Managing Community Healthcare Information in a Multi-Agent System Environment

Richard Hill, Simon Polovina and Martin D. Beer

Web & Multi-Agents Research Group
Faculty of Arts, Computing, Engineering & Sciences
Sheffield Hallam University
Sheffield, United Kingdom
r.hill, s.polovina, m.beer@shu.ac.uk

Abstract. Most older, frail or disabled older people prefer to receive care in their own homes, in preference to the care provided within hospitals or residential home environments. Whilst the aims of community care address humanitarian issues, it is a challenging and expensive task to manage the organisation, logistics, quality assurance and efficiency of these services. UK National Health Service managers also recognise that hospitals can achieve a higher throughput rate of surgical cases if routine, rehabilitative care is delegated to the local community, removing it from the hospital ward. In recent years, UK Local Authorities have created policies that off load the delivery of care to private sector care providers. The community care scenario is thus an immensely complex and politically charged healthcare market place, freely trading care services in a competitive environment. In particular, contractual agreements between community healthcare agencies create a complex economic market place that must be described in a robust way if agent-managed services are to be accepted commercially. We consider the 'Event Accounting' model in relation to the myriad of payment transactions within the community care environment, and propose a robust transaction-based framework for the management of community care Multi-Agent Systems, that attempts to address the gulf between abstract concept and low-level, multi-agent system implementation.

1 Introduction

Most older, frail or disabled older people prefer to receive care in their own homes [4], in preference to the care provided within hospitals or residential home environments. UK National Health Service managers also recognise that hospitals can achieve a higher throughput rate of surgical cases if routine, rehabilitative care is delegated to the local community, removing it from the hospital ward. Home-based community care requires a variety of healthcare services to be delivered within the recipient's own home, allowing them to continue to live independently, and maintaining the best possible quality of life. Healthcare services include help with domestic cleaning, 'meals-on-wheels', medical treatment and assistance with basic bodily functions. Whilst the aims of community care address humanitarian issues, it is a challenging and expensive task to manage the organisation, logistics, quality assurance and efficiency of these services [4].

The exponential rise in costs has, in recent years, led to UK Local Authorities creating policies that off load the delivery of care to private sector care providers. The community care scenario is thus an immensely complex and politically charged healthcare market place, freely trading care services in a competitive environment [3]. It is apparent that the community care environment is comprised of a number of autonomous agencies, such as local authorities, different care providers, medical staff and the care recipients themselves.

As each element of care is often delivered by independent agencies, the number of autonomous command and control systems quickly increases, leaving the overall managers of the care (the Local Authority) to protect the individual bodies from disclosing sensitive and irrelevant information. Although information technology is established in community care management, it is clear that in many instances the vast quantities of disparate heterogeneous information repositories can lead to the undermining of effective system operations.

It would seem that using collaborative intelligent agents, which overcome the difficulties of integrating disparate hardware and software platforms, queries can be mediated to the most appropriate information source, with the potential to build effective, co-ordinated healthcare management systems. As such the benefits of multi-agent systems, and examples of the types of improvements offered for community healthcare management, are documented by Zambonelli et al. [23] and Beer et al. [2].

Human agents regularly engage in economic transactions and Beer et al [3] demonstrated the transactions involved when processing emergency alarm conditions in a community care environment (INCA - INtelligent Community Alarm). These apparently innocuous transactions proved much more difficult to deploy than first envisaged, though there were distinct advantages in favour of the agent approach. Upon raising the alarm, the message from the Elderly Person required brokering to determine the correct type of service, as well as locating the nearest, most available source of help. The multi-agent approach also assisted the development of the prototype demonstrator, using the ZEUS Agent Building Toolkit [16], and it appeared relatively straightforward to 'map' actors to agents. The development of the INCA prototype[2] illustrated that several problems remain when developing community care MAS applications:

1. The process of gathering requirements can be problematic in the healthcare domain, and whilst use case models enable the various actor representations to be established, there is unfortunately no inherent model verification, so it is feasible that some details are missing from the first iteration [15].
2. Community care is full of complex qualitative issues that require challenging from a business process perspective, plus we must be able to build a MAS that can provide the reasoning qualities required to deliver an improved application.

