A Virtual Marketplace for Goods and Services for People with Social Needs

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***Abstract*—The needs of vulnerable populations have been addressed, traditionally, by an ecosystem of private and public agencies that rely on donations (goods, money and services) which they re-distribute based on their perception of what is needed and where. This approach lacks a comprehensive understanding of the demand side as well as the ability to coordinate between various suppliers of goods and services, predict future demand and identify latent supply. We present a knowledge-based platform that utilizes advances in several Artificial Intelligence fields for a more efficient and effective way of provisioning goods and services to people in need.**

I. INTRODUCTION

The ecosystem of social welfare agencies that tend to the needs of vulnerable populations is under pressure to meet the demand for goods and services for the impoverished [1], and the rapidly growing demand of migrants in their re-settlement countries. There is, however, a great societal reservoir of goodwill and resources that can help alleviate the strain on the established welfare system, given a fast and cost-effective way to tap into it.

Consider the case of a family of refugees recently re-settled in Toronto and are soon to have a baby. What do they need? Some items are obvious, e.g., a crib, some are not as they relate to local laws, e.g., an infant requires a car seat to be transported. The family has a problem but doesn't know what all their needs are, both goods and services. We call this "latent demand". Focusing solely on their needs for a crib, they are eligible to use furniture banks in the city, but this is of no help as furniture banks do not store cribs as a matter of policy. Meanwhile, there exist many grandparents in Toronto who bought cribs for their grandchildren to use when visiting their home. Their grandchildren are now older and no longer use it, and the crib sits in their basement unused. We call this "latent supply". Imagine we could indentify this latent supply and match it to the latent demand. Transportation then becomes an issue: the donor cannot deliver the crib, commercial delivery is cost prohibitive and public transport is not an option. In yet another part of the city, a contractor who works on a flexible schedule and owns a large pick-up truck would gladly help transport donated items while en route from one work site to another, but does not know to whom to offer his services. Imagine we could match latent demand and supply with volunteer transportation.

In this paper we describe the Social Needs Marketplace (SNM) Portal, a knowledge-based platform that aims to provide an efficient way to identify latent demand and supply of goods and services and efficiently allocates them. The SNM Portal enables the demand side to make known their needs and the supply side to make known what they can provide in a richly structured representation that further allows for the discovery of latent needs and potential supply.

The Portal employs methods from multiple disciplines such as artificial intelligence, operations research and human-computer interaction (e.g., ontologies, machine learning, constraint programming, human factors principles) to collect requests and offers, suggest matches between them, and address the logistical problems related to transporting goods from donors to the people in need and scheduling services within the time windows that people are available, using a Uber/TaskRabbit-like volunteer network.

The main research questions addressed in this work are: (1) representing the knowledge related to the users of the system, and the goods and services requested and offered (Section 3), matching the donated goods and services to the demand, and allocating them fairly and efficiently (Section 4), and scheduling the pick-up and delivery of the donated goods from donors to recipients (Section 5). We present additional research challenges in section 6 and discuss our conclusions in section 7.

II. OVERVIEW OF THE SNM PORTAL

The overall architecture of version 1 of the Portal is presented in figure 1. The Portal's users place requests and make offers for goods and services donations via a web based interface. All offers and requests are processed by the Portal's Core, whose architecture is based on the Blackboard paradigm [2], [3]. As depicted in figure 1, a blackboard architecture is comprised of a shared data structure called a Blackboard, a Controller and a series of Knowledge Sources (KS). The blackboard acts as a central point of coordination of tasks (goals) to be performed by the knowledge sources, serving a number of purposes, including: (1) a means of managing SNM problem solving by representing all goals, sub-goals, goal assignments, goal status, and goal priorities, (2) a means to notify a KS that there is a goal to be satisfied, (3) a means for a KS to notify the status of their achieving goals.

