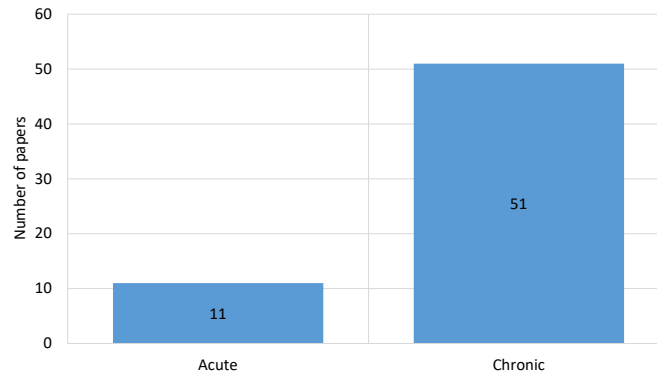


Within the elderly population, there are many people who have multiple long-term conditions (MLTC), which may explain why there were many papers that focus on chronic conditions. Eleven papers focused on the acute care setting [1, 8, 25, 48, 59, 64, 65, 66, 67, 70, 76]. This is surprising given frail and elderly patients are more likely to suffer from acute conditions as a result from chronic illness. The eleven papers were all based in the single hospital setting with no overlap between community care (Figure 5).

Figure 5: Cross analysis of setting and condition categories of publications
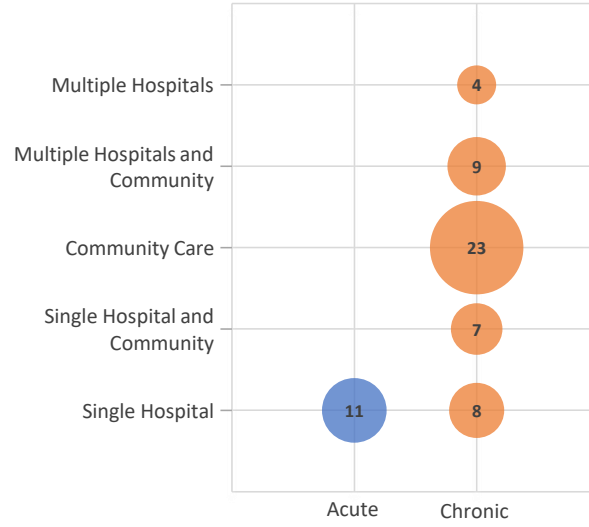


## 3.3. Methodological Content

This subsection will analyse the technical side of the research. Firstly, discussing the research aims, then moving on to the planning decision levels discussed in Hulshof et al.'s taxonomy [41]. Finally, the different OR/MS methods used within frail and elderly care planning are identified.

### 3.3.1. Research Aims

The literature can be grouped into three main aims of the papers in terms of care planning: examining, forecasting and improving. These categories indicate the direction of the research and the main interest to the authors.

- Examining - Using OR methods to determine how a care plan was performing, e.g., characteristics of patients who move within community care [29], hospital outcomes following an updated care pathway [76].

- Forecasting - Predicting future scenarios with the current care plan in place, e.g., forecasting length of stay in hospital and community care [32], capacity planning in community care settings [57].

- Improving - Improvements were made or suggested to enhance the quality of care planning, e.g., improve elderly care in hospital [63], improving quality and efficiency in home care [22].

Figure 6 displays the quantity of papers in each research aim category.

Figure 6: Research aims of the papers
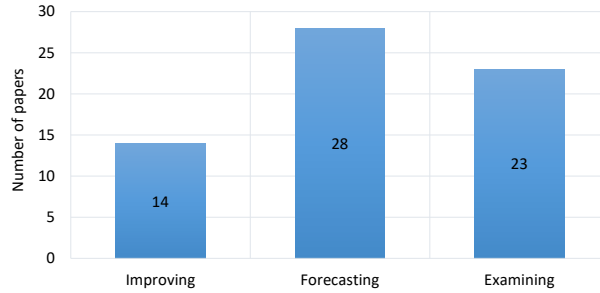


There were three papers which considered a multiple combination of the research aims. Abe et al. [1] examined how polypharmacy affected gastrointestinal surgery patients, whilst also identifying the effects on length of stay if measures reducing polypharmacy were implemented. Garg et al. [28] and Patrick [62] both have improving and forecasting aims: Garg et al. focused on improving admission scheduling with resource forecasting and Patrick focused on improving waiting times along with capacity planning. All three of these papers, focused on a single hospital setting.

The results show most papers aim to forecast frail and elderly patients in the system. Out of the 28 papers, 16 focused on predicting future demands and how the corresponding departments would be required to adapt to this change [4, 9, 12, 15, 18, 20, 33, 34, 37, 43, 45, 49, 57, 62, 83, 84]. A further nine papers aimed to predict the length of stay of patients in hospitals or within community care [1, 32, 40, 53, 54, 55, 66, 69, 81]. Surprisingly, of these nine, one author was co-author on five of these papers, suggesting that the research within this field is limited to a few research teams [32, 53, 54, 55, 66].