3. Role modelling is an inherent part of the MAS modelling process [7], yet there is little guidance as to how roles should be allocated for best performance [6].
4. The generation of terms and rules for ontologies provides the foundation for MAS interoperability, yet we tend to rely on the process of eliciting use cases from existing processes to obtain the majority of the agent's behaviours.
5. Actor-to-agent mappings are convenient, though the assignment of agent behaviours is often arbitrary and based on current working practice. Additionally there is no implicit check as to the validity of a role, nor is there an audit trail of how the roles were delegated.

Our aim is to provide an extended means of capturing requirements for community care systems, by addressing the need to scrutinise qualitative concepts that exist in the MAS environment, prior to more detailed analysis and design with existing methodologies. We consider an established transaction model in relation to the multitude of payment transactions within the community care management environment, and explore the notion of transaction management as a design metaphor for the management of information within a community care MAS.

2 Event Accounting

Using the notion of economic scarcity as a conceptual basis, Polovina [20] argues that accounting transactions are a too narrow abstraction of economic reality, referring to the Event Accounting model [10] by Geerts and McCarthy. Transactions in fact are likely to represent an exchange of non-monetary as well as monetary resources. In the case of INCA the transactions involve payment in return for a package of care services. These transactions need not only represent monetary exchanges, as this notion could be applied to much more qualitative transactions as well. For instance the carers in a community healthcare environment may trade their personal time to study for new care skills, or a recognised qualification. In such instances the carer would consider the balance between reduced leisure time and time with their family, in pursuit of enhanced promotional prospects as a result of successful study. This illustrates the qualitative, rather than purely quantitative, exchange of resources, indicating that there are many more aspects of a complex domain such as community care that can be explored and scrutinised.

Indeed the community care scenario is rich with qualitative transactions. Such transactions conclude when the relevant parties have gained from the participation, and is represented as a 'balance' in that very debit is countered by a credit. The inclusion of a balance within the transaction model ensures an implicit validation that the transaction has occurred successfully. The agent transactions evident in community healthcare systems are an example that our desire for robust multi-agent systems, must be underpinned by a solid transaction foundation.

3 Capturing Transactions

3.1 Agent-oriented Unified Modelling Language

The Unified Modelling Language (UML) presents a form of notation for object-oriented analysis and design; it provides system architects working on object analysis and design with one consistent language for specifying, visualising, constructing and documenting the artefacts of software systems, as well as for business modelling [17]. All of the models can be constructed, viewed, developed and evaluated during systems analysis and design. Bauer et al., [1] describe Agent-oriented UML (AUML) as a notation for the description of agents and their environment, which is based on the meta-model that is the Unified Modelling Language, and presents a consistent representation for specifying, visualising, constructing and documenting the artefacts of MAS software systems. FIPA-ACL [9] uses AUML to express its definitions as a set of protocol diagrams, assisting the comprehension of agent system behaviours and characteristics. Agent modelling requires a greater richness of description, especially since the complex interactions often need to be represented graphically.

The INCA prototype design process created a requirement to formally represent various aspects of the agent-managed community healthcare system. AUML facilitated a large proportion of this work, enabling agent models, and the resultant pseudo-code, to be generated in readiness for deployment with the Zeus Agent-Building Toolkit [14]. Whilst it was possible to produce models of the agents that embodied the required behaviours, and consider the nuances of the community care domain concurrently, it became apparent that some real-world issues were much more difficult to capture. As described earlier, the representation of relatively simple payment transactions proved elusive, as AUML lacked the ability to capture high-level qualitative scenarios [13].

3.2 Designing Community Care Systems

A specification for INCA was determined by consulting the ZEUS role-modelling guide [16], and using this approach to derive the roles of agents, services offered and task descriptions to be described using AUML. These models were then used as an input specification for implementation activities with the ZEUS Agent-Building Toolkit. The abstract input specification was described by a collection of use case, class, interaction and deployment diagrams, which provided a consistent representation of the community healthcare complexities across a number of disparate domains [14]. Whilst this process was remarkably simple in some areas, as the agent architecture mapped directly onto significant portions of the problem domain, a number of areas were identified that proved more problematic. The tasks of selecting the most appropriate care service and brokering service requests were particularly difficult without compromising the accuracy of the model [13]. It is fundamentally important that agent representations are not unduly compromised if they are to gain acceptance as a resilient and life-like solution to complex management problems, and it was deemed appropriate to investigate the aspects of the community care scenario that did not translate as effectively to an agent architecture. The payment transactions required for community healthcare do not immediately appear complicated as they are conducted (albeit often quite inefficiently) by human agents, who are familiar with the concept that the agency who requests a service does not always pay for that service, or pays a proportion of the total amount, depending on a variety of circumstances [2].

