Homecare planning, a challenging task in a growing market

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Abstract

The homecare services market is large and rapidly growing due to ageing populations and increasingly skewed age demographics. Human resources are the dominant factor simultaneously determining quality of care and driving costs. The planning of homecare services involves allocating personnel among shifts, assigning staff members to patients, routing staff members' client visits and scheduling treatments. Homecare planning is primarily done manually even though optimisation techniques have aided in solving similar problems in other domains. Efficient homecare planning requires optimisation techniques, but current, related optimisation research suffers from several shortcomings (above all, a lack of integration in handling the different planning sub-problems) and needs certain changes. This paper highlights these shortcomings and suggests approaches to realise the benefits of optimisation techniques in homecare planning.

Introduction

In developed countries, ageing populations and skewed age demographics have driven a rapid increase in cases of care-dependent people. Simultaneously, technological advances have increased public expectations for quality of care even as authorities have attempted to cut or cap health expenditures, which consume substantial portions of their budgets. These trends have placed heavy strains on the healthcare system. For long term patients, conventional hospitalisation is neither economically viable nor desirable, and alternatives, such as nursing homes, are increasingly costly. Homecare, though, costs up to 60% less than a nursing home (Eveborn *et al.*, 2009), and treating one patient at home can realise annual savings of approximately 600 KNOK (~70 000 $) (Grut *et al.*, 2012). Consequently, homecare services are considered a cost-effective, flexible solution, and their market is large and growing rapidly.

In Norway, the homecare market generates 20 billion NOK (~2.3 million $) yearly, while the EU market is roughly 80 times larger. The growth rate of homecare is similar in most industrial countries and even some developing countries (UN, 2016). Projections indicate that, by 2035, maintaining today's quality standards will require that every third pupil take up a career in health and care services (Roksvaag *et al.*, 2012). To avoid this crisis, it is crucial to improve the efficiency of homecare services.

The planning of homecare services is a complex process that involves 1) allocating personnel among shifts, 2) assigning staff members to patients, 3) routing staff visits and 4) scheduling treatments while considering, for example, required competences, patient and caregiver preferences, labour laws, union regulations, organisational policies and temporal precedence of activities within a limited budget. Although highly time consuming and inefficient, manual planning is widespread in practice. This negatively affects quality, efficiency and costs and leads to unnecessarily long driving routes, mismatches between patient assignments and staff competences, a lack of available staff and patient visits by continuously changing personnel (Hallgren, 2015), (Syversen *et al.*, 2014). Moreover, homecare services require time consuming re-planning for nearly every shift due to unforeseen changes caused by staff, patients, treatments and visits from relatives. Typical examples are staff calling in sick, patients re-scheduling their appointments, sudden unavailability of medical equipment and more. In these settings, optimisation based decision support can drastically improve the ability to find efficient solutions.

The interrelated tasks of homecare planning: rostering, assignment, vehicle routing and scheduling have each been studied at length in the scientific optimisation literature, but still present open research challenges. In other industries (e.g. aviation, oil, transport), mathematical optimisation has been successfully applied to individual problems for decades. However, homecare service planning is different as efficiency requires solving these four problems simultaneously. Due to this inherent combinatorial complexity, none of these problems lends itself well to a manual solution approach—let alone if tackled jointly. The few existing optimisation tools approach problems independently and simply merge the solutions, potentially losing the global perspective on the problem.

Overcoming these limitations requires developing an innovative planning system based on in-depth domain knowledge and research-based optimisation innovations. A unified approach to the overall planning problem increases the challenges but also the possible benefits in efficiency and quality. Such as, significant savings from in personnel costs, dispatching and planning time and driving time and costs (smarter routes). Other, less quantifiable benefits were also identified: increased service quality (e.g. correct competence, continuity of care, predictability), improved supervision and control (better decisions) and fairer rosters for employees (more satisfied employees, fewer absences, high savings).