Fourteen papers focused on making improvements to an aspect of the path-

way. Five of these aimed to improve the flow of patients [14, 36, 64, 67, 70]. Only three papers had the primary focus on improving patient care [22, 63, 65]. Their results highlighted the importance of appropriate care to the elderly, which in Rossille et al.'s [65] paper can be achieved by successfully scheduling patients in an emergency department and not categorising these patients by their symptoms. Ragab et al. [63] used simulation modelling to improve the management of frail patients by introducing intermediate care beds for those admitted to acute hospitals. Eveborn et al. [22] used the vehicle routing problem to improve quality for patients receiving home care.

*3.3.2. Planning Decisions*

Hulshof et al's. [41] research on taxonomic classification in healthcare systems highlighted a hierarchy of decision making techniques. There were three different decision levels discussed: strategic, tactical and operational. A brief description is given as follows:

- Strategic planning focuses on structural decision making such as determining the locations of facilities or resource capacities, these often have a long planning time.

- Tactical planning addresses the execution of strategic plans on the mid-horizon planning time, e.g., staffing levels.

- Operational planning analyses short-term decisions and focuses on the individual patient and resources. Patient appointment scheduling would be an example of this.

Figure 7 displays the breakdown of publications by planning decision level.

Figure 7: Planning decision level of publications
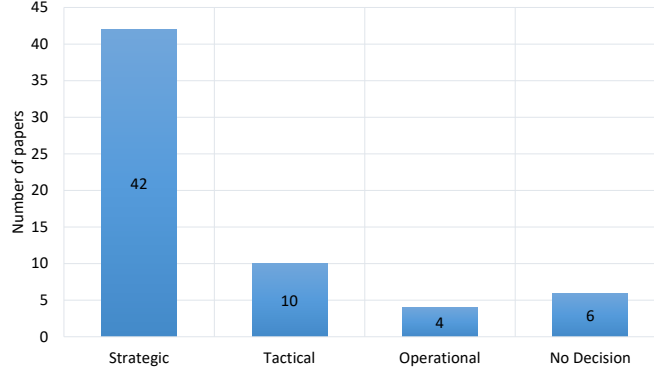


The majority of papers focused on strategic planning, with a high concentration on capacity planning and placement policy. Xie et al. [81] used strategic planning and created a Markov model to represent the length of stay of the elderly moving within and between residential and nursing homes. By developing this model, it aimed to assist planning authorities to fully understand the pattern of resource usage within their local area. Further work included an extension of their model to incorporate particular attributes of patients, e.g., age, gender and physical conditions, to predict differences in survival by treatment locations.

The number of papers (two) on the operational planning level is smaller than the number of papers (six) that have no planning decision level. The results showed that care planning for frail and elderly pathways was being addressed on some scale across all three decision levels; day-to-day; mid-level planning; long-term, wider policy decisions. However, as there were substantially fewer papers in the tactical and operational decision levels it would suggest these areas are more difficult to plan in frail and elderly healthcare.

Two of the four operational planning papers focused on staff scheduling [22, 34] and the other two focused on readmission of patients [31] and treatment outcomes [48]. Kul et al. [48] evaluated the effect of the heart failure care pathway on geriatric patients. Logistic regression showed positive results supporting

the use of care pathways, highlighting reduced mortality and readmission rates along with no increase in hospital costs.

Figure 8 displays the cross analysis between the planning decision and the medical setting. To some degree, tactical planning levels were addressed in each setting, although the operational papers had only been addressed within community care and single hospital settings.

Figure 8: Cross analysis of planning decision and setting

Figures/PlanningSetting.pdf
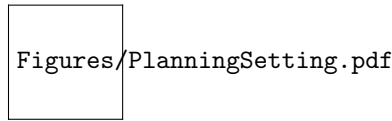
Hulshof et al. [41] analysed the taxonomy for papers within the OR/MS JCR category. This has been further extended to include four additional JCR categories. The cross analysis can be seen within Figure 9.

Figure 9: Cross analysis of JCR category and decision level
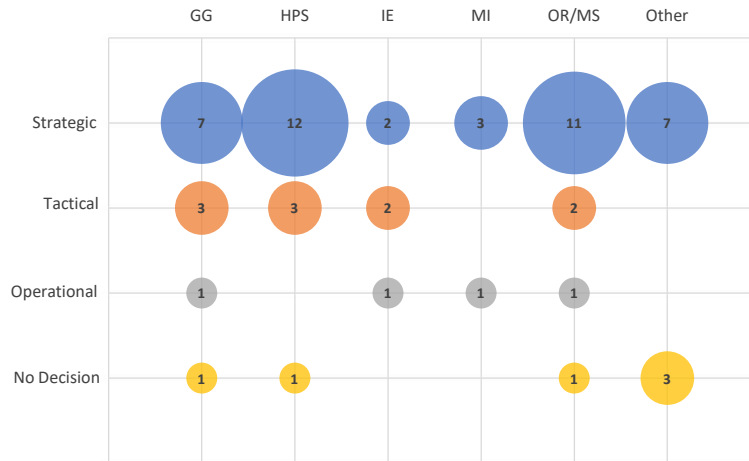


Figure 9 shows there is a spread of decision levels against each JCR category. It demonstrates that the decision level taxonomy discussed within Hulshof et al. [41] can be successfully applied to JCR categories other than OR/MS.