Whilst the INCA Demonstrator addressed the issue of complex care requests and receipts, plus the intricacies of message routing and brokering, the payment transactions did not sufficiently mimic the real-world scenario. If this aspect could be investigated, then it would be possible to establish the requirements of agent-managed transaction systems, whilst also evaluating the suitability of agent architectures in the community care domain. It is also noted that in effect, community healthcare management systems are similar to commercial enterprise systems that manage the delivery of services by controlling and recording transactions.

Using the Event Accounting approach [10], we have developed INCA to incorporate a robust transaction design framework that addresses the issues of community care payment complexity and agent-managed transactions. In particular, Local Authority agents who tender the services of healthcare provider agents, are an example agent trading scenario that has a fundamental requirement for a model that is robust and life-like. Initially AUML representations of auction protocols [14] were included within INCA, but the combination of quantitative and qualitative aspects of transaction management, together with the 'gap' between abstract life-like representations and low-level deployment practicalities directed us towards an alternative method of representation, to assist the improved capture of qualitative requirements.

3.3 Modelling Notation

The representation of community care transactions in INCA initially proved elusive with AUML. In particular it was evident that consideration of the qualitative aspects of community care also gave insight into concepts which had not been clear at the outset, thus providing more complexity and a greater need to more accurately map the problem domain. Lucid representations of qualitative and quantitative transactions have been demonstrated using Conceptual Graphs (CG) [21], not only to accurately record complex transactions, but also to provide a means of eliciting domain facets which are difficult to determine with other, more recognised notations. An aspect of the CG approach that is particularly relevant to agent managed community care systems is that the production of CG, and the resulting predicate logic, can be easily transferred across domains using Conceptual Graph Interchange Format (CGIF). and Knowledge Interchange Format (KIF) [11]. This assists the rapid generation of domain ontologies, whilst also considering qualitative issues from the initial modelling activities. This capture of the qualitative transactions allows much broader issues to be modelled, and through an iterative process, representations can 'drill-down' to reveal new aspects. Community care management is an example of a system that has to manage an enormous range of services, and this management inevitably will include the resolution of unsatisfactory service, as well as the provision of satisfactory service, suggesting that CG would assist the modelling of INCA payment transactions.

Multi-agent interoperability between disparate agencies necessitates a neutral interchange format, and this has been explored by Harper with the use of CG [11]. It follows that CG models appear suited to accommodate a range of representation vehicles, such as AUML and Entity Relationship (ER) diagrams, enabling the generation of an accurate high level conceptual model. Community care management has a fundamental requirement that the management system must be sufficiently capable of accommodating disparate software and hardware platforms, in order to be able to effectively command and control the requisite care services. Therefore we feel that the use of CG, as a precursor to modelling with other notations, is an important first step in the elicitation, specification and implementation of qualitative and quantitative agent managed transactions

4 Community Care Transactions

Throughout the process of developing the INCA Demonstrator we have encountered an increasing number of qualitative issues, that support the need for a framework that considers the wider issues of community care provision. The complexity of the payment transactions within INCA has required a representation medium that is richer than AUML, to permit the determination of a solid transaction model for agent-managed community care payments. A combination of the requirement for a transaction model, and a deployment domain that is inherently complex, as led to the development of a payment model for INCA that embodies the notion of robustness, whilst also representing the real-world scenario more faithfully, negating the need to compromise the implementation unduly. Figure 1 illustrates how we have used CG to represent the INCA payment transaction model, using the Event Accounting model as a basis [10]. This transaction model thus allows iterations of various community care scenarios to be projected.

All transactions comprise two Economic Events, denoted by *a and *b that determine the exchange of two corresponding Economic Resources *c and *d. The transaction is complete when both Economic Events balance, showing that *a counters *b, representing the corresponding debits and credits. The two related Economic Resources *c and *d, each having independent source and destination agents, are thus exchanged. After the initial requirements have been captured and modelled, further analysis is conducted using AUML to generate the required programming specifications. Thus agent system specifications that incorporate an established, robust transaction model can be developed.