The Controller is responsible for posting problems to be solved to the Blackboard, e.g., requests from users, and encapsulates control mechanisms such as prioritization of goals

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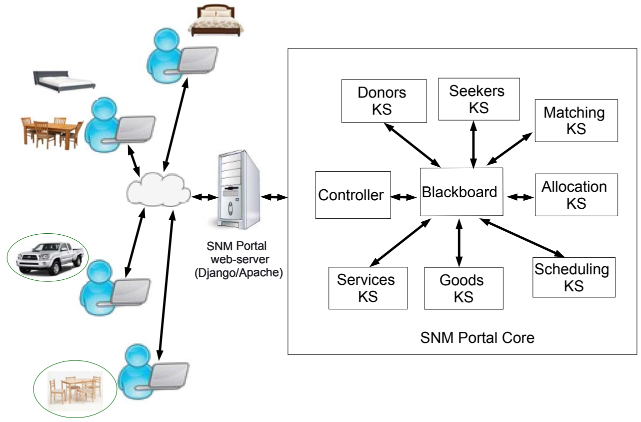

Fig. 1. The SNM Portal - Architecture Overview

and conditions for terminating the system. The knowledge sources monitor the blackboard, respond to requests placed there by the web interface, and place responses back onto the blackboard. A Knowledge Source (KS) is a process that operates asynchronously. The current KSs are implemented in Python and C++. A KS can perform one or more tasks (e.g., matching requests for goods, allocation of goods, scheduling of pick-up and deliveries) and has its own data or knowledge base. A KS shares information with other KSs only through the blackboard. When a KS is activated, it receives all information on the Blackboard about the goal(s) it needs to solve. The KS then performs its computation using whatever information is available within its own knowledge base and posts results of its computation on the Blackboard as an update to its activating goal, and, possibly, additional new goals and elaborations of goals. The Core's architecture is rounded off by helper modules, which have functions that help maintain the blackboard and support the functioning of the knowledge sources.

User Interface. The design of the Portal's web-based interface reflects several assumptions made about the users of the portal: (1) *context of need*, e.g., urgent vs non-urgent, (2)*information-retrieval behavior*, e.g., preference for simple account features and interactions, (3) *literacy/proficiency in English*, e.g., heterogeneous, a large proportion of users have a limited command of English, (4)*digital literacy*, e.g., mostly limited literacy.

In order to accommodate users with reduced language skills, such as recent immigrants or refugees, we opted for simple vocabulary and phrasing throughout. The assumed level of digital literacy informs the amount of information to be displayed at any given point, and we implemented a conversational style interaction that asks for, or provides data in comparatively small chunks, in order to give users the ability to manage the information requested or given.

Donors can register to provide service, donate goods, or both, and seekers can place requests for goods or services. After users navigates through the menu and select the type of service of interest, they are asked to provide information that will allow the portal to search for an appropriate match. Services identified as high demand, e.g., Goods, Food, Transportation, Housing, have their individual pictorial tabs on the interface, while services that are less frequently requested, e.g., Legal, Home Services, are grouped together and shown on a different page. For each individual type of request a user will need to fill in a series of related questions that will allow the portal to present them with a list of goods or services that best meet their criteria.

The data elicited from the users is stored in a rich semantic representation, which allows the Portal to use ontology-based reasoning.

Seekers are offered the opportunity to express their preferences for the goods or services that are matched to their requests by ranking them, information which is then made available to the allocation and scheduling knowledge bases.

Both seekers and donors of goods and services are permitted to specify strict windows of availability, which are taken into account when scheduling pick-ups, deliveries and appointments for various services. At the end of each day, the Portal's Allocation KS produces an allocation of goods and sends emails to the seekers asking them to confirm that they accept the goods allocated to them, and to donors to confirm that the goods are still available. The Scheduling KS then produces a daily schedule that allocates the volunteer drivers available on that day for transporting the confirmed goods from donors to seekers.

Usage Scenario. Said, his wife Sara and their two young children, aged 6 months and 24 months, have recently relocated to Toronto after spending a year in a Turkish refugee camp. Said used to be a financial analyst in Syria, and Sara used to be a Biology teacher. Said's proficiency in English is intermediate, while Sara's is very basic.

The five Ontario families who sponsored them rented a small unfurnished apartment on their behalf, but could only partially furnish it. Within a few days of arriving in Toronto, Said logs into the SNM Portal and places a request for a dinner table for four, a sofa-bed and a crib. Upon receiving Said's request, the Portal inquires if the family would also need a stroller, a baby changing table and car seats. Said answers yes and indicates that the family needs help with transporting any donated goods and would be available to receive the requested items in the evenings, between 6pm and 9pm, on week days and at any time during the day, 8am to 9pm, on weekends, for the next month.