### 3.3.3. OR/MS Methods

The final area for analysis was investigating the OR/MS methods that have been utilised within these studies. There has been a variety of different OR/MS techniques which have been used to demonstrate the effectiveness of care planning designs specifically for the frail and elderly. Figure 10 demonstrates the quantity of each of these methods, with statistical analysis encompassing a wide range of traditional statistical/operational analysis techniques, including Cox's regression analysis [40], mixed exponential distributions [38] and time survival analysis [58]. Optimisation included mixed integer programming [18] and quadratic programming [68]. Simulation included discrete event simulation [83] and system dynamics [13]. There were two papers which focused on multiple methods.

Figure 10: Quantity of publications by mathematical method
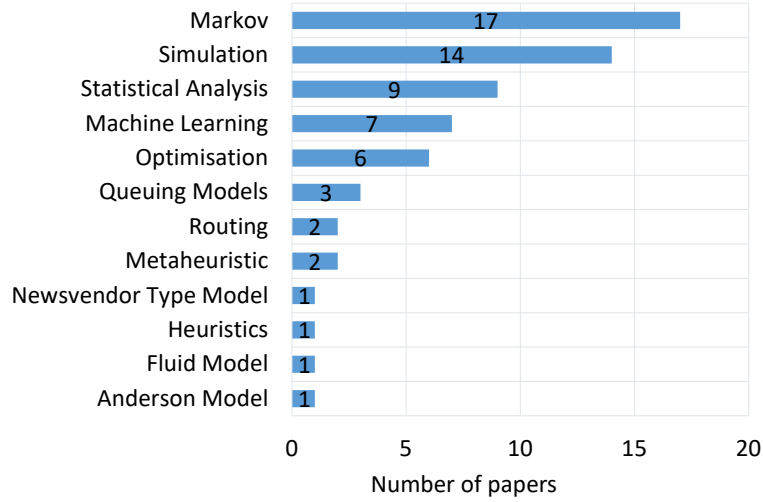


Patrick [62] as discussed in Section 3.2.1 used discrete event simulation along with a Markov decision process model to predict demand for long-term care.

Mohammadi Bidhandi et al. [57] used both simulation and queueing theory methods to plan demand capacities within community care. They focused on six services and ran their optimised queueing model through a simulation to

determine transient behaviours of the system. By combining these two methods, capacities were optimised over the entire network at one time, instead of considering them as separate isolated units.

Table 3 shows the breakdown of each OR/MS method and its corresponding setting. The seven papers which looked at the overlap between single hospitals and community care all used Markov methods. This may suggest that Markov methods are the most applicable ones to this setting, particularly for frail and elderly individuals. The data available may also lend itself well to fit into a Markov model. Expanding upon this, when analysing both single and multiple hospitals with community care, only Markov, simulation and statistical analysis methods were used, suggesting these methods were useful when applied to multiple services at the same time. This leaves room in these settings, for further research using alternative OR/MS methods to the Markov model.

Community care settings used the widest range of methods, thirteen in total, for care planning. This showed the data available within community care can accommodate a variety of methods. There is potential for further investigation and expansion into the methods utilised as an area for future research.

Table 3: Setting and OR/MS method used within the published research

| | Single Hospital | Single Hospital and Community | Community Care | Multiple Hospitals and Community | Multiple Hospitals | Total |
|---|---|---|---|---|---|---|
| **Markov** | [15, 25, 36, 53, 54, 66] | [23, 27, 28, 31, 32, 37, 69] | [81] | [56, 62] | [55] | 17 |
| **Simulation** | [59, 64, 84] | | [9, 13, 20, 21, 45, 57, 83] | [62, 63, 75] | [24] | 14 |
| **Statistical Analysis** | [8, 10, 67, 76] | | [12, 35, 58] | | [38, 40] | 9 |
| **Machine Learning** | [1, 48, 65, 70] | | [4, 29, 78] | | | 7 |
| **Optimisation** | | | [5, 6, 68] | [18, 42, 43] | | 6 |
| **Queueing models** | [14, 33] | | [57] | | | 3 |
| **Metaheuristic** | | | [34, 52] | | | 2 |
| **Routing** | | | [82] | [51] | | 2 |
| **Anderson Model** | | | [46] | | | 1 |
| **Fluid model** | | | | [86] | | 1 |
| **Heuristics** | | | [22] | | | 1 |
| **Newsvendor type model** | | | [49] | | | 1 |
| **Total** | 19 | 7 | 24 | 10 | 4 | 64 |

Note: Mohammadi Bidhandi et al. [57] and Patrick [62] utilise two methods and therefore appear twice in the table. This results in a total of 64.

Figure 10 and Table 3 highlight that Markov models were the most frequent method used, followed by simulation and statistical analysis. Within these 17 papers, there were a variety of Markovian methods utilised, however these were subgrouped into continuous and discrete time models. Figure 11 shows the breakdown of the Markov category from Figure 10. Continuous time Markov models were more often used with a total of fourteen papers [15, 23, 25, 27, 31, 32, 36, 53, 54, 55, 56, 66, 69, 81]. There were a variety of different types of continuous time models with many focusing on Coxian phase-type Markov models. There were three papers which used discrete time [28, 37, 62] to model frail and elderly patients.