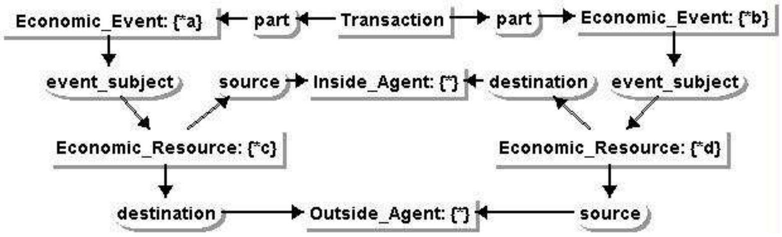

Fig. 1. Economic Event Transaction Model (TM).

5 Building the Community Care Payment Model

Figure 2 illustrates the INCA payment scenario using CG notation. In this particular scenario the Elderly Person (requester), receives a package of care services from a Care Provider agent. This activity is managed by the Local Authority agent (UK), who coordinates and controls the delivery of the care package. This

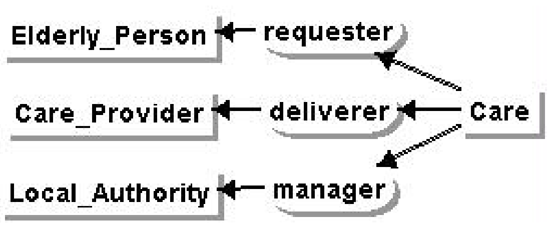

Fig. 2. INCA payment scenario.

transaction is relatively straightforward if the requester (Elderly Person) pays the Care Provider agent for the care package in full. However, the nature of community care is such that it is managed by a Local Authority agent, who also manages the expenditure of welfare payments for individuals who do not have sufficient funds to pay for the care themselves. Scrutiny of the community care scenario reveals at least two other variants:

- The Local Authority meets all of the care costs;
- Part of the cost of the care is paid by Elderly Person, and the Local Authority contributes the balance.

If the Local Authority is responsible for all of the care costs then only one party settles the bill. However this is a situation which is complicated by the fact that the party who pays the bill is not the party who receives the care. Furthermore this complexity is compounded when part payment scenarios are introduced; an assessment of the requester's financial assets by the Local Authority results in varying amounts of contribution from the requester depending on their own personal funds available.

In all of these cases the care provision is managed by the Local Authority, and controls and coordinates payments and invoicing to and from care requesters and between care provider agencies. However the care package may be delivered by a combination of public and private sector bodies, necessitating familiarity and interoperability between many disparate systems. The variety of payment scenarios and the number of individual care packages results in an immensely complex management scenario that often results in high cost and poor service delivery, and there is much more detail to be considered when designing an agent-managed community care system. However we feel that the INCA approach is successfully illustrated using three general scenarios.

Care packages are administered with reference to the requester's needs, which are recorded during an assessment exercise conducted at the beginning of the process. The nature of a needs-led approach dictates that each care package is tailored, and there is considerable scope for variation. Each assessment captures the needs of the care requester and translates those needs into a comprehensive specification of care requirements, known as the Individual Care Plan (ICP). The contents of this plan are crucial to the delivery of the most appropriate care services to the care requester, though by nature of the assessment procedure, this artefact is a snap-shot of the individual's care requirements. ICP are typically paper-based forms which are administered by a representative from the Social Services Department of the Local Authority, who is responsible for the assessment of the requester in the environment in which they are to receive the care. The Social Services Department also maintains the ICP by conducting repeated assessments in an attempt to monitor the condition of the care requester. Thus exceptions to normal conditions are captured by appropriate modifications to the ICP, to maintain the care requester's quality of life.

It is evident that the condition of many elderly people deteriorates far quicker than the Social Services' assessment procedure can cope with [2], thereby relegating the importance of the ICP as care requirements change. The inflexibility of the ICP not only has a negative impact on the requester in terms of their quality of life, but also the Local Authority who becomes more reactive in terms of care provision, often swamping exceptional situations in a wasteful manner. The cooperative abilities of agents offer the potential of a dynamic ICP that is continually updated with a current picture of the requester's care requirements. Such timely information also offers the potential of managing the care provision in such a way that preventive measures could be planned and coordinated in advance.

