Master Thesis

MECHANISMS FOR SOCIALLY SUSTAINABLE PUBLIC TASK ALLOCATION

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Abstract

The Dutch government expressed its desire to transform the welfare state into a participation society. An adjusted policy concerning this desire is that municipalities are required to see
to, and pay for ambulatory care for those who need it. This instigated the idea in Vasse, a village in the province of Overijssel, to develop a platform to support and facilitate the community to perform public tasks. Currently, the local government spends tax money to have public tasks performed by professional companies. The local community members may very well be able to perform these tasks themselves, is the reasoning. These tasks are generally too large to be taken care of by individuals and the platform should help them to split large tasks into smaller ones and divide them amongst those who are willing to perform them.

In this study, we look into mechanisms for this platform to make the project fair, beneficial and durable. We start with determination of a pricing mechanism and conclude that combinatorial auction mechanisms give participants the opportunity to express preference for task bundles and thereby allow for efficiency benefits with tasks from different domains. The auction mechanism is augmented with a Vickrey-Clarke-Groves-payment (VCG) mechanism, which is incentive compatible. However, the VCG mechanism requires undesirably many valuations from participating bidders and may lead to an NP-hard problem. To achieve close-to-optimal solutions and prevent complete-valuation requirements, we propose additional mechanisms. Restricting bundle possibilities requires less valuations, but also restricts the possibilities for bidders to fully express their bundle preferences. The use of demand oracles is promising, but requires a large pool of participating bidders to be able to develop reliable and accurate oracles. Preference elicitation algorithms should be able to not only prevent complete evaluation requirements, but also aid in achieving complete solutions.

Furthermore, the Vasse council expressed its desire to have a blockchain technology implementation for record keeping and providing trust. We propose a private blockchain network where contract hashes are stored so that its contents are not publicly accessible, but its existence is publicly known. This way, both privacy requirements and reliability requirements are met.

The design is currently not feasible due to the small scale in the early stage of the project. Also, current legislation concerning liability and the employment of individuals poses difficulties in the realisation of the project.

Keywords: Community-based public task division, Combinatorial auction, VCG mechanism, Incentive compatibility.

Preface

I have conducted this research as the final assessment of my graduation. It has been a long and bumpy ride, and so I am pleased to fulfil the last part of it. I have been, and still am, genuinely excited about the project that I have been working on during the past couple months and so I would like to thank the HOI^2 cooperative board for giving me the opportunity to work on it.

I would like to thank Gartjan, my supervisor at the project, for the pleasant cooperation. We have had some long days where we thought of all the problems that could arise, worked out possible solutions and had an occasional laugh. My ideas would sometimes run wild and he has been great at separating main and side issues, and keeping focus on matters at hand.

I would also like to thank my supervisors at the university, Reinoud Joosten and Berend Roorda. I occasionally felt that my thesis was going nowhere and the meetings really helped me to continue and get inspired again.

Finally, I would like to thank friends and family who kept faith and patience over the years, and who motivated me when I was stressed.

Michiel Groenestein

Contents

1. Introduction

1.1. Statement of the problem

The Dutch government, like most Western countries, faced at least a decade of budgetary cuts each year (Gravey, 2014). One of the results of these cuts is that as of 2015, municipalities in the Netherlands have become responsible for ambulatory care of their inhabitants (Movisie, 2016).[1] In this new situation, the municipalities are 25% short on monetary resources in comparison to the old scenario and, as Movisie states, as such initiatives by patients, volunteers and resident associations have become of great importance. They continue by stating that in order for the transformation to be a success, collaboration of municipalities, providers and local communities is essential. The goal of this restructuring is to prevent fragmentation of care supply, to reduce the cost of the welfare state, and to support the development of society participation.

Data from Statistics Netherlands (CBS) show a number of differences between urban and rural areas in terms of public services (GP, elementary schools) and income (CBS, 2017[A]) (CBS, 2017[B]). Their data show that the distance to these services and the percentage of low-income households is higher in rural areas. They indicate that this polarisation in the population is an effect of urbanisation. However, their data also show a higher level of social contact and participation in these areas (CBS, 2017[C]).

While urbanisation does not need to have a negative connotation, it does increase polarisation in society and is perceived as a problem to those who live, or wish to live, a rural life.
In this paper, we will consider Vasse, a village under the municipality of Tubbergen, Overijssel.
Vasse has about 1000 inhabitants, but like many other countryside villages in the Netherlands, it is subject to population decline and aging (CBS, 2017[D]) (PBL, 2013) (CBS, 2017[E]). These factors influence the social liveability in Vasse the causality appears to be cyclical.

Next to the social domain, under which ambulatory care is mapped, the municipality assigns resources to maintenance of infrastructure and works of art, maintenance of buildings, environmental planning, waste disposal, etc. (Gemeente Tubbergen, 2016). The government can enter into a public-private partnership (PPP) with contractors. Under such a PPP, contractor companies execute tasks within the public domain. The PPP is an alternative to public tendering[2], which is more common for large one-off projects, and is aimed at preventing complexity (Rijksoverheid, 2016). Tasks within the public domain in Vasse are currently outsourced through PPP's.

A cooperative is founded that aims to bring the villages' entrepreneurship and social needs together in order to turn the downward spiral around and increase the attractiveness of the village through a platform called *HOI*[2].[3] The goal of the platform is to increase wealth and wellbeing in Vasse by facilitating social entrepreneurship and thereby increasing the turnover of Vasse by € 3.000.000 in 3 years time.

[1] This is called the Wmo, transl.: *Social Support Act.*
[2] (Rijksoverheid, Aanbestedingsregels, 2017).
[3] House of Entrepreneurship, Innovation and Inspiration.

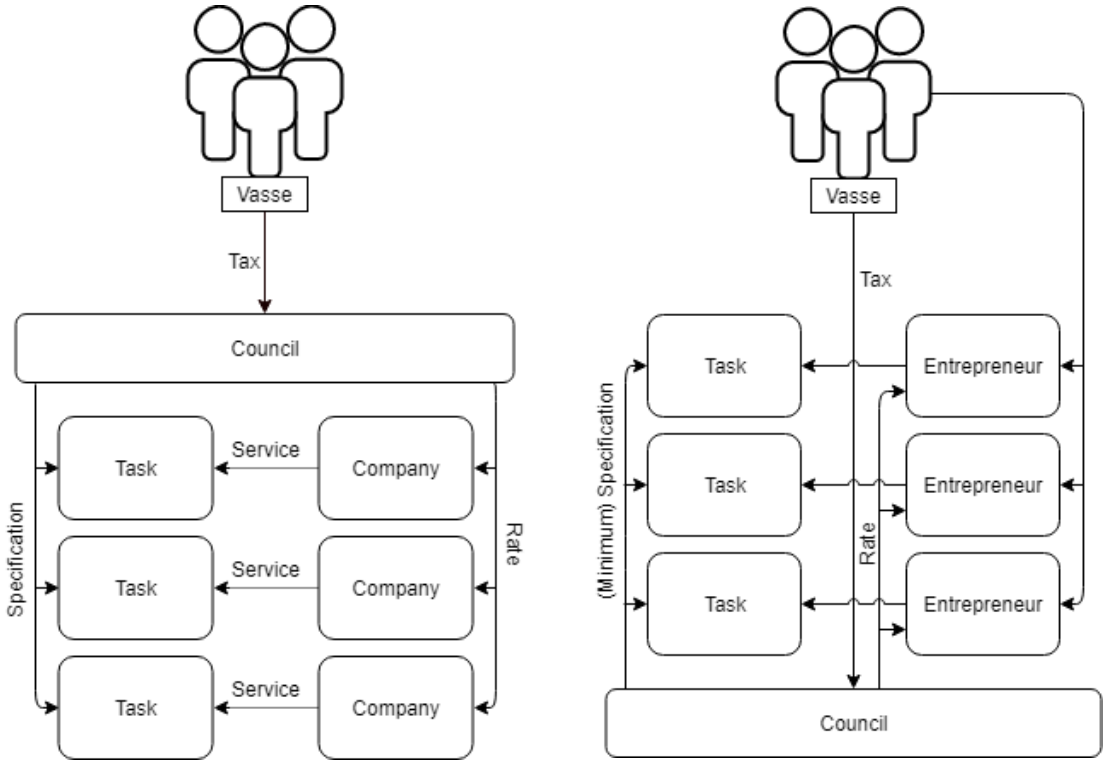

Figure 1 - Left (a): Current situation. Right (b): Desired situation.