Background

The design of efficient homecare services is a new, challenging research field (Cappanera *et al.*, 2014) that tackles the hard, interrelated combinatorial-mathematical problems of rostering (Ernst *et al.*, 2004), assignment (Yalcindag *et al.*, 2012), vehicle routing (Bräysy *et al.*, 2014) and activity scheduling (Pinedo, 2012). Most studies in the field of operations research and optimisation (e.g. (Yalcindag *et al.*, 2012), (Yalcindag *et al.*, 2014)) have addressed these problems separately in two-stage approaches which allow no interaction between the processes of handling these problems. In a two-stage approach, routing and scheduling decisions are made in the second stage based on the assignment decisions determined independently in the first stage. However, in homecare, substantial benefits in efficiency can be obtained from a unified approach. This requires pushing forward state-of-the-art research into practice. A few researchers have recently ventured in this direction but have worked on only three problems (assignment, routing, scheduling). For instance, pure mathematical models have been developed to jointly address the problems of assignment, routing and scheduling in forming daily plans (Trautsamwieser *et al.*, 2011) and weekly plans (Cappanera *et al.*, 2014), (Nguyen *et al.*, 2013). Also, a discrete-event driven metaheuristic has been developed to deal with dynamic routing and scheduling scenarios using combined trip sharing and walking (Fikar *et al*, 2016). Aside from exact methods, the many constraints and sheer size of real-life (or realistic) instances make heuristic approaches the most suitable for handling these problems sequentially and interactively. For instance, researchers have proposed a hybrid solution combining metaheuristic algorithm and constraint programming (Rendl *et al.*, 2012) and an optimisation algorithm based on matheuristic algorithms and robust optimisation (Nguyen *et al.*, 2015). For more details about studies on the problems of rostering, assignment, routing and scheduling, see the reviews in (Ernst *et al.*, 2004), (Burke *et al.*, 2004), (Yalcindag *et al.*, 2011). To the best of our knowledge, no study has proposed a unified approach to jointly handle these four problems (rostering, assignment, routing and scheduling).

Homecare service planning is by nature a multi-criteria problem due to the many stakeholders involved and activities to be planned and performed, so models must be sufficiently rich to be used in practice. Constructing such models is difficult, as indicated in (Eveborn *et al.*, 2006). The scientific literature on homecare planning focuses on short term (daily, real time) planning problems (Trautsamwieser *et al.*, 2011) due, in part, to their relevance but also to the large modelling and computational challenges of doing otherwise. A few papers have looked at longer horizons (e.g. (Nickel *et al.*, 2012), (Cappanera *et al.*, 2014), (Nguyen *et al.*, 2013), (Nilssen *et al.*, 2011)), but no such research has been applied in a real-life setting. Studying planning problems and their interactions at different time horizons and developing a new approach for a coordinated solution is a major research challenge.

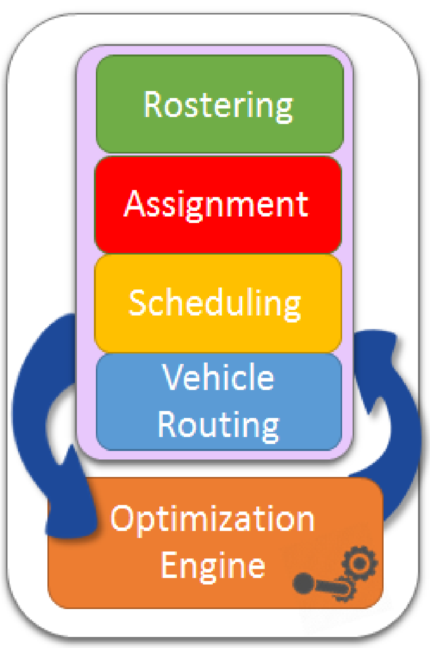
One more critical topic requires attention: planning under uncertainty. Homecare service planners must constantly deal with unpredictable deviations from plans: nurses calling in sick, changes in patient demand and disruptions to travel times. To our knowledge, only three works have taken uncertainty into account in homecare planning, and these have not been applied in practice (Nguyen *et al.*, 2015), (Lanzarone *et al.*, 2010), (Carello *et al.*, 2014).