However management of the assessment and subsequent monitoring process does assume that the care packages are delivered in a timely and responsive fashion, again suggesting an agent-oriented solution. The practicalities of administering part-franchised care delivery means that there needs to be an infrastructure in place that can rapidly and effectively process ordering and invoicing transactions; the introduction of private sector organisations also creates a need for a robust tendering process to ensure the most cost-effective price is achieved. Without such assurances, agent-managed care systems will not be accepted in commercial environments. The figures so far represent the INCA payment scenario in a manner similar to how they might be described verbally. This particular aspect proved helpful when conducting the initial modelling and provides further evidence of the suitability of the CG notation for requirements gathering. Having documented the overall transactions, more detail was exposed by applying the transaction model to the INCA models.

A multi-agent solution for community care delivery must be able to accommodate heterogeneous domains, and therefore it is necessary to select a suitable transaction model to apply. As discussed in Section 2, opposing economic events can be balanced in the same way debits and credits would be dealt with in double-entry bookkeeping. As in the real-world, each event contributes to the transaction, requiring an Economic Resource, with sources and destinations used to associate the Inside and Outside Agents. This has similarities with role modelling in AUML, as depending upon the view of the system selected, the Inside Agent may change.

The INCA payment transaction is thus transformed by applying the Event Accounting transaction model, and the results are illustrated in Figures 3 and 4, illustrating the lucidity of the CG representation. This generation of greater detail has not been at the expense of the previous models however; these are still valid and serve as both a proof that the opposing economic events balance and as an audit trail of the train of thought leading to the solution derived. Of course the inclusion of a method 'check' plus a paper-trail of ideas is an important part of any framework, assisting the multi-agent system designer ensure that a robust transaction model is incorporated within the design specification of an agent-managed community care system, whilst also providing for model verification at later stages.

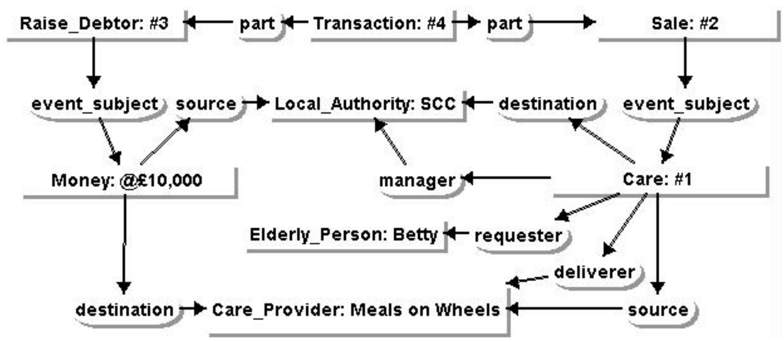

Fig. 3. INCA payment scenario after Transaction Model applied; assets 'low'.

After considering generic transaction models, we can now consider a specific instance of a community care scenario encountered by INCA. An Elderly Person,

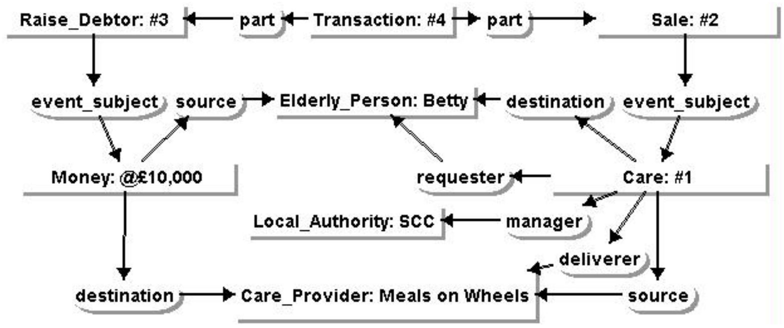

Fig. 4. INCA payment scenario after Transaction Model applied; assets not 'low'.

'Betty' has been assessed by Social Services, who have identified a need for cooked meals to be provided to Betty's home three times daily. This service is commonly referred to as 'meals on wheels'. The Local Authority, SCC (Sheffield City Council), manages the delivery of this care (Care:#1), which incurs a cost of £10,000. If we consider the overall transaction model for this particular scenario, we can define a basic ontology for both sides of the transaction, as in Figure 5.