Figure 1a shows the current structure in which tasks are accomplished. The inhabitants pay taxes and the council (as representative of the inhabitants) establishes the tasks and requirements. Companies commit to these tasks through a PPP and receive payment.
In the situation as desired by HOI^2 (Figure 1b), the inhabitants themselves operate as entrepreneurs in order to accomplish these tasks, thereby receiving back their tax money and hence increasing wealth in Vasse.
Furthermore, the council could establish some minimum requirements and leave anything else to the community. For example, maintenance of the green area is subject to laws concerning safety and environmental protection. The interpretation, in terms of flowers, grass, bushes, etc. could be left to the community. This way they could furnish the neighbourhood to their bid, thereby increasing wellbeing.
In order for the platform to accomplish the goals set, four requirements have been formulated by the HOI^2 board as conditions. These conditions call upon both the platform, as well as on the community. They are as follows.

- ☐ Innovation as unique selling proposition: The platform must characterise itself by the use of modern, and innovative technology in order to be progressive and community-driven, thereby keeping governmental meddling out and being distinctive.
- ☐ The platform must allow explorative behaviour and the freedom to make mistakes and experiment with different methods in order to achieve envisioned goals.
- ☐ Initiatives for new projects are with the community. The initiator takes ownership of- and responsibility for the success of their project.
- ☐ Small-scale bureaucracy must be prevented. There is no purpose to recreate government-like institutions. The platform, therefore, must provide a safety net that sees to correct performance of tasks and professional guidance if required.

As a starting point for the first condition, the cooperative decided to investigate into the possibilities of blockchain technology as a driver.

1.2. Objectives of the study

One of the tasks currently being outsourced, is to maintain the green areas of the village. Being a farmers' community, inhabitants of Vasse have the means, in terms of material and knowledge, to perform these tasks themselves, is the reasoning. However, maintaining the green area as a whole is too large a task to digest in one piece.

The specification must be partitioned so that the resulting tasks fit the capabilities of the community. Questions that arise here are in the nature of how to split the tasks, how to determine a fair reward, who is responsible, and so on. However, this is likely to result in an unclear bookkeeping with many small parties fulfilling a task and claiming a reward. The platform must assist with this bookkeeping and see to a fair and transparent settlement with all parties involved. It is important that the platform supports and stimulates cooperation and participation by the inhabitants of Vasse in order to be socially durable. Figure 2 shows where the platform is imagined to come into play. The council specifies a task. An entrepreneur divides it into small tasks presented on the platform and are fulfilled by the community in exchange for remuneration.

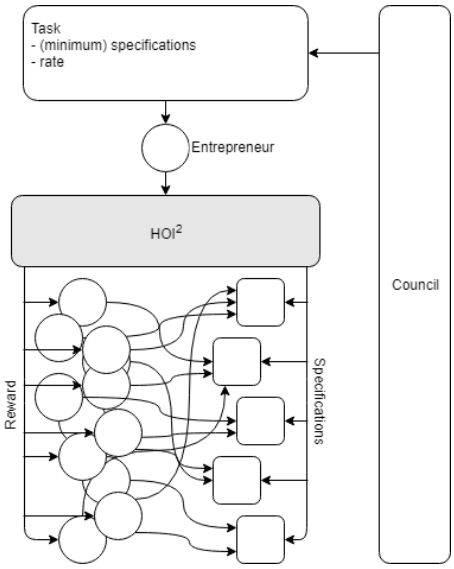

Figure 2 - The role of the HOI² platform.

The main question to be answered here is what this platform should look like and how it should work. This study looks into the aspects of this question with respect to task allocation and risks involved with this task allocation. We design a platform that supports the goals set by HOI² and takes the conditions into account.

Although the model will be developed with focus on the task of maintaining the green area, it must be applicable to any task set by (members of) the community. Furthermore, if such a model proves useful, it should be able to support not only Vasse in its efforts. Ideally it would be applicable to any community.

Additionally, we investigate the ability of blockchain technology to support such a platform. It is a fairly new technology with many promises, but very limited application. In essence it is a ledger that is shared and maintained by many peers in order to create a trustworthy timeline of events without the hassle and costs induced by involving third parties.

Considering these objectives, we come to our main question that should be answered in order to address the problem.

How can we design a platform for wealth and wellbeing increasing, and socially sustainable public task allocation in a local community?

1.3. Significance of the study

The situation that Vasse faces (aging, depopulation and budgetary cuts) is not unique to Vasse alone. Successfully creating a system that increases wealth, and thereby possibly attractiveness, could be beneficial to many more countryside villages and cities.

The SER (social economic council) published a report in 2015 on the current situation and difficulties concerning social entrepreneurship (SER, 2015). The problems addressed concern rules on tender and funding (among others[4]). In order to tackle these problems, the SER proposes collaboration between

[4] The recommendations and difficulties that are not mentioned here concern legislation and initiatives that are on the central governments part.

entrepreneurs and to increase awareness on both governmental and entrepreneurial sides of the possibilities and difficulties with social entrepreneurship.
The goals and conditions set by HOI[2] are in line with these recommendations and as such, the platform could increase the success of social entrepreneurship.

Besides an answer to the society participation proposal by the Dutch government, the problems that are to be addressed can also be related to current developments and issues of (inter)national political debate concerning the basic income[5] and shorter workweeks (Doorlag, 2015). Initiatives like this one, and the solutions that result from them, can potentially help to solve such issues.

1.4. Time and place of the study

The project was started early 2017. Development of the platform was started in June, with the aim to start the first trials early 2018.
Development of the platform will be done with the use of BeInformed software. BeInformed is an IT company situated in Apeldoorn that offers business modelling software. The model we create can be translated into a business model after which the software automatically produces an application that, with a little fine tuning, should yield the desired functionalities. This results in an app that can be used by the different users/roles in order to accomplish the goals of HOI[2].

1.5. Scope and limitation

The stakeholders that have been identified with the goals of HOI[2], along with their roles and interests, are shown in Table 1.

Stakeholder	**Role**	**Interests**
Inhabitants of Vasse	As consumer	Ethics (privacy), health care (quality), law (qualification), IT (UI/UX[6]), sociology (group dynamics)
Inhabitants of Vasse	As (potential) entrepreneurs	Micro-economics (competition), law (entrepreneurship)
Inhabitants of Vasse	As workforce	Reward, spare time, ethics (privacy)
City council	As buyer	Law (public tender), micro-economics (competition), politics (goals, agenda)
City council	As supervisor	Safety, politics, law (environmental)
HOI[2]	As initiator	Goals (wellbeing and wealth)

Table 1 – Identified stakeholders involved with the project.

We can identify many different disciplines covering the interests involved with this undertaking. Not all of these interests will be addressed. We focus on the considerations involving value and risk. The model on which the platform is built should be able to support the goals and initiatives of entrepreneurs given the feasibility of the project in terms of legislation, ethics and so on.
The success of the project relies heavily on the capabilities of the entrepreneurs and the willingness of the community to participate in fulfilling the tasks. These variables are assumed to be in line with the

[5] https://basisinkomen2018.nl
[6] User interface/User experience

goals of HOI[2] and are thus, not further taken into account in the development of the model on which the platform will be built.