Figure 11: Further breakdown of the Markov model category
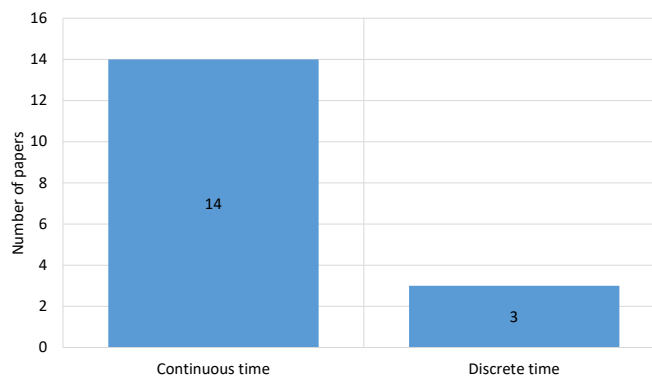


### 3.4. Common Themes

Section 3 has provided an overview of the work on care planning for frail and elderly. Markov models were the most common method applied to healthcare settings. In more recent years, there has been the emergence of newer techniques being applied to healthcare, i.e., metaheuristics, the Anderson Model and fluid models. Strategic planning remained the most common planning decision level across the OR/MS methods, showing research was being accomplished in longer term care planning. There has been a wider spread of research aims across the papers, although, the majority tend to focus on forecasting future scenarios rather than improving the current systems in place. Finally, the emphasis of

these papers has been on single settings, whether this be within a hospital or the community. The current research provides a wide range of different techniques for readers to apply to their own hospital or community care facility. However, there remains scope for future research to be conducted in the frail and elderly patient setting.

## 4. Research Gaps

The literature found within this review covered a wide range of facilities, locations and patient types within frail and elderly care planning. Despite this variety, the majority of papers fit into a few groupings as discussed previously, with heavy focus on certain methods and locations.

### 4.1. Gaps in terms of Methodology

Across 62 papers, there were twelve different methods utilised, with a heavy focus on Markov and simulation. Research conducted between 1990 and 2015 has shown that the most common OR methods used in hospital applications were discrete event simulation and deterministic modelling (optimisation) [2, 3]. It was interesting to see the disparities between methods within frail and elderly care and general hospital applications. In the simulation method category (Table 3), only five papers used discrete event as their simulation method [24, 45, 59, 83, 84] and papers focusing on optimisation techniques were embedded within other methods [9, 27, 52, 57, 67, 68, 82, 84].

Within Abe et al.'s paper [3], the statement was made that the introduction of the Patient Protection and Affordable Care Act in 2010 (USA), has led to hospitals being required to improve quality of care and alongside this, there has also been an increase in the demand of services in U.S. hospitals. The seven papers that were based on data from the U.S. post 2010, focused on capacity planning and improving outcomes [5, 9, 29, 35, 49, 76, 86]. This suggests that the implementation of Government policy provides another avenue for research topics and should be closely monitored when identifying new areas to study.

Although healthcare data may lend itself well to some OR/MS methods explaining their higher frequency of papers (Markov, simulation, statistical analysis and machine learning), the remaining eight methods highlight the potential for further exploration into these fewer applied techniques. Soft OR methods, even though included in the search criteria, did not result in any papers being identified. This leaves potential for research using these techniques, such as soft systems methodology, and applying this to frail and elderly healthcare.

*4.2. Gaps on the Intersection between Research Aims and Decision Levels*

Successful care planning should consider long-term and day-to-day planning. The work has highlighted a large number of papers with strategic decision levels (long-term), with only fourteen papers analysing tactical and operational approaches, ten and four combined. Reviewing the 23 community care papers, three focused on tactical planning [12, 21, 82], and two with operational planning [22, 34]. Despite being long-term care facilities, day-to-day planning of staff, resources and occupancy demands should be investigated for improving care planning. Such investigation could provide an interesting avenue to explore further, by comparing how factors vary day-to-day for private care companies compared to government funded elderly care services. Operational planning levels were addressed in single and not multiple hospital settings. One potential reason for this could be that when addressing multiple hospitals, the authors are more interested in strategic developments within care planning.

Another area examined were the research aims, which were able to be grouped into three streams for care planning: examining (23 papers), forecasting (28 papers) and improving (14 papers). The most popular aim, forecasting, mainly used simulation and Markov methods. Potentially the data needed for forecasting techniques lends itself well to these methods, however there were eleven papers that showed forecasting techniques can be used alongside different methods and therefore should be further explored [1, 5, 12, 18, 20, 34, 33, 43, 51, 57, 82].

*4.3. Shortcomings on the Intersections between Medical Settings*

Within the community care setting, there were only six papers which focused on the overlap between settings in the community [9, 29, 49, 57, 78, 83]. The remaining papers from this setting focused their research in a variety of settings including long-term care facilities, nursing homes, home care and day care.

When studying the application of the methods, the common research focus has been on capacity planning for community care services. This is important, as bed blocking often occurs when patients are medically fit to be discharged from hospital but there are insufficient places available within community care settings [45]. However, there has been little research into capacity planning for care of the elderly wards within hospitals. Patient flows [14], occupancy levels [15] and the length of stay [55] are the main focus of research based in geriatric wards. These papers do not address future demands or predictions. This leaves potential for capacity planning research within care of the elderly wards, incorporating both short-term and long-term predicted demands. If capacities within these wards remain constant over time, with an increased demand, these wards are likely to reach maximum capacity at a quicker rate. It is therefore important for research to focus on hospitals and how they feed into community care services. This overlap, between hospital and community care, will allow a successful integrated care system, similar to these nine papers [18, 42, 43, 51, 56, 62, 63, 75, 86].