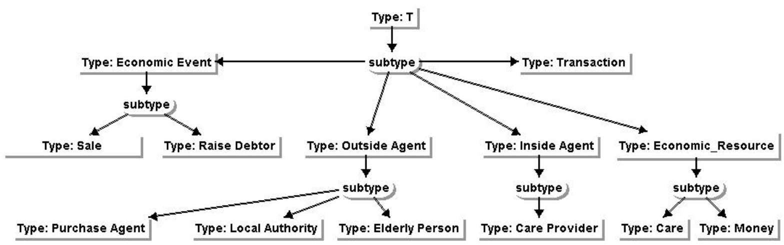

Fig. 5. Ontology creation.

During an initial attempt at modelling INCA using AUML, it was difficult to specify the agents (beyond mapping actors from use case models) as a domain ontology was required [13]. We proceeded by specifying a rudimentary system, which was iterated with further revisions as domain knowledge was captured and enriched [12]. The Event Accounting approach has enabled the early elicitation of domain knowledge, and subsequent ontology specification, whilst incorporating a robust transaction model from the beginning. This has allowed representations of agent-managed transactions to be assembled at a much faster rate, especially since we have greater confidence that the underlying design is based upon a rigorous framework. This approach does not compromise further development with AUML, rather it ensures that the qualitative issues have been captured and considered prior to detailed system specification.

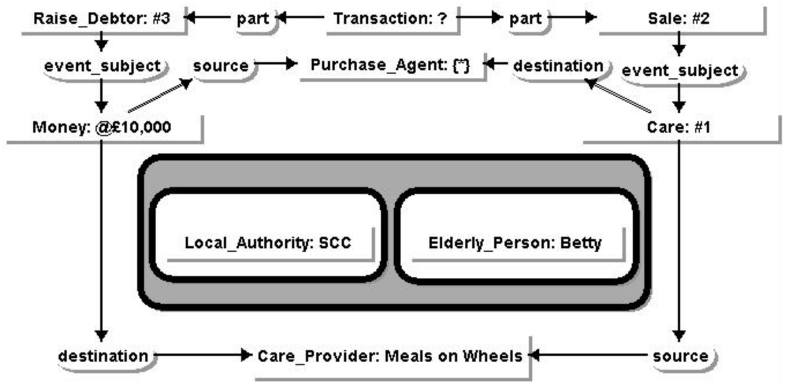

Fig. 6. INCA 'meals-on-wheels' care provision transaction.

The INCA meals on wheels example in Figure 6 illustrates which aspects of the ontology have been defined, as well as aspects which have not been determined such as the Economic Events, Debt and Sale, hence the '?' designation. Therefore the transaction model must be complete before further modelling can take place. Ignoring the scenario whereby Betty can settle the invoice for her care in full, we can consider the opposing situation in which the Local Authority, SCC pays for the care package. Figure 7 illustrates Betty's financial status as being eligible for a full care package at zero cost as she is classified as having 'low assets'. This exercise was then repeated for the other full and part-payment

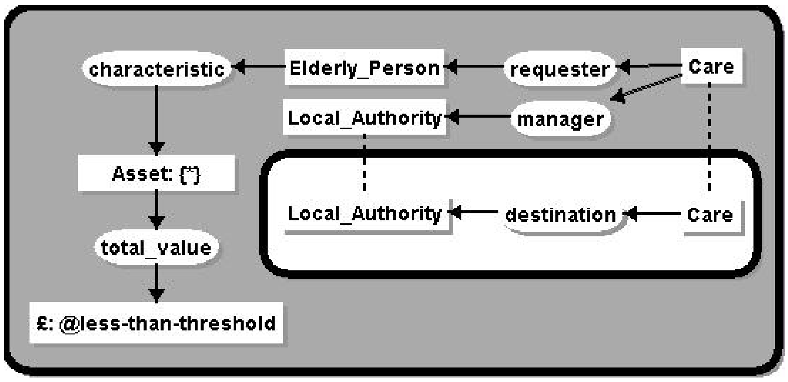

Fig. 7. INCA payment scenario: Elderly person 'Betty' with 'low assets'

scenarios discussed earlier. It has therefore become apparent that the CGs have revealed and documented the transaction whereby the party receiving the care does not pay for it, which has proved problematic to express as a multi-agent design specification previously. The expression of agency and agent relations is implicit with this framework, thereby facilitating rapid deduction of complex transactions. Figure 8 also illustrates how the scenario has been extended further to model much wider qualitative issues such as the relationship between the Purchase_Agent and Society.