1.6. A critical view on the problem statement

Budgetary cuts
Municipalities are responsible for ambulatory care and have 25% less resources
Low public services quality
Population decline
Aging
Low social liveability

Table 2 – Problems mentioned in Section 1.

The project, as outlined in Section 1, mentions several problems that must be solved (shown in Table 2). Furthermore, the solution is proposed in the form of the projects' goal; increased turnover of € 3.000.000,- in 3 years time. The project itself, the HOI[2] platform, is proposed as the means to reach its goal.
In this section we evaluate this chain from problem to solution for a deeper insight into the value of this project. For this, we use several steps from the General Business Problem Solving method as developed by Heerkens & van Winden (2012).

1.6.1. Problem web

We can organise the problems in Table 2 to find the core problem that should be solved. Figure 3 shows this problem web.

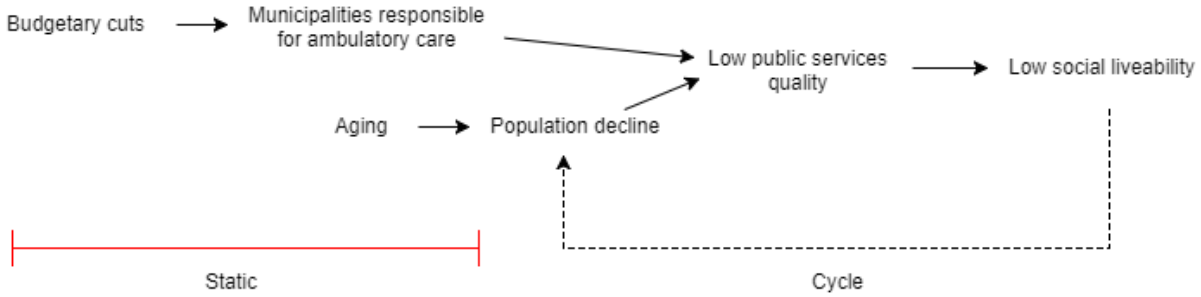

Figure 3 - Problem web.

Budgetary cuts and aging are causes to the problems. However, we are not able to change policies on national level[7] nor the course nature runs. These are therefore not interesting as core problem, we are simply unable to solve them anyway. The other three problems show a cyclical pattern, as mentioned in Section 1.1. If we can increase public services quality, we may be able to increase social liveability and attract new inhabitants which in turn increases social liveability.

1.6.2. Indicators

Next, we must define the problems we are left with in terms of indicators. By doing so, we can measure how well our solution performs in solving the supposed problem. Population decline is an easy one; we could simply measure the number of inhabitants in Vasse before and after the implementation of our solution. Assuming all other factors the same, we could draw conclusions based on this number.
Public services quality is quantified by the CBS in terms of distance to schools and health care. We could, if needed, simply use this definition as well. Measurable aspects that describe social liveability could be number of vacancies, contact hours with neighbours, number of crimes, internet speed, etc.

1.6.3. Alternative solutions

To be able to solve the problem, the solution should alter the variables that are considered undesirable which requires that both the problem and the solution are expressed in the same variables.

[7] The discussion on Dutch democracy and the influence one has through voting is left for another day.

The chosen solution here, platform HOI^2, has the purpose of increasing wellbeing and wealth, and the goal of increasing turnover. Turnover, however, is measured in Euros. This is compatible with the wealth indicator, but not with the wellbeing indicator (directly). We could think of indicators of social liveability that are in terms of Euro. Income, housing prices and cost of living are examples of that. By choosing this solution, it is implied that social liveability is the core problem (among problems indicated by the cooperative). From our problem web, we can conclude that this is not true. Of the mentioned problems, at least population decline and public services quality are causal to low social liveability.

1.6.4. Conclusions

The proposed solution does not seem to be in line with the problem as formulated. It seems either significantly based on assumptions (for example that more turnover increases attractiveness of the village), or it could be the case that the solution needed a problem in order to gain (governmental) support, or even some other motive.
Either way, it may be difficult to solve the core problem with the proposed solution. Nevertheless, it is interesting to see whether such a platform is able to answer to the governmental request of society participation in a socially durable way.

2. Theoretical framework

The idea for this project originated as an answer to the Dutch governments' call for society participation to solve the problem of increasing costs of the welfare state. In this scenario, the government retreats as caretaker and shifts its role as stimulator to local governmental bodies (Rijksoverheid, 2013). Civilians step up as care takers to each other.

These plans appeal to the willingness of people to voluntarily take care of family, friends, and neighbours. However, there are growing concerns and signs of this new society being only available to an elite, rich and native minority while it is especially important for a group of people who are poorly educated, immigrants, or suffer from a mental disorder. Furthermore, those who support the policy and the liberal ideology behind it, are not the ones who will eventually commit to voluntary work (NOV, 2016).

The HOI[2] board noticed that it is not particularly difficult to activate people to take initiative in creating something new for the community, such as a play pen for children. However, maintaining the play pen was something that posed difficulty in organising which resulted in fewer people taking action over time until eventually a single person did all the work. To prevent this from happening again we must look in to systems that are able to provide durability to the platform.

2.1. Public and social services

Public services are offered by the government to serve the public interest (Public service, n.d.). This definition does not impose restrictions on the nature of such services, although in practice, not any kind of service is offered as a public service. In this section we look into this difference. Furthermore, the project is concerned with social services. These are services that are not necessarily of the same nature as public services, but appear as such by desire of the people.

2.1.1. Tax system and the free rider problem

If we look again at Figure 1 in Section 1, we could ask ourselves whether it would be possible to eliminate the government as cost centre from the chain and thereby cut costs. In terms of cash flow, Figure 1b could be reduced to something shown in Figure 4.

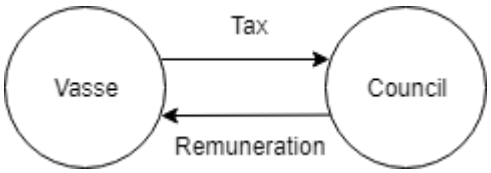

Figure 4 - Simplification of Figure 1b.

The inhabitants of Vasse pay taxes, which is assigned to public services and facilities by the council after which the inhabitants receive back their taxes in exchange for providing said services and facilities. Once the community is able to perform tasks according to their own preferences and without the need for outsourcing, the tax system may seem redundant. However, using tax money to provide public goods and services prevents the occurrence of free riding (Miceli, 2011). Free riding arises when anybody is able to enjoy a good, independent of whether they contributed to the cost of the good. As an example, let us consider the play pen from the introduction of this section. If out of 10 households, 9 decide to pay for the play pen, the costs per household are higher than when all 10 would have paid. For the 10th household, the play pen is free. However, the 9 paying parents would probably not forbid any child to use the play pen. This creates an incentive towards not contributing to the costs of the play pen for any family.

Other examples of such goods are infrastructure, clean air, and street lighting, among many others.

Taxation turns free riders into forced riders. Tax is used to provide such goods to anyone. Some people may not use them although they do contribute to the cost. Tax payers are thereby forced to contribute to the costs goods and become forced riders.

Al-Dhanhani *et al.* (2014) propose the use of a reputation based system as a solution to free riding in social groups stating: "Our study suggests adding reputation as a parameter in users' profiles in collaborative groups to improve their survivability." They suggest a *Tit for Tat* mechanism that motivates free riders to cooperate under the threat of being punished by cooperative group members.