## 5. Discussion

The purpose of this paper was to review previous literature on care planning for frail and elderly patients across the care pathways. Initially, the criteria was set out for researchers to systematically search papers in this field (Section 2). The papers were then methodically categorised and discussion around these papers took place to identify major research streams in Section 3. Future research opportunities were considered in Section 4. This interdisciplinary review has highlighted the importance of bridging the gap between care of the

elderly journals (GG) with HPS, IE, MI and OR/MS journals to consolidate papers with the focus of care planning for frail and elderly. Within Section 2, the Scopus search resulted in 65 papers of relevance being identified, including three literature reviews which focused on nursing home admissions, transition between community care settings and the use of Digi-PIP methods for frail and elderly pathways. As this review spans twenty-one years, it highlights the limited research published and provides avenues for further study. Furthermore, if this research had been limited to OR/MS journals the number of publications would have been reduced to fifteen papers and therefore limiting the results shown. Whereas, if only care of the elderly journals, e.g., Geriatrics and Gerontology (GG), were analysed this would have restricted the findings further to only twelve papers. This review has shown the importance of combining these areas, to avoid excluding valuable literature.

Frail and elderly care planning is a growing area of research with many potential opportunities. To summarise this review, three overarching research possibilities were identified.

1. When analysing the twelve methods utilised, nearly half of the papers focused on either Markov or simulation models. Although there were variations within the type of Markov model used, such as non-homogeneous discrete time and Coxian phase-type distributions, this leaves potential for further research to expand on the other methods discussed such as queueing models or routing. This could be further developed by combining multiple methods to create a more diverse model, as this review only identified two papers using this approach (Markov and simulation, and queueing theory with simulation). The features of the data which is routinely collected within community or hospital care settings might impact which OR/MS method is chosen. A further research possibility is the use of soft OR methods, which although included within the search terms discussed in Section 2 did not produce any relevant results.

2. More research would be beneficial in care planning across the care pathway for frail and elderly. Only nine papers were identified where the focus was on the

combination of multiple hospitals and community care. Community care had the highest setting focus followed by single hospital settings. Whilst it is important to consider these separately for improvements in efficiency, they may not be able to be implemented successfully without consideration for one another. There were eight papers identified that focused on a specific illness and tended to focus on general wards for care of the elderly. Hospitalised frail and elderly patients can be admitted to specialised wards for a specific medical condition or general geriatric wards. This means it can be difficult to plan for the next step of the pathway when they are medically fit to be discharged. To predict future demands and assist capacity planning in both hospitals and in community care, it would be valuable to understand the complete patient journey from first point of contact to discharge. Many frail and elderly care pathways do not differ from other patient pathways, and as a result these groups are included in more general studies. However, frail and elderly patients suffer with more age-related issues, often with longer recovery times, so it is important to consider frail and elderly patient care planning separately for a successful healthcare system.

3. There was only one paper with research conducted on how systems would manage if a sudden rise in frail and elderly patients were to occur [6]. Sudden increase in demand is not a novel area to healthcare modelling with a high quantity of papers investigating this issue, e.g., intensive care units [17, 44, 79]. The Covid-19 pandemic has demonstrated why research is important to help healthcare providers meet increasing and sudden changes within demand [80]. Future research could investigate the effect Covid-19 has had within long-term care settings and the effectiveness of different Governmental policies for frail and elderly patients.

*5.1. Limitations of the Study*

This review has provided a consolidation of care planning for frail and elderly across the care pathway, identifying gaps in research. A reproducible approach was given in relation to the search strategy in Table 1. We acknowledge that searching papers by keyword criteria can fail to identify relevant papers, which

could be identified through other approaches. The keywords used were not an exhaustive list of all OR/MS approaches, patient flow terms or classification of patients, however they provided a broad range of terms. To mitigate the number of papers excluded, reference lists and forward references of the initial 39 papers were included in the search. Similarly, only one search database was used (Scopus) to allow the results to be reproducible, however this may have resulted in a small number of papers being excluded. To only include recent developments in OR/MS methods, this review restricted the literature to papers published in English between 2000 to 2020. The quality of the papers was not a factor in whether they should be included within the analysis. Despite the limitations of the study, the results have yielded some valuable findings which will be beneficial to both researchers and healthcare managers.

## 6. Conclusion

Within the health sector, there are continuing demands for improved medical care for patients. Many industrialised countries are facing the prospects of a rising ageing population adding to further pressure on health systems which are already under immense strain. Frail and elderly patients are highly vulnerable and are often a cause of bed blocking within hospitals due to the lack of or unsuitable community care resources available. Since 2000, there have been 62 papers on the subject of care planning for frail and elderly, with the rate of publication increasing since 2015. These papers had a broad range of applications with a variety of OR/MS methods utilised.

Papers which focused on improving the flow of patients and patient outcomes, have been widely accepted by their intended audience. On the contrary, papers which have a data-driven focus by generating new models which calculate optimal solutions or demand predictions, can easily be overlooked by health professionals as they often opt for an experience-driven approach. There are many opportunities for research to continue to develop within this area, with particular attention applied to care planning across the pathway for frail and

elderly patients.