The Portal's Matching KS produces a list of available items, from local donors and furniture banks, that fit Said's requests and he is asked to rank them.

After the completion of the request, the Portal presents Said with a short questionnaire concerning proficiency in English. Upon learning that one family member's knowledge of English is basic, the Portal asks if the services of a language tutor would be wanted. Said answers yes to this question and also indicates that a female tutor with knowledge of Arabic will be preferred. The Matching KS produces a list of available female English tutors who also speak Arabic and Said is asked to make a selection.

The Portal matches Said's request for a crib with an existing offer and schedules one of the volunteers registered with the Portal to pick up and deliver the crib on a Saturday morning. It also puts Said's wife in contact with another registered volunteer for English language tutoring.

III. Representing Demand and Supply: Ontologies for the Social Needs Marketplace

The match of supply and need of physical objects requires a detailed description of used goods from multiple aspects, for the use of classification as well as transportation. Such a representation faces several daunting challenges. First, the terminology that people use for these descriptions is rife with ambiguity. Second, it is often unclear whether or not the terminology used is adequate to provide complete descriptions of a given range of goods and services. A third challenge is that many of the terms that people use to describe goods and services are ad hoc and arbitrary.

We base our representation of knowledge of users, goods, services, logistics, and preferences on ontologies. Ontologies are computer-interpretable specifications of the meanings of the terminology used by software applications.

They play a key role in advanced applications in artificial intelligence, such as search, decision support systems, and the semantic integration of software systems. Several ontologies for products and services have been developed. Foremost among these is the GoodRelations Ontology [4] and the Schema.org, [5] effort. One drawback of these ontologies is that they are primarily taxonomies, and consequently do not fully address the challenges of ambiguity, incompleteness, and arbitrariness.

The first objective focuses on the design and evaluation of ontologies for goods and services that are correct and complete with respect to the semantic requirements that arise from the motivating scenarios for the Supply/Demand Module. This involves specifying taxonomies of classes of goods and services, logical definitions for properties of goods and services, the relationships among goods and services, and the identification of other related concepts, such as offers.

We are using the methodology for the design and verification of first-order logic ontologies originated in [6] [7], and [8], which outlines the lifecycle leading to the development of a correct ontology.

Automated reasoning plays a critical role in the specification of requirements, design, and verification of the ontology. Competency questions are queries that impose demands on the expressiveness of the underlying ontology. Intuitively, the ontology must be able to represent these questions and characterize the answers using the terminology. The relationship between competency questions and the requirements is that the associated query must be provable from the axioms of the ontology alone. Since a sentence is provable if and only if it is satisfied by all interpretations, competency questions implicitly specify the intended semantics of the ontology.

Evaluation is at the heart of the ontology design methodology, allowing a rigorous way to measure success and progress. The specification of competency questions is a formal approach to capturing the requirements for the goods and services ontologies.

To name a few motivating situations, the system needs to know the level of mobility in the case of matching appropriate chairs for disabled individuals; in order to obtain eligibility for transportation, the matching algorithm needs to be told if a furniture is able to be assembled and reassembled or not; both the demand side need to have the complete knowledge of damage and condition of a good to make the decision of acceptance, for example a dining furniture set with a missing chair and a table with a chipped surface.

We have identified five ontologies to be developed in order to realize the full functionality of the SNM project: parthood, material, product condition, shape and mobility.

From the parthood ontology perspective, when describing a mereological relationship, the use of the words part and whole hides the intended semantics of the relations. Existing studies in mereology usually either present part of as a general top level mereology relation and all other mereological relations are sub-relations under it, or having a part of relation to summarize all parthood relations. Such as Winston et al. [9] presented a taxonomy of part-whole relations with including different part-whole relations as specializations of a single, general part-of relation satisfying the basic axioms of mereology. We present an alternative approach, in which all relations that are associated with mereology are formalized in different modules of the ontology.