2.1.2. Game theory

Free riding can be understood with the principles of game theory. “Game theory is the study of strategic interactions among two or more economic actors”, as concisely articulated by Goolsbee *et al*. (2013). A game has at least the following three elements namely, two or more players, their strategies, and payoffs. The decision that the players make affect both their, and their fellow players' payoffs[8].

Our platform is meant to facilitate many players who are the inhabitants of Vasse. Their decision to perform certain tasks under certain conditions will be their strategies, and the benefit they experience is their payoff.

The inhabitants of Vasse are asked to work together in order to achieve the goals set by HOI[2]. This is called collective action (Dowding, 2013). Collective action problems are prone to end in suboptimal situations such as the well-known prisoner's dilemma and, aforementioned, free riding. These are results of situations where players recognise that they may end up suffering if they act towards the best outcome of the game while not knowing whether the other players of the game will do the same. In the prisoner's dilemma, this leads to both convicts defecting while cooperating would be beneficial to both. In other words, the nature of the game withholds both players from achieving the optimal state due to uncertainty about the other players' decision. The outcome of a game from where no player can unilaterally increase his payoff is called a Nash equilibrium (Webb, 2007).

Ideally, we apply mechanisms that are incentive compatible, meaning that players achieve their optimal payoff by choosing the strategy that fits their preferences best (Nisan, 2007) and by doing so, maximise social welfare. The game's Nash equilibrium is then no longer suboptimal.

2.1.3. Conclusions

If a community provides services that are paid for by tax money of that same community, one could wonder whether the tax system may be expensive and cumbersome. However, the tax system prevents free riding by turning people within the community into forced riders. We might be able to reduce this risk by introducing a reputation parameter, as suggested by (Al-Dhanhani *et al*., 2014). Furthermore, if we are able to employ incentive compatible mechanisms for task division among the inhabitants of Vasse, we are able to maximise social welfare.

2.2. Pricing mechanisms

The local government makes an annual budget in which it assigns its expected income to different services that benefit the inhabitants. This project aims to assign the expected income back to the inhabitants in exchange for their services. In Section 2.2. we are looking to understand how the value of something like a service or good is established and how we can use this knowledge to design a durable pricing scheme for the tasks.

2.2.1. Supply and demand

Our current economy, however complex it may seem, can be brought back to the principal underlying the supply and demand model (Goolsbee *et al*., 2013).

The Indian philosopher Thiruvalluvar denoted about 2000 years ago already that when the price of a good rises, the demand for the good decreases (Chendroyaperumal, 2010).

[8] When a decision only affects the decision maker's payoff it is called a single-agent problem.

Figure 5 shows a simple example of a supply curve where supply increases when the price rises.

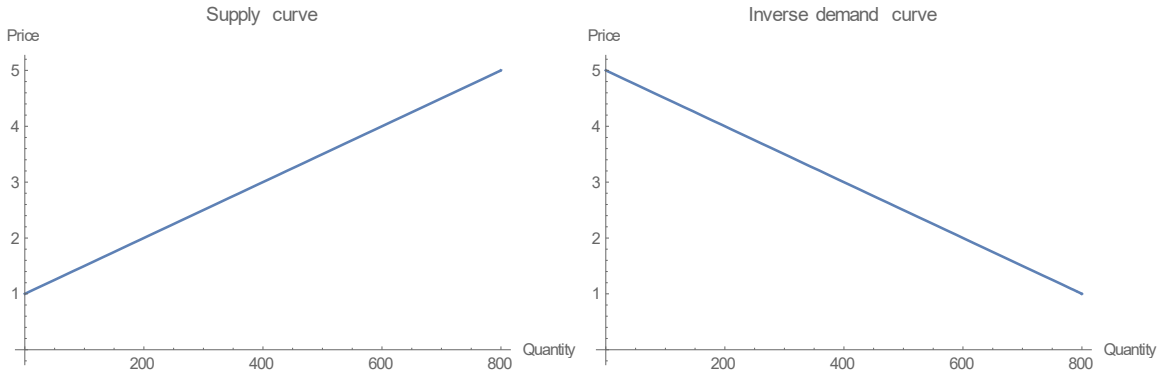

Figure 5 - Example of supply curve (left) and inverse demand curve (right).

The left curve in Figure 5 is given by the function $P = 0.005Q + 1$ where Q denotes quantity and P price. Furthermore, we consider an inverse demand curve given by $P = 5 - 0.005Q$, as shown in Figure 5 on the right.

The point where the supply curve and the inverse demand curve intersect shows us the market equilibrium (red dot in Figure 6). At price equal to 3, both demand and supply will be 400 in our example. Below 3, demand is higher than supply, whereas above 3 demand is lower than supply.
If at some point the supply is not high enough to answer demand, the price will increase as demand increases. Inversely, if suppliers find no market for their goods, they may lower their price to increase demand.

How much a party should offer to its respective market depends on the market structure because, naturally, if one can offer something that nobody else can offer, they are able to meet the entire demand by themselves. If anybody else can offer the same, entire demand is likely to be met by multiple parties. Between these cases are different market structures.

There a four types of market structures and we can use three characteristics of a market to determine the market structure of said market (Goolsbee *et al.*, p. 304). Figure 7 shows the market structures and how they can be defined by their characteristics.

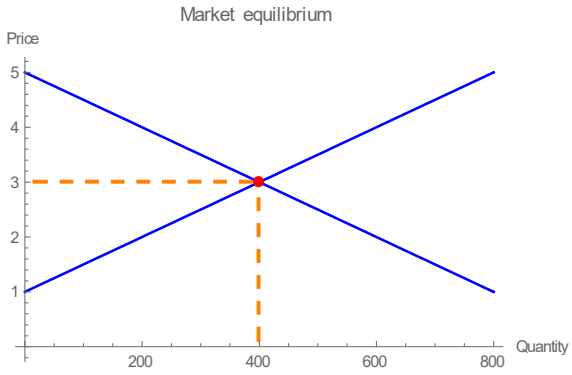

Figure 6 - Intersection between the supply curve and inverse demand curve.

The market structure indicates the market power that parties in the market have. Market power is the ability to influence the price in the market. For instance, if the market structure is a monopoly, the single party is free to ask whatever price it wants because there is no alternative to the good. In a highly competitive market, individual parties have very little market power. Consumers can easily switch to one of the many alternatives in case one party's price is reckoned to be too high.

Perfect competition	Many parties
	Identical goods
	No barriers to entry
Monopolitic competition	Many parties
	differentiated goods
	No barriers to entry
Oligopoly	Few parties
	Either identical or differentiated goods
	Low barriers to entry
Monopoly	One party
	Unique good
	High barriers to entry

Figure 7 - Market structures as identified by Goolsbee et al.

If the goal of a party in a certain market is profit maximisation, however, the price they ask for their good must be in line with this goal as well. As we have seen, demand is inversely related to price and as such, asking a high price will not necessarily result in a high profit, even in a monopoly market. To maximise profit, the provider of a good can use the inverse demand curve to determine what price yields the highest revenue. Area A under the inverse demand curve in Figure 8 shows what turnover the provider can expect at a certain price[9]. To maximise turnover, they should determine what choice of price maximises area A under the inverse demand curve.

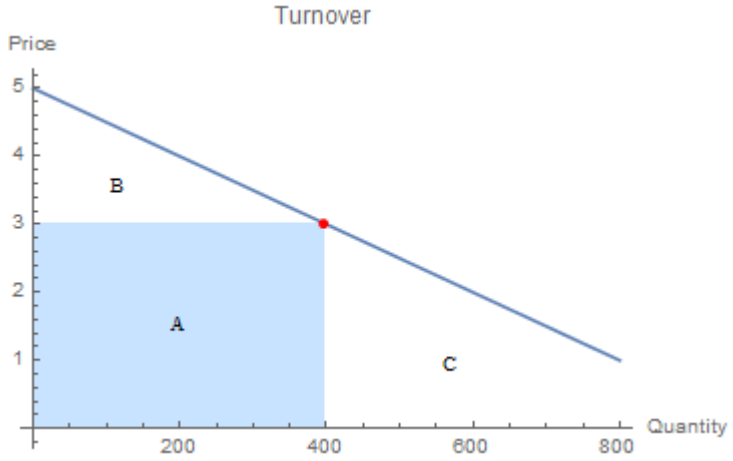

Figure 8 - Expected turnover at price 3 given the inverse demand curve.