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Table A1: **Publications categorised by JCR**

| JCR Category | | Total |
|---|---|---|
| Geriatrics and Gerontology (GG) | [1, 4, 8, 12, 25, 46, 48, 58, 67, 70, 76, 78] | 12 |
| Health Policy and Services (HPS) | [5, 15, 20, 21, 28, 32, 37, 38, 42, 45, 54, 65, 83] | 16 |
| Industrial Engineering (IE) | [34, 36, 49, 52, 82] | 5 |
| Medical Informatics (MI) | [13, 14, 23, 32] | 4 |
| Operations Research and Management Sciences (OR/MS) | [9, 18, 22, 24, 43, 51, 53, 56, 57, 59, 62, 64, 66, 84, 86] | 15 |
| Other | [6, 10, 27, 29, 55, 63, 68, 69, 75, 81] | 10 |

Table A2: **Publications classified by Hospital Setting**

| Medical Setting | | Total |
|---|---|---|
| Community Care | [4, 5, 6, 9, 12, 13, 20, 21, 22, 29, 34, 35, 45, 46, 49, 52, 57, 58, 68, 78, 81, 82, 83] | 23 |
| Community Care & Multiple Hospitals | [18, 42, 43, 51, 56, 62, 63, 75, 86] | 9 |
| Single Hospital | [1, 8, 10, 14, 15, 25, 33, 36, 48, 53, 54, 59, 64, 65, 66, 67, 70, 76, 84] | 19 |
| Single Hospital & Community Care | [23, 27, 28, 31, 32, 37, 69] | 7 |
| Multiple Hospitals | [24, 38, 40, 55] | 4 |

Table A3: **Publications categorised by Condition Area**

| Condition | | Total |
|---|---|---|
| Acute | [1, 8, 25, 48, 59, 64, 65, 66, 67, 70, 76] | 10 |
| Chronic | [4, 5, 6, 9, 10, 12, 13, 14, 15, 18, 20, 21, 22, 23, 24, 27, 28, 29, 31, 32, 33, 34, 35, 36, 37, 38] | |
| | [40, 42, 43, 45, 46, 49, 51, 52, 53, 54, 55, 56, 57, 58, 62, 63, 68, 69, 75, 78, 81, 82, 83, 84, 86] | 51 |

Table A4: **Markov Model Publications by Type**

| Markov Method | | Total |
|---|---|---|
| Continuous time | [15, 23, 25, 27, 31, 32, 36, 53, 54, 55, 56, 66, 69, 81] | 14 |
| Discrete time | [28, 37, 62] | 3 |

Table A5: **Publications classified by Research Aims**

| Research Aim | | Total |
|---|---|---|
| Examining | [1, 4, 6, 8, 10, 13, 23, 24, 25, 27, 29, 31, 35, 38, 42, 46, 48, 56, 58, 59, 75, 76, 78] | 23 |
| Forecasting | [1, 5, 9, 12, 15, 18, 20, 21, 28, 32, 33, 34, 37, 40, 43, 45, 49, 53, 54, 55, 57, 62, 66, 69, 81, 82, 83, 84] | 28 |
| Improving | [14, 22, 28, 36, 51, 52, 62, 63, 64, 65, 67, 68, 70, 86] | 14 |

Table A6: **Publications classified by Planning Decisions**

| Planning Decision | | Total |
|---|---|---|
| Strategic | [1, 4, 5, 6, 9, 13, 14, 15, 18, 20, 23, 24, 25, 29, 32, 33, 35, 37, 40, 42, 43, 45] | |
| | [46, 49, 52, 54, 55, 56, 57, 58, 62, 63, 64, 66, 68, 69, 76, 78, 81, 83, 84, 86] | 42 |
| Tactical | [12, 21, 28, 32, 36, 38, 51, 53, 67, 70, 82] | 10 |
| Operational | [22, 31, 34, 48] | 4 |
| No Decision | [8, 10, 27, 59, 65, 75] | 10 |