Firstly, we introduce tests to validate whether a relation is mereological and evaluate relations from previous work. Secondly, we propose a new relationship among the mereological relations that is different from an abstract conceptual hierarchy relationship. Thirdly, using a bottom-up technique, we identify four mereological relations based on use cases developed for the Social Need Marketplace. These relations are capable of representing the physical structure of used household goods, including the description of damage and relationship between multiple goods. We provides a standard ontology of mereology that is more simple, comprehensive and semantically rich.

The parthood module ontology is capable of describing the different containment and connection relations, as well as incorporate the representation of damaged products which has not been explored before in the field, for example describing paint scratch and tearing of silk material. In the situation of accommodating possible industrial use, the ontology could be applied through a domain extension steered into incorporating concepts required for enabling the automatic eligibility identification for special assembly, delivery and transportation handling activities according to the parthood characteristics of the product, for example a product can be processed in the disassembling activity only if it is a whole object or a member in a collection but not a dense thing and has externally connected components.

There are many different relationships that can be close to parthood, portion, component part, component, constituent, piece, region, share and percentage can be perceived as part. However, in our approach these are treated as multiple distinct mereological relations, each of which is axiomatized in its own module of the ontology rather than being sub-relations of part. Our claim is that there is no super-relation of the mereology relations, but each mereology relation is comprehensive by its own.

In the shape and mobility ontologies, we need ontologies that go beyond textual description or taxonomy of terms for shapes to support reasoning. A shape ontology to represent the complicated shapes with logical relations with the least number of primitive or predefined concepts is in need. We also need a formal mobility ontology to represent the mobility of products or physical objects for the use of intelligently identifying the functionality and installation requirements of a product. Examples include deciding the space needed for the sway of a swing, the eligibility to support disable personals with the rotation and lifting of an office chair or wheelchairs, and the handling requirement causing from internal part movement of adornments.

Other modules supplementing the product ontology include the study of material, the indication of product condition and representing an "ideal product" to determine the completeness of an object.

IV. Matching and Allocating Goods and Services

A request placed by a seeker of goods or services is processed by the Matching KS, which identifies using the rich semantic representation of offers and demands, a list of matches. The identification of potential matches involves a combination of database look-ups and ontology-based reasoning, provided by Z3 [10] an open source SMTsolver.

Requests placed by clients can have several matches, each with various associated preference rankings, and similarly, offers registered with the Portal can be matched to several requests. In order to establish a feasible distribution of goods and services, the Allocation knowledge source employs several existing techniques.

The goods allocation problem in our framework has been described in the literature as the house allocation, or the assignment problem [11], for which several algorithms exist. The default mode of the Allocation KS uses the Serial Dictatorship Method [12], which requires that the preferences expressed by users be strict. If a user declares that he or she is indifferent between two or more of the goods presented as potential matches, the allocation of goods to clients is computed using a variant of the Top Trading Cycles algorithm [13].

Currently, the system does not take into account information related to past requests made by clients, i.e., each allocation is performed in isolation. We are currently exploring extending the framework to deal with repeated allocation problems and include information about past requests, e.g., if a client has made several requests that have not been satisfied, or the goods he or she was allocated have not been among his or her top choices. In essence, we have a repeated fair division combined with a routing problem, whose solving requires the introduction of a social welfare function that captures social fairness without compromising computational efficiency.

V. Pick-up and Delivery Scheduling

Given a set of allocations, the Transportation Scheduler KS seeks to assign and route vehicles and drivers from an existing volunteer pool to deliver the goods during the times at which the driver and the source and destination clients are available. As we assume we have volunteer drivers, it is likely that not all the goods can be delivered in one day and that each driver is only willing to perform one or two deliveries per day while incurring a small additional distance on a trip that they were already planning. For example, a volunteer driver may be willing to perform a pickup-and-delivery on his/her way to work.

Problem Definition Let $G = (\mathcal{V}, \mathcal{A})$ be a complete directed graph with vertex set $\mathcal{V} = \mathcal{D} \cup \mathcal{C}$ where $\mathcal{D}$ represents the start and end locations of each driver and $\mathcal{C}$ represents the source and destination client vertices. Each arc $(i, j) \in \mathcal{A}$ has a non-negative routing time $T_{i,j}$ satisfying the triangular inequality.