This strategy, though, maximises the revenue at a single price point. Assuming our inverse demand curve is accurate[10], there are potential customers who are willing to pay more, and customers who want the product, however at a lower price. These are missed opportunities of income represented by Area B and Area C respectively in Figure 8. Area B is called consumer surplus, Area C is called deadweight loss.

If we were able to sell our good to each customer for the true value they would assign to the good, we could increase area A to be the entire area under the inverse demand curve. This would be called perfect price discrimination (Goolsbee *et al.*, 2013).

2.2.2. Administrative allocation

The inhabitants of Vasse will come to face many different small tasks. Some of those may require no expertise at all (no barriers to entry) and may thus be services in a highly competitive market whereas other tasks could require specific knowledge or competence and are thus services in a monopolistic market.

[9] Because the price determines expected quantity sold and turnover equals $price \times quantity$. Furthermore, marginal costs are zero in Figure 8.

[10] Techniques to do this exist, but are beyond the scope of this research.

Using the laws of supply and demand we can determine the right[11] price for every type of task if we know its parameters. We could then offer each task to the inhabitants in exchange for the fair price we have established and thereby buy their services until all tasks are assigned. This is equivalent to how one would buy a commodity in a shop. It is called posted pricing and is an administrative first-come-first-served allocation mechanism (Gruber, 2005).
Once we have established the market structures for each type of task we must try to find a representative supply curve and marginal cost. However, this would only work under the assumption that profit maximisation is the goal of each potential provider.
Also, it will be very difficult to determine marginal costs for each task. People will value their time and effort differently and may even be willing to do something for free out of solidarity, or for a price well below commercial rates if they perceive gratitude more valuable than money. Using such approaches could therefore lead to an overly complex or expensive business.

Another administrative allocation method is a lottery. Again, we could determine a price per task and divide all tasks randomly amongst inhabitants or participants. We would run, however, into the same problem established above, namely that people may value tasks differently. In this case, it could lead to a secondary market where tasks are resold between inhabitants. This could be time consuming and usually only works well when it is difficult to distinguish participants from each other in terms of preferences (Bade & Parkin, 2013).

A beauty contest is a third administrative allocation method. Contestants provide their plan of action and the jury chooses which plan fits their view best. This allocation method is, to certain extent, quality-based rather than quantity-based. All plans must be reviewed and compared which can be time consuming. Furthermore, because the criteria on which the winner is based are qualitative, this method knows certain controversy due to the possibility of favouritism and corruption (Klemperer & Binmore, 2010).

As mentioned above, these methods require us to establish a fair, or *right,* price. In practice, demand can be very difficult to measure. In our case, for example, the demand of custom green spaces could vary with the amount of money residents must deposit themselves. How it will vary exactly, is difficult to determine beforehand.
Furthermore, the services that the people deliver will not always be identical. Surely quality could be recorded in the specification of a task, but the nature of some tasks could induce, for example, privacy issues. In such cases, both supply and demand sides are subject to unquantifiable valuation differences.

Administrative allocation methods can become very consuming in terms of time and money and may not always lead to a transparent and satisfactory allocation to all inhabitants. To avoid this, we could try to find a system in which each potential provider can announce their valuation of the different tasks.

2.2.3. Auctions

In the previous section we mentioned that it may be favourable to the system if providers can announce their own price for a predefined task in which they are able to value their time, effort and expertise as they see fit. We could then select the provider that we consider to be best in line with the task specifications or projects' goals, e.g. the one who asks the lowest remuneration. This form of buying is called an auction (van Damme, 1997). We can furthermore distinguish between forward auctions, where items are sold, and reverse auctions, where items are bought. In this case we are looking for a provider who can perform a service. We are, in this case, not selling, but buying and

[11] The market equilibrium.

thereby looking for the best offer. Also, both the selling and buying party remain closely involved after the sale is made. This is called a tender.
In this section, we will look into different types of auctions in terms of characteristics and goodness of fit for the purpose of the project.

Probably the best known auction type is the English auction. It is an open-bid auction where the price is raised until only one party remains. The good is then sold for the last price. Next to this ascending-bid auction there is also a descending-bid auction, also known as a Dutch auction. In this case the price is lowered until one of the participating parties accepts the then current price. Both auction types are used, for example in art auctions (English) and flower auctions (Dutch).

These types of auctions are particularly useful if the seller is looking for profit maximisation (van Damme, 1997, p. 42). Biddings in these types of auctions are known to be subject to a phenomenon called *winner's curse.* Bidders value the good they are bidding on, but do not know the true value of the good. Considering the presence of other bidders, bidding aggressively increases the chances of winning the item. Although high bids increase the chance of winning, they also increase the chance of overpaying which may leave the winner unhappy or *'cursed'* (Thaler, 1988).
The project is, however, not aimed at shaking down inhabitants and get them to do work for the least amount of money possible. The providers may have to commit to tasks for a certain period. Feelings of too low rewards or at least less than they are actually content with, may jeopardise the social durability of the project.

An alternative to open-bid auctions are sealed-bid auctions. Participants hand in their bids to the auctioneer and have no insight in other participants' bids. The auctioneer sells the good to the bidder with the highest bid in so-called first price sealed-bid auctions. In second price sealed-bid auctions, or Vickrey auctions, the auctioneer sells the good to the highest bidder, but for the second highest price. Although the latter form may seem unfavourable for the auctioneer, it has some interesting characteristics.
Let us consider a sealed-bid first price auction of a good. If you would receive the item for the exact value that you consider the item worth, you are indifferent between owning the item or owning the amount of money. Your gain would thus come from receiving the item for less than it is truly worth to you. By bidding less, you may gain if you are the highest bidder although your chance at winning is lower than when you would bid your true value (Vickrey, 1961).
Hence, the first price system does not incentivise bidders to bid their true value. By using a second price mechanism, bidding true value guarantees profit gain for the bidder in case of a win.

2.2.4. Combinatorial auctions

When a seller has multiple items (homogeneous or heterogeneous) to offer, auctioning them off individually can be cumbersome and time consuming. Furthermore, the value of owning certain items can vary depending on whether one owns several of these items.
For example, a collection of some sort can be worth more than the sum of the parts, or a real estate broker could be interested in a lot only if they can acquire neighbouring lots as well. This is called *superadditivity.* When the sum of two items combined is lower than the sum of the same items individually, it is called *subadditivity.*
In such cases, it may be favourable to auction multiple items at once so that buyers can express how they value combinations of items. This type of auction is called a combinatorial auction.

When many items are sold, the number of combinations one can make of all those items can become enormous. The task is to determine, from all combinations offered by the bidders, how to divide all

items among the bidders at optimal[12] pricing. A useful mechanism for this task is the Vickrey-Clarke-Groves (VCG) mechanism, which is an incentive compatible, utility-maximising mechanism for solving social choice problems (Nisan, 2007). In social choice problems, the individual preferences of the group members are combined to form a single decision. These types of problems occur not only in auctions like ours, but even more so in, for example, network routing in information technology.
While doing so, each participant contributes to maximising the social welfare. This is best explained by Jeremy Bentham's utilitarianism. From the field of ethics theory, utilitarianism states that the best action, is the action that maximises utility. Utility is measured as the sum of all pleasure achieved from an action, minus the harm done to anyone as a result from that action (Bentham, 1948).