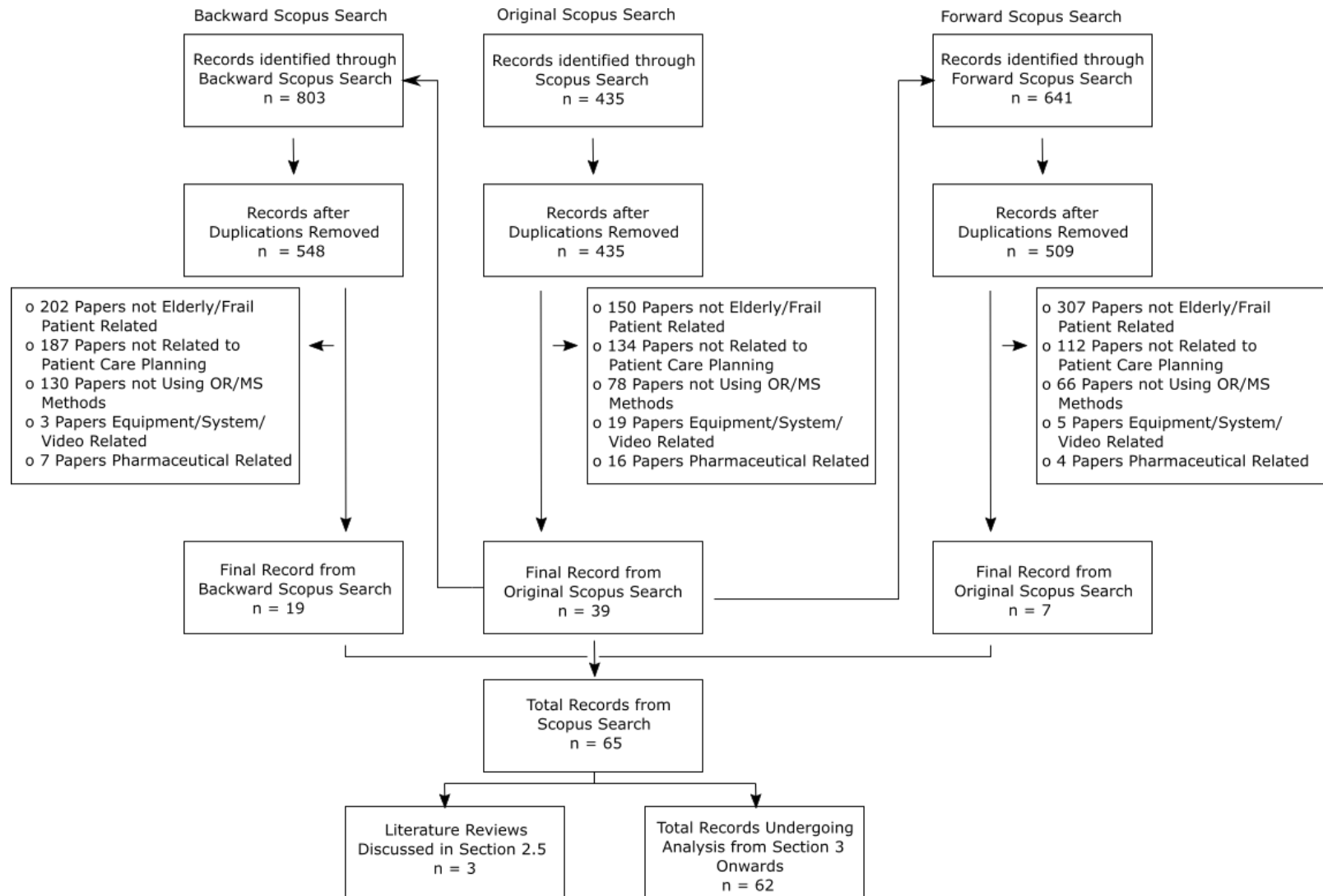Figure 12: Flow chart of literature search results

Table A7a: **Summary of literature with a total of 62 papers**

| Ref | Authors | JCR | Country | Research Aim | Condition | Method | Planning Decision | Setting |
|---|---|---|---|---|---|---|---|---|
| 1 | Abe et al. | GG | Japan | Examining and Forecasting | Acute | Machine Learning | Strategic | Single Hospital |
| 4 | Ambagtsheer et al. | GG | Australia | Examining | Chronic | Machine Learning | Strategic | Community Care |
| 5 | Arling et al. | HPS | USA | Forecasting | Chronic | Optimisation | Strategic | Community Care |
| 6 | Arvelo et al. | Other | Spain | Examining | Chronic | Optimisation | Strategic | Community Care |
| 8 | Azad et al. | GG | Canada | Examining | Acute | Statistical Analysis | None | Single Hospital |
| 9 | Bae et al. | OR/MS | USA | Forecasting | Chronic | Simulation | Strategic | Community Care |
| 10 | Beaupre et al. | Other | Canada | Examining | Chronic | Statistical Analysis | None | Single Hospital |
| 12 | Borowiak et al. | GG | Poland | Forecasting | Chronic | Statistical Analysis | Tactical | Community Care |
| 13 | Cepoiu-Martin and Bischak | MI | Canada | Examining | Chronic | Simulation | Strategic | Community Care |
| 14 | Chaussalet et al. | MI | UK | Improving | Chronic | Queuing Models | Strategic | Single Hospital |
| 15 | Christodoulou and Taylor | HPS | UK | Forecasting | Chronic | Markov | Strategic | Single Hospital |
| 18 | Davari and Van Woensel | OR/MS | UK | Forecasting | Chronic | Optimisation | Strategic | Multiple Hospitals and Community |
| 20 | Desai et al. | HPS | UK | Forecasting | Chronic | Simulation | Strategic | Community Care |
| 21 | Eggink et al. | HPS | The Netherlands | Forecasting | Chronic | Simulation | Tactical | Community Care |
| 22 | Eveborn et al. | OR/MS | Sweden | Improving | Chronic | Heuristics | Operational | Community Care |
| 23 | Faddy and McClean | MI | UK | Examining | Chronic | Markov | Strategic | Single Hospital and Community |
| 24 | Franck et al. | OR/MS | France | Examining | Chronic | Simulation | Strategic | Multiple Hospitals |
| 25 | Franklin and Hunter | GG | UK | Examining | Acute | Markov | Strategic | Single Hospital |
| 27 | Garg et al. | Other | UK | Examining | Chronic | Markov | None | Single Hospital and Community |
| 28 | Garg et al. | HPS | UK | Improving and Forecasting | Chronic | Markov | Tactical | Single Hospital and Community |
| 29 | Gassoumis et al. | Other | USA | Examining | Chronic | Machine Learning | Strategic | Community Care |
| 31 | Gordon et al. | MI | Italy | Examining | Chronic | Markov | Operational | Single Hospital and Community |
| 32 | Gordon et al. | HPS | Italy | Forecasting | Chronic | Markov | Strategic | Single Hospital and Community |
| 33 | Gorunescu et al. | HPS | UK | Forecasting | Chronic | Queuing Models | Strategic | Single Hospital |
| 34 | Grenouilleau et al. | IE | Canada | Forecasting | Chronic | Metaheuristic | Operational | Community Care |
| 35 | Guo et al. | Other | USA | Examining | Chronic | Statistical Analysis | Strategic | Community Care |
| 36 | Hamdani et al. | IE | France | Improving | Chronic | Markov | Tactical | Single Hospital |
| 37 | Hare et al. | HPS | Canada | Forecasting | Chronic | Markov | Strategic | Single Hospital and Community |
| 38 | Harrison | HPS | USA | Examining | Chronic | Statistical Analysis | Tactical | Multiple Hospitals |
| 40 | Heggestad | HPS | Norway | Forecasting | Chronic | Statistical Analysis | Strategic | Multiple Hospitals |
| 42 | Intrevado et al. | HPS | Canada | Examining | Chronic | Optimisation | Strategic | Multiple Hospitals and Community |