Let $\mathcal{R} = \{1, ..., N\}$ represent the set of pickup-and-delivery requests. Each request i is paired with a positive weight, W_i reflecting its importance. A request $i \in \mathcal{R}$ has associated pickup and delivery vertices $i^+, i^- \in \mathcal{C}$ and a positive load size, Q_i. In addition, each request i is associated with two time windows, $[E_i^+, L_i^+]$ and $[E_i^-, L_i^-]$ and two service times, S_i^+ and S_i^-, representing the time windows and durations of the pickup and delivery activities, respectively.

Let $\mathcal{K} = \{1, ..., M\}$ represent the set of vehicles. Each vehicle $k \in \mathcal{K}$ is associated with a start and end vertices $k^+, k^- \in \mathcal{D}$ which may represent the same geographical location, a capacity P_k, and an availability time window $[E_k, L_k]$ representing the time within which the driver must travel from start to end, including any additional time for deliveries.

A $route$ for vehicle k is a sequence of vertices, $[k^+, ..., k^-]$. A request is $served$ when it is part of a route. For served requests, the set of routes must satisfy the following constraints:

1) The pickup and delivery vertices of any request must be on the same route;
2) The pickup vertex must precede the delivery vertex;
3) A vertex is only visited by at most one vehicle;
4) The load of a vehicle k cannot exceed its maximum capacity P_k at any point;
5) A route must start and end within the vehicle availability window;
6) No subtours are allowed in any route;
7) The vertex is served within its specified time window.

The objective is to maximize the weighted sum of served requests.

Our problem requires the selection of time-window constrained pickup-and-delivery requests to serve, the assignment of requests to vehicles, and the routing of each vehicle. Assignment and routing are common aspects of the standard dial-a-ride problem (DARP) [14] and pickup-and-delivery problems [15], [16]. However, selectivity is unusual for these problems as the objective is typically to serve all requests with minimum total travel cost.

Though these three components have been studied extensively, their combination has received little attention in the literature. Baklagis et al. [17] proposed a branch-and-price framework to tackle this problem and Qiu et al. [18] proposed a graph search and a maximum set packing formulation that is specially tailored for homogeneous fleets. However, these papers do not consider multiple depots and heterogeneous fleets.

Solution Approaches. The time window and routing aspects of these problems make them challenging to solve to optimality. While many of the approaches seek heuristic solutions, the state of the art for exact approaches has typically been based on sophisticated mathematical programming such as the branch-and-price framework of Baklagis et al. [17]. Even with such approaches, the problem size for which optimal solutions can be found is typically in the range of 100 to 200 requests [15], [16].

Building on our previous work [19]–[22] on constraint programming and decomposition methods for scheduling and routing problems, we are developing pure constraint programming approaches as well as a hybrid of mixed integer programming and constraint programming based on logic-based Benders decomposition for this problem. The current KS implements our initial constraint programming model which we expect to evolve as both our research on problem solving and our experience with the pickup-and-delivery problems within SNM develops.

VI. Conclusion

We present the Social Needs Market Portal, a knowledge-based platform for the efficient and effective provisioning of goods and services to people in need. The Portal enables the consumer side to make known their needs and the supply side to list their available goods and services. It also enables the discovery of latent supply and assists with solving the logistical problems related to the provisioning of goods and services by supplying the means to schedule and route the capacity provided by a network of individual and agency-based volunteers. The Portal also provides NGOs and government-sponsored organizations with the capability to gain a better picture of the needs people have, post what they are able to provide, when and where, as well as reach a larger segment of the vulnerable populations and achieve better outcomes by being able to seamlessly combine and coordinate their efforts.

A major benefit of this project is the impact on the quality of life of the vulnerable. The flexible and nimble provisioning of basic needs reduces the stress of many segments of our population. Reducing stress provides a better quality of life, and a better quality of life, in turn, results in better work place performance and productivity and reduced social costs.

As future work, we plan to improve users' experience by making the interface of the Portal available in several major languages, as well as by including more graphical icons to assist with navigation. We are also working on a mobile app for the SNM Portal to be made available with the next release.

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