There are, however, some downsides to the use of auction systems. Foremost, there is the risk of bidder collusion (Sandholm, 1996). Bidders could conspire to keep the price of the items low. Bidders are then no longer incentivised to bid their true value. This could damage the VCG auction because it may no longer be maximising the utility of all participants. Sandholm (1996) notices that a way to prevent collusion, is keeping bidders anonymous. Another risk mentioned in his paper is the risk of an untrustworthy auctioneer. In sealed-bid second price auctions, the auctioneer could add a fake bid just below the highest bid, thereby increasing his income by the difference between the fake bid and the actual second-highest bid. This is called shill bidding. This risk is, obviously, only present when the auctioneer's goal is profit maximisation.
Another difficulty is found in the implementation of the theory to practice. The VCG-mechanism is aimed at achieving optimality. Using it for complex problems such as combinatorial auctions makes it computationally infeasible (Nisan & Ronen, 2007). The optimum can be increasingly approached when the number of valuations made by bidders increases. However, there are $2^n - 1$ possible bundles when there are n items. This high order means that bidders must make numerous valuations in order for the mechanism to be able to approach optimality.

2.2.5. Conclusions

A simple approach would be to divide large tasks into smaller ones and price those as we see fit. This could be based on many parameters such as time required, competence required, or anything else we deem relevant. We do not know, however, whether this valuation matches the valuations that people make themselves for each task.
If we look again at Figure 8, the total demand of services we have is the entire area under the inverse demand curve. Using administrative allocation, we are only able to fill area A[13], which means we must buy services from outside to cover the rest of the tasks. This is undesirable and potentially expensive.

Alternatively, we could apply an auction system to perfectly distinguish people according to how they value a task and thereby minimise costs. Open-bid auctions can minimise cost, although that may cause regret among winners. This can be solved by using sealed-bid second price auctions which are incentive compatible. Unfortunately, these give participants no possibility to value combinations of tasks.
For example, someone may be willing to sweep the street in front of their own house for a certain price, but may be willing to sweep the whole street for proportionally less because it is relatively more efficient. Combinatorial auctions can solve this because they do give people the opportunity to value combinations. The VCG auction mechanism is furthermore incentive compatible. Computational feasibility could prove troublesome although there are proposed additions to the original mechanism that ought to be both computationally feasible and incentive compatible. Ultimately, we need two approximation algorithms; one for task allocation, and one for resource allocation.

[12] Optimal can be either maximising- or minimising the total price, depending on the seller's goals.
[13] It is possible to increase turnover using posted pricing by using different price discrimination techniques.

2.3. Blockchain technology

This section discusses blockchain technology, of which the use is required by the HOI[2] board. We look into what it is, how it can be of use to the project, and possible alternative solutions.

2.3.1. What is blockchain technology?

A blockchain is essentially nothing more than a ledger. A ledger contains data on incoming and outgoing units of some sort. This could be money in case of bookkeeping, wares in case of a shop, medicine in a hospital and so on. Depending on the type of ledger, it is usually managed by people, or larger entities.[14]

A notable example is Bitcoin, which originated from the whitepaper by Nakamoto (2009). Bitcoin is designed as a substitute to government-backed currency. Fiat currencies, as these are called, are regulated by national banks (Mankiw, 2015). Under these national banks are the commercial banks, which verify transactions between clients. The banks act as trusted third party intermediaries. They provide security and trust to the monetary system by assuring the validity of transactions. This may seem redundant, but it is a very important aspect for money to keep its value.
These trusted third parties, however, can be expensive. If we would be able to provide trust to the monetary system without the interference of banks, we would be able to retain the value of a transaction between the transacting parties.

With blockchain technology, there is not a single entity that owns the ledger. Instead, every participant can choose to own a copy. All participants together form the blockchain network in which all ledgers are tied together to achieve consensus on the network (Bashir, 2017).
Transactions between participants are recorded in blocks. After a predefined amount of time, a block is closed with a so-called hash. A hash is a key, based on the contents of the block. This is used to tie the new block to the previous one. Through this process, a chain of blocks is created which contains the entire transaction history of the blockchain network.

Validation of transactions is done by the participants through a process called mining. The participants perform proof-of-work computations to validate transactions, which is only profitable if they are honest (Ammous, 2016). Validators are rewarded for their work in the form of a small transaction fee. Tampering with the network by adjusting older blocks requires a lot of computational power, without reward and without consensus from the other peers in the network.
These characteristics make blockchain technology a potentially safe and relatively cheap method for sharing information when correctness of the information is of utmost importance. Because the contents of the blockchain cannot be tampered with unnoticed, it is said to be *immutable* (Lewis, 2016).

Despite its promising features, there is a downside to this setup that has been experienced on multiple occasions by participants in blockchain networks during the last decade. Blockchain networks are software based. By virtue of transparency and trustworthiness, the software's code is open source, meaning that anyone can take a look at it and thereby is able to find possible errors. The two most well-known blockchain networks, Bitcoin and Ethereum, have both faced misuse which turned out to be difficult to solve due to the decentralised nature of the technology.

2.3.2. Applications for blockchain

In general, application comes down to making an agreement that cannot be manipulated by either party and where no trusted third party is required to ensure this (Rikken, et al., 2017). We have explained the workings and use of blockchain technology by the example of monetary transactions.

[14] For example, bookkeepers in a company and notary offices which affirm property ownership.

There are many more applications we can think of where blockchain technology could be of value. Eventually, it comes down to a piece of information that we must be able to trust. Other examples we could think of are identity information, patient data, asset ownership, logistic networks and so on.
The nature of the agreement, however, is not limited in scale or sophistication. Any two parties in the network can enter into any agreement with each other while the contents of the agreement do not necessarily have to be accessible to others.

Furthermore, specific blockchain networks offer the application of smart contracts. A smart contract is a piece of deterministic software that can be replicated and executed on a blockchain (Rikken, et al., p. 1). Such a contract can be programmed to execute once predetermined conditions are met.
A smart contract on its own could be as simple as paying a counterparty on a predefined date, while more complex (chains of) contracts can form an entire virtual entity, so-called decentralised autonomous organisations (Ethereum Foundation, 2017).

Alternatively to decentralised networks, one could decide to run a local, privately owned blockchain. This private chain can be set up according to specific preferences without losing immutability. This makes the technology potentially suitable for auditing. The auditing party can be granted *read-only* access to the blockchain so that it can verify that the specific orderbook is not tampered with.

2.3.3. Alternatives to blockchain

Instead of using a peer-to-peer distributed network to record agreements and transactions, one could use a central database to keep track of the phases of an agreement. Each user of the system can get authorisation for altering the record only on specific fields of the database, comparable to buying a good from a store.
A trusted third party is a hub between untrusting strangers in a network. The peers in the network may not trust each other, but if they trust the third party they can do business. The need for trusted third parties originates from the physical separation between parties who want to do business (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 1999).
The first question that must be asked and answered before setting up a system to create trust, is whether there is a situation where trust is an issue.

2.3.4. Conclusions

If the nature of the agreements is such that a trusted third party is not required or not expensive at all, a blockchain mechanism may be overly complex. After all, the ledger becomes more reliable as more peers are participating in the network. This means that many, ideally all, inhabitants of Vasse (or any other group) must run proof-of-work software to validate transactions on the network.
It is important, even to a close community, that there is a single source of truth. Be it not out of fear for misuse or misconduct, the many contractors, many small tasks, and many respective payments must be recorded somewhere to keep track of progress.
Private blockchains could be used as less cumbersome alternatives, but their benefit over contemporary databases may not outweigh the fact that ready solutions do not currently exist.