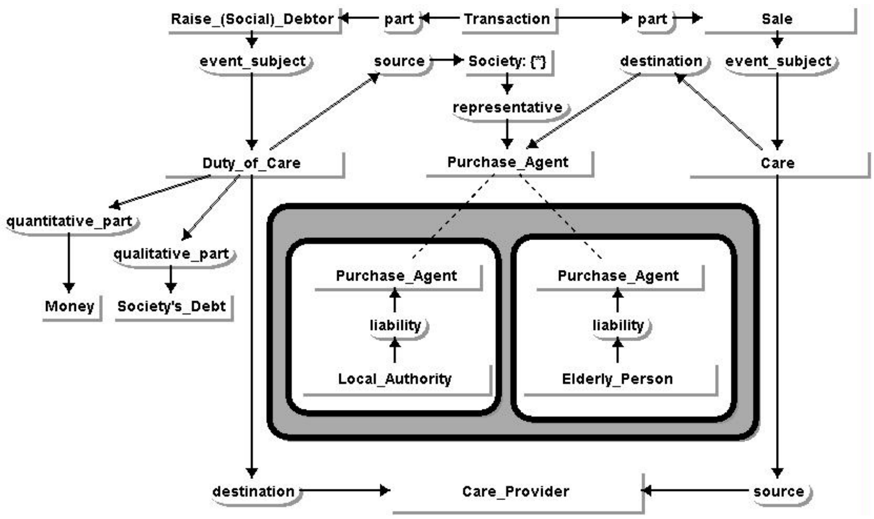

Fig. 8. Extended 'meals-on-wheels' in community care scenario.

6 Conclusions

Using the design, specification and implementation of an agent-managed community care system we have illustrated the development of a complex multi-agent system that embodies the notion of robust transaction management. AUML has illustrated how the enhanced richness of this notation can assist the expression and description of agent behaviours, interactions and architectures, especially when a multi-agent system designer needs to produce software specifications. We also recognise the limitations of AUML, particularly at the requirements gathering stage, where it is necessary to capture complicated, qualitative transactions that may not readily appear initially. Community care management exposes a vast number of qualitative issues in the widest sense, and it is apparent that AUML has limitations when attempting to elicit these conceptual issues. Our experiences with CG illustrate that this notation appears to offer the multi-agent system designer a considerable advantage when it comes to assembling a specification of requirements that captures the essence of real-world representations, particularly when used in conjunction with AUML. It is also apparent that CG models lack the detail necessary to specify agent program code, unlike the comprehensive representations that can be expressed with AUML. The key features of this approach are as follows:

1. CGs represent the problem in a more abstract way, and provide a foundation for modelling the knowledge exchange within a system. The abstraction is such that high-level, qualitative issues such as 'quality of health care received' are addressed, so it is feasible that the system is questioned from the point of view of concepts, rather than relying on an individual's prior experience.
2. Conceptual modelling allows the agent models to be considered at a much higher level, prior to further work with AUML. Whilst there are some similarities between CGs and AUML, in that there are some obvious mappings from concepts to agents, there appears to be more consistent elicitation of qualitative issues with the CG approach..
3. Using the transaction model represented as CGs, inferencing can take place at a much earlier stage in the MAS design process. Additionally the notion of 'balance' can be employed to assess qualitative issues prior to representation with AUML [18].
4. The transaction model assists the generation of terms and rules for ontologies much earlier in the design process.
5. Early model verification is implicit as any missing nodes (concepts or relations) render the model out of balance and thus unable to satisfy both sides of the transaction.

We believe that the combination of CG, AUML and an established transaction model is a first step towards providing a unified framework for community care information management in a MAS. We have demonstrated the lucidity of the CG approach, particularly with regard to the capture of concepts and the 'softer' aspects of a system. Subsequently, it is possible to derive the multi-agent interactions and behaviours required using AUML, assisting the specification of multi-agent systems that incorporate robust transaction management and real-world traits. It is of vital importance that such models are realistic if the potential benefits of multi-agent systems architectures are to be realised. Whilst multi-agent systems can appear an attractive solution to many complex domain problems, we have hitherto been hindered by a tool set that makes the description of realistic architectures difficult.

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