Time to do things differently

So, the problem consists of rostering (assigning staff members to shifts), assignment (assigning staff members to patients), vehicle routing (determining the sequence of visits for each staff member) and activity scheduling (setting the timing for a large set of treatments and visits). The inherent combinatorial complexity and the many criteria and constraints (competence requirements, caregiver and patient preferences, labour laws, union regulations, temporal relations between activities) make the problem highly challenging and unlikely to be solved adequately with a manual approach. The time required to identify and evaluate each solution is high, so only the first (or few) feasible solution(s) are checked, and it is highly improbable that these solutions are close to optimal. In a study on the homecare crew scheduling problem in the context of the Danish homecare company Zealand Care, a branch-and-price algorithm significantly increased the quality of solutions obtained compared to manual solutions (Justesen *et al.*, 2008). Taking workers' perspective into account in the optimisation process has been found to be beneficial in unexpected ways. In a Swedish case study, sick leave dropped from 563 to 166 days a year after the introduction of an optimisation-based system for planning (human) resource utilization (Eveborn *et al.*, 2009). However, most homecare service providers still perform manual planning (Nickel *et al.*, 2012), sometimes with the aid of basic information-technology tools for visualisation and staff management. Only a few commercial tools use optimisation, and these still tackle each problem independently. The solution to one problem is input for the next, so this approach often results in suboptimal solutions to the overall problem. Although planning software has been available in the homecare market for nearly a decade, none has emerged as the de-facto tool for planning. This lack can be partly attributed to a change-adverse sector and poor marketing, but the main reason is that homecare planning simply is not a problem that software developers can solve. It is a complex combinatorial optimisation problem that requires the development of a rich mathematical model and efficient solution algorithms that identify nearly optimal solutions within a short response time. This is a demanding task, even for experts in optimisation. Indeed, effectively combining and solving these four sub-problems is a major research challenge. *We need research in optimisation to meet the challenges in homecare service planning*.

Major current shortcomings of current approaches

Lack of integration and insufficiently rich models. Rostering, assignment, routing and scheduling are tackled manually or with limited tools and treated independently. However, these problems are highly coupled, and the solution to one affects the others. Treating them as independent of each other is a suboptimal approach, which ignores many combinations from the solution space. For example, a rostering solution developed without considering relevant assignment constraints (competence requirements, patient preferences) might affect the assignment problem, and an assignment solution developed without considering relevant routing constraints might affect the routing problem, so the resulting solution is globally inefficient. Effectively integrating the problems can yield high-quality solutions that can improve homecare services in both quantifiable and non-quantifiable ways. Another issue to be addressed is insufficiently rich models. Many researches test optimisation algorithms in simplified problems, but rich models are needed to ensure that solutions are applicable in practice. Our investigation indicates that insufficiently descriptive models are a major source of dissatisfaction among users. There generally is a trade-off between efficiency and model richness, and the difficulty lies in determining this trade-off.



Different time horizons and uncertainty. Planning problems typically are categorised by their horizon: strategic (long term: yearly), tactical (mid-term: weekly or monthly) and operational (short term: daily or real time). At the strategic level, problems, such as shift design and manpower planning, require determining a suitable set of shifts that meet the work demand for the planning horizon and take into consideration employees' skill attributes and the time-dependent demands of each skill type. For labour-intensive organisations, finding a good match between the predicted workload and the scheduled workforce is crucial (Slettholm *et al.*, 2015). A prerequisite for good rosters is good shift design. However, most (recognised) challenges in homecare planning lie at the tactical and operational levels. Selecting services for clients, designing a schedule and assigning staff members to shifts, patients and routes are common *tactical* problems. They are generally solved on a weekly or monthly basis, and these plans are often reused. However, input to tactical plans often changes (e.g. staff absences, changes to the patient list), forcing planners to redo plans. These are *operational* planning problems that often occur on a daily basis or in *real time*. Although homecare planning involves strategic, tactical and operational planning, existing tools do not take these different levels into account. This lack is unsurprising as addressing these issues requires further research, and the scientific community so far has focused on operational problems, with a few exceptions that have also considered tactical planning (Cappanera *et al.*, 2014) (Nickel *et al.*, 2012), (Nguyen *et al.*, 2013), (Nilssen *et al.*, 2011). As well, very few studies have examined uncertainty (e.g. (Nguyen *et al.*, 2015), (Lanzarone *et al.*, 2010), (Carello *et al.*, 2014)) and how it affects the overall planning process, even though this is an undeniably relevant issue.

A new integrated approach to homecare service planning.

An effective approach to homecare service planning should include designing a model sufficiently rich to support all criteria identified as necessary for user adoption. Criteria might include, for example, *maximising* quality of care factors (e.g. correct competences, patient and operator preferences, continuity of care between patients and staff members) and *minimising* operating costs (e.g. travel time, unscheduled visits, overtime, not mentioned in (Cappanera *et al.*, 2014). This model should also take into account *multi-modal* transport for staff members (e.g. cars, public transport, bicycles) and staff skills (e.g. a set of high skills and a set of low skills representing activities for which staff members have full or partial training sufficient for emergency cases; for similar ideas, see (Nilssen *et al.*, 2011)). The model should fairly distribute workload among staff members, which has been shown to have a number of positive results, such as significant decreases in sick leave use (Eveborn *et al.*, 2009). Given the challenges these joint problems represent, we expect that different optimisation techniques might have to be deployed in an effective solution framework, such as decomposition, meta-heuristics, matheuristics, integer programming and constraint programming. The approach developed by Hooker (Hooker *et al.*, 2000), which has been applied to homecare (Cire *et al.*, 2012) and other challenging planning problems (e.g. (Lamorgese *et al.*, 2015)), deserves further investigation.

Planning on the tactical and operational levels is essential in homecare. Research on the relationships between these problems on different levels should include the appropriate recourse actions in optimisation. As advocated by Nordlander *et al.* (Nordlander *et al.*, 2013), strategic level investigations should target advanced approaches for presenting planners with optimised strategic plans, for instance, combining problems that traditionally have been solved independently, such as shift design and rostering. In homecare, many parameters are inherently uncertain, and treating them as purely deterministic can lead to low-quality or infeasible solutions. A first approach could be to produce tactical plans with buffers and to handle uncertain events through fast, effective re-planning. This approach has been proven to be highly effective in some cases (Lamorgese *et al.*, 2015), (Kjenstad *et al.*, 2013). When making necessary changes while re-planning, one must keep much of the original plan stable to avoid imposing too many changes on staff members (e.g. getting completely work patients and routes several times a day). Re-planning models should take into account the trade-off between efficiency and stability and allow planners to manually lock part of the solution if desired. Other approaches to handling uncertainty should also be further explored, such as robust optimisation (Bertsimas *et al.*, 2003), which has produced promising preliminary results in application to homecare service planning (Nguyen *et al.*, 2015). As well, it is important to investigate parameterless solution that can treat large real-life instances in reasonable computational time. Another significant capability of the new approach is to provide solutions in different situations (instant solutions might be needed within a very short computational time, or solutions might only be needed in weeks or months, allowing for longer computational time). Finally, the approach should be able to generate good alternative solutions, so managers can pick the most suitable one based on their experiences (e.g. (Nguyen *et al.*, 2015), (Toklu *et al.*, 2013)).

Conclusions

In countries with public healthcare, optimised homecare can deliver significant savings for municipalities, regions and hospitals. From the patient's perspective, higher-quality homecare services provide higher living standards. Improved service quality results in better treatments (assignment of staff members with the appropriate competences), higher continuity of care (less rotation of staff members for the same patient) and fulfilment of patient preferences. More efficient homecare services allow treating more patients at home, which patients indicate is their preferred place of care. However, homecare planning is still mostly performed manually. Researchers need to address the integrated optimisation problem to obtain efficient, global solutions. Existing research has focused on planning on the operational level, but attention also needs to be placed on the strategic and tactical levels. As well, very few studies have considered uncertainty and how it affects the overall planning process, even though this is a highly relevant issue.

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