3. Design

So far, we have investigated what is desired by HOI^2 and the means to achieve their goals as they appear in theoretical work. In this chapter we use these to identify some case-specific problems that must be dealt with in this design. Not all problems need to be dealt with by the final application. However, the application should be able to provide the entrepreneur with all relevant information to deal with potential problems. In this section we move from a theoretical level to an applied level in the design process.
We also look into appropriate auction algorithms and adjustments to existing algorithms in order to determine what type of algorithm satisfies our requirements in terms of fairness and feasibility best.

3.1. HOI^2 model

We can view the course of a project in terms of the stakeholders shown in Table 1 in Section 1.5 in a simplistic diagram as shown in Figure 9. The model shows how different stakeholders are involved in a project as time progresses. The dotted line represents the HOI^2 platform contribution to the project.

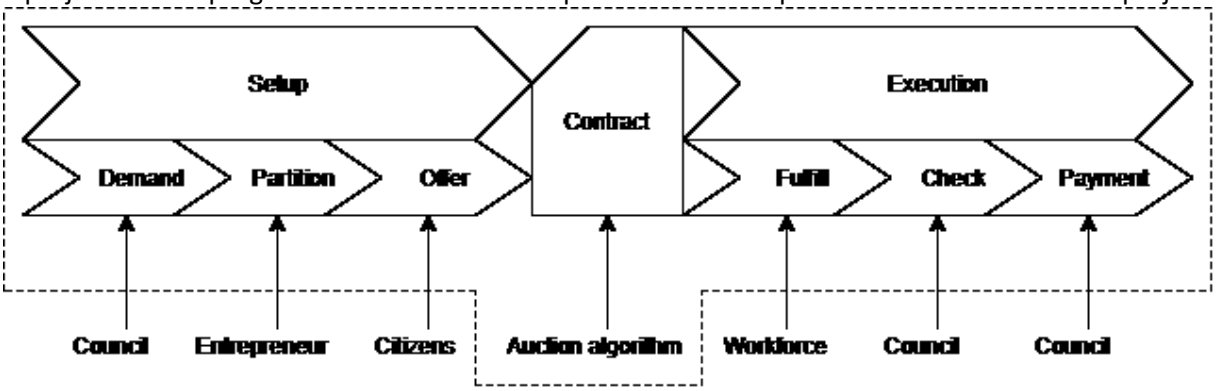

Figure 9 - Stakeholder involvement during different project phases.

In the setup phase the council puts down a task, such as public space maintenance or domestic help. Inhabitants can take the role of entrepreneur and divide the large task, as indicated by the council, into small tasks as they see fit. Next, other members of the community offer to perform certain small tasks. This leads to a contract in which the tasks, specifications and payments are recorded.
In the execution phase, contractors fulfil their tasks as required. The council ensures that this is done according to the contract after which the payments follow.

In Section 3.1 we will expand this model in accordance with restrictions and possibilities as we explore in its subsections.

3.1.1. Case specific design choices

In this section we cover pre-set design choices and properties that we regard as requirements for the platform to fit the board's wishes.

Tasks and task ownership
We have decided to apply a working method that has worked well for BeInformed in previous projects of theirs. In this method, each project has a project owner under which task owners are responsible for smaller sets of tasks. We could think of the entrepreneur dividing a specification into district-separated tasks, type-separated tasks, or any other division they see fit. Then each partition is assigned a new project owner who again, separates into smaller tasks until the level of individually executable tasks is achieved.

By doing so, responsibility is divided over several layers which eases the burden on individuals. Furthermore, project owners monitor performance of their respective tasks. This approach is in line with the conditions set by HOI[2] as indicated as bullet points in Section 1.1. In this structure, people are only involved with those in layers adjacent to their own as we show in Figure 10.

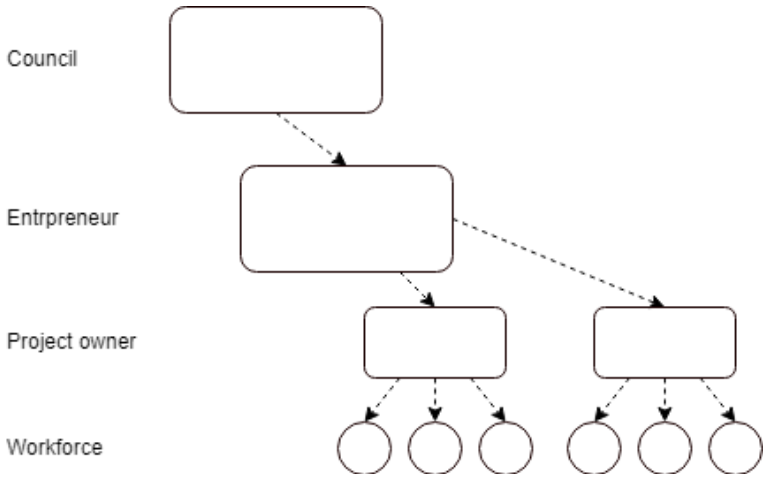

Figure 10 - Visualisation of multilevel projectownership.

As mentioned in Section 1.1., the ability for the inhabitants of Vasse to shape their neighbourhood to their own liking should increase wellbeing within the community. Demands should therefore not only be made by the council, but by the community as well. We have decided that consensus on these demands or wishes should be achieved outside the application, but the tasks that emerge from it must be allocated through the auction system.

Top-down and bottom-up approach
The division of tasks by the project owner may not be in line with the wishes of the potential workforce. This top-down approach could thus lead to a mismatch between offer and demand. A bottom-up approach, with which inhabitants can offer to perform a piece of a larger task could solve this. Also, it is not unlikely that people put down offers that are not exactly in line with the requirements. Offering to perform tasks bottom-up makes the system more versatile, but also more complex. After all, it requires project owners to make price/quality ratio-considerations and revision of task division.

Disagreement on task performance
It may occur that people disagree on how well a task was performed with respect to contract agreements. To solve such problems, we could introduce an arbitration committee between the *check* and *payment* phase from Figure 9. The specification of tasks plays a role in this. Ambiguity in task specification is prone to misunderstanding. For example, “Mow the grass every month” is a different task than “Make sure that grass never grows beyond 10 cm height”.

3.1.2. Practical difficulties
This section covers some difficulties that have been recognised and are more specific to the case of the Vasse community and the nature of the projects.

Agent rationality and revealing bidding information
When you can buy or sell a good or service in exchange for your true value, you are indifferent between having either the money or the good or service. To put it bluntly, if you buy something and you are happy about it, you bought it for a price below your true value and hence made a profit. Determining what this true value actually is, however, is not easy. If we consider a task in our project, say, mowing a lawn, one must consider many aspects to determine its value. Aspects that can be considered include, but are not limited to, the required time, the required equipment, the physical effort, the fact that the commitment could conflict with more desirable activities, appreciation from neighbours and/or the sheer feeling of gratification. All such aspects must come together and be reflected in a single number (price). This is not something that is easily done and it is not unlikely that people will struggle with this. Over time they may be increasingly able to approach this true value as they get experienced with the work and how they feel about it.

The auction in this project is without *free disposal*, meaning that all tasks must be filled for the council to be able to 'hire' the community for its public service obligations. In order to have all tasks filled, it could be beneficial to reveal bidding information so that inhabitants are able to see which tasks have received no offer yet and are thus waiting to be filled. Furthermore, even when disbenefits of irrational behaviour are recognised by the participating community members, we can assume that *word gets around* in a small community and that after the auction closes, people share bid information. To what extend would this influence future auctions or the project as a whole? We now look into the consequences of bid disclosure. The following implications follow from an explanation of the VCG-mechanism which can be found in Section 3.2.1.

Let us assume two bidders b_1 and b_2 that bid 200 and 220 respectively on the same task (or bundle of tasks). Let us further assume that bidder b_1 won the auction.

- If they recognise that they are the only two bidders and have reason to believe they will be the only two bidders during the next period, they are able to collude and increase the price beyond their true values to increase gains. In Section 2.2.4. we have already seen that auctions do not work well if bidder collusion is possible.
- If they have no reason to believe they are the only bidders, we notice the following: Bidder b_2's true value is 220. Decreasing his bid may increase his chance to win, but doing so could result in a loss. On the other hand, bidder b_1 has no incentive to change his bid either. As we have seen in Section 3.2.1., the *winning* bid only determines to whom the task(bundle) is assigned. The remuneration is determined only by bids from other participants. Increasing his bid to just below what he thinks competitors will bid does not increase his gains.

A flaw that we can immediately recognise is the notion that bidder b_2, or any other bidder that participated and did not win, has no reason to participate in an auction for this task(bundle) ever again[15]. If there is only one bidder, the VCG mechanism yields the same result as a first price auction, which, if recognisable, is unfavourable for reasons considered in Section 2.2.3. Participants should thus in theory not bid on a bundle that they did not win in the past, but rather look for alternative bundles with overlapping tasks to bid on. In practice, it is not unlikely that people change task valuation over time. For example, when someone retires and no longer needs to take a day off work to perform tasks, they may value their time lower in terms of money. Another reason could be that a task is more cumbersome than anticipated or that people enjoy participation more than they thought they would and hence respectively increase or decrease their task valuation in terms of money.

We have seen that the auction's winner is not able to increase future profit by increasing his valuation to just below that of the runner up bidder and the latter is not able to increase future profit by undercutting the winner (given that he bid his true value). But what if they reveal their bidding information before the auction date?
If bidder b_1 announces that he will bid 200, bidder b_2 may be discouraged to participate as he already knows he will not win. The announcement from bidder b_1 is working against himself because now, his profit decreases by 20.[16]
Recognising this, we can come up with a crafty strategy. We could announce a much lower bid than we actually place in the hopes of discouraging potential competitors and receive a remuneration well above our true value.

[15] Assuming that the true value of all participants remains the same and they continue to participate in future auctions.
[16] Bidder b_1 would receive the winning price if he did not bid (220) minus the wins of other bidders (0), but without the participation of b_2 the auction becomes a first price auction and he will only receive his own bid of 200.

Revealing bidding information is an easy solution to prevent the occurrence of such strategies. If there are multiple bundles of the same task[17], people can still bid on the alternative bundles if their true value for a bundle is higher than the lowest bid or bid on a bundle of their liking. However, by revealing the biddings the auction becomes an open bid auction which is ideal for profit maximisation of the auctioneer, but not for the utility maximisation of the community. People may doubt their own value once they see that others value tasks much lower and could be inclined to lower their own valuation. Valuations can become very fluid and by no means reflect true value. Also, if people can see that a task has no biddings yet, they may be inclined to put down an offer well above their true value. This potentially jeopardises the feasibility of the project in terms of price-competitiveness and feelings of satisfaction within the community. Furthermore, recognising this opportunity incentivises people to postpone bidding.
The mechanisms for utility maximisation depend on this notion of true value and neglecting this could jeopardise long-term content and as such, the social sustainability of the project. Having said that, collusion and price manipulation are no guarantee for disproportional gains. The auction should yield a competitive price for the council to contract the community and if it is not, the council is free to appoint contractors in the same way that it currently does. There is, in that sense, a ceiling price.
To summarise, bid disclosure affects the mechanisms of the auction and its utility maximising features. This is undesirable for the social sustainability of the project and hence not in line with the goal of the project.

The true effect, however, depends heavily on the nature and size of the community. Large anonymous communities may be more susceptible to this kind of behaviour than small and close-knit communities where people know each other and value social cohesion over self-enrichment.

Figure 11 – a) Because task valuation is subadditive, it is not clear how the tasks are valued seperately. b) Task bundles of which the individual task size is measured in different units could be difficult to value beforehand.

a)
There are two tasks to be done: sweeping the sidewalk in front of my house, and sweeping the sidewalk in front of my neighbours' house. I value the first task at 5, considering my valuation of the required time and my valuation of having a neat sidewalk in front of my house. I value the second task at 10. However, when I'm sweeping my own sidewalk, the extra effort of sweeping the sidewalk of my neighbour is so little that I value the combination of tasks at 6.

b)
Offer A: laundry for 15 per instance and lawn mowing for 500
Offer B: laundry for 20 per instance and lawn mowing for 400.

At 10 times laundry requirement offer A costs 650, and B costs 600. At 25 times laundry requirement offer A costs 875 and B costs 900.

Uncertain task size

Using combinatorial auctions, it is not clear how separate tasks are valued. Let us take a look at the stylised example in Figure 11a. If we only offer to do both tasks for 6, it is not known how this value is divided amongst the two tasks.
Especially in social care taking, tasks may not have a predefined size and are therefore more difficult to value beforehand. An example is a laundry service that some people are entitled to by law. The council works with a pay-per-instance structure for this task. Of course, if the offers are 15 and 16 per instance, it is clear that 15 is always better than 16. If, however, the offers would be combined with an entirely different task, say, lawn-mowing, it may not be clear which offer is the better one as we can see in the stylised example in Figure 11b.

[17] In case bundle restriction (Section 3.2.2.) is applied.

Possible solutions would be to work with an estimate and use that as measurement for what offer is best. Another possible solution would be to switch to a different model where all laundry is done for a predefined price. There is of course the risk that either party (council or contractor) is at disadvantage which could harm the wellbeing or wealth experienced and, thereby, the durability of the project.

Privacy

Some tasks, especially some within the social health care domain, are subject to a privacy component. In such cases, it may not be desirable to have anyone perform a task. People may be entitled to ambulatory care for different reasons such as illness, disabilities or age. In such cases some people will prefer care taking by family or acquaintances. The best price is then no longer a leading argument and additional constraints must be met.

This does not fit well with our auction because, naturally, designated providers face no competition and announcing their own price would be unreasonable. Furthermore, letting the people in need select the provider of their liking from the available bidders is prone to collusion.

Currently, people in need are entitled to home care depending on their condition. They receive home care through different channels which are mainly their health insurance, the *Wlz* and the *Wmo* (Rijksoverheid, n.d.) of which only the latter is paid for by the local government. Tasks within the *Wmo* domain are grocery service, home cleaning, day care, etc. These tasks are generally assumed to be non-intrusive and as such, privacy aspects are not considered automatically, but can be taken into account if the person in question desires so (Rijksoverheid, personal communication, may 3, 2018).

It is clear that the rights and interests of the client conflict with the impartiality of the auction, but it is not clear to what extent this problem will occur.

The arbitration committee could possibly offer a solution here if we consider this a matter of task performance.

Another consideration in this matter is how to separate tasks that consider specific households or individuals. An obvious task may be the delivery of groceries around the village, for example. On the other hand, some people may be willing to help family of neighbours specifically and are less interested in doing the same for anybody. In such cases, their value for such tasks is highly affected by personal or emotional components and less by resources components such as time material. In such cases, the ability to apply for tasks bottom-up gives inhabitants the possibility to express these preferences.

Bidder trustworthiness and improper incentives for the entrepreneur

Another potential problem that we have identified is that of people bidding on unrealistically many tasks or tasks that they are not allowed to execute, for example when safety certifications are required. This could result in an unrealistic task allocation. A possible solution may be to delete such offers afterwards and re-allocate tasks with the remaining offers. To prevent such problems, it could be helpful to give the project owner insight into the biddings. They may be able to recognise undesirable biddings and process these accordingly. However, giving the project owner insight into biddings could lead to the risk of an untrustworthy auctioneer, as was mentioned in Section 2.