Table A7b: **Summary of literature with a total of 62 papers**

| Ref | Authors | JCR | Country | Research Aim | Condition | Method | Planning Decision | Setting |
|---|---|---|---|---|---|---|---|---|
| 43 | Johnson et al. | OR/MS | USA | Forecasting | Chronic | Optimisation | Strategic | Multiple Hospitals and Community |
| 45 | Katsaliaki et al | HPS | UK | Forecasting | Chronic | Simulation | Strategic | Community Care |
| 46 | Kerpershoek et al. | GG | European wide | Examining | Chronic | Anderson Model | Strategic | Community Care |
| 48 | Kul et al. | GG | Italy | Examining | Acute | Machine Leaning | Operational | Single Hospital |
| 49 | Li et al | IE | USA | Forecasting | Chronic | Newsvendor Model | Strategic | Community Care |
| 51 | Lim et al. | OR/MS | Hong Kong | Improving | Chronic | Routing | Tactical | Multiple Hospital and Community |
| 52 | Lin et al. | IE | Hong Kong | Improving | Chronic | Metaheuristic | Strategic | Community Care |
| 53 | Marshall and McClean | OR/MS | UK | Forecasting | Chronic | Markov | Tactical | Single Hospital |
| 54 | Marshall and McClean | HPS | UK | Forecasting | Chronic | Markov | Strategic | Single Hospital |
| 55 | Marshall et al. | Other | Italy | Forecasting | Chronic | Markov | Strategic | Multiple Hospitals |
| 56 | McClean and Millard | OR/MS | UK | Examining | Chronic | Markov | Strategic | Multiple Hospitals and Community |
| 57 | Mohammadi Bidhandi et al. | OR/MS | Canada | Forecasting | Chronic | Queuing models and Simulation | strategic | Community Care |
| 58 | Muramatsu et al. | GG | USA | Examining | Chronic | Statistical Analysis | Strategic | Community Care |
| 59 | Onggo et al. | OR/MS | UK | Examining | Acute | Simulation | None | Single Hospital |
| 62 | Patrick | OR/MS | Canada | Examining and Forecasting | Chronic | Markov and Simulation | Strategic | Multiple Hospitals and Community |
| 63 | Ragab et al. | Other | Ireland | Improving | Chronic | Simulation | Strategic | Multiple Hospitals and Community |
| 64 | Rashwan et al. | OR/MS | Ireland | Improving | Acute | Simulation | Strategic | Single Hospital |
| 65 | Rossille et al. | HPS | France | Improving | Acute | Machine Leaning | None | Single Hospital |
| 66 | Shaw and Marshall | OR/MS | UK | Forecasting | Acute | Markov | Strategic | Single Hospital |
| 67 | Silverster et al. | GG | UK | Improving | Acute | Statistical Analysis | Tactical | Single Hospital |
| 68 | Tao et al. | Other | China | Improving | Chronic | Optimisation | Strategic | Community Care |
| 69 | Taylor et al. | Other | UK | Forecasting | Chronic | Markov | Strategic | Single Hospital and Community |
| 70 | Trevisan et al. | GG | Italy | Improving | Acute | Machine Learning | Tactical | Single Hospital |
| 75 | Walker and Haslett | Other | Australia | Examining | Chronic | Simulation | None | Multiple Hospitals and Community |
| 76 | Wallace et al. | GG | USA | Examining | Acute | Statistical Analysis | Strategic | Single Hospital |
| 78 | Welberry et al. | GG | Australia | Examining | Chronic | Machine Learning | Strategic | Community Care |
| 81 | Xie et al. | Other | UK | Forecasting | Chronic | Markov | Strategic | Community Care |
| 82 | Yalçindağ et al. | IE | Italy | Forecasting | Chronic | Routing | Tactical | Community Care |
| 83 | Zhang and Puterman | HPS | Canada | Forecasting | Chronic | Simulation | Strategic | Community Care |
| 84 | Zhang et al. | OR/MS | Canada | Forecasting | Chronic | Simulation | Strategic | Single Hospital |
| 86 | Zychlinski et al. | OR/MS | USA | Improving | Chronic | Fluid Model | Strategic | Multiple Hospitals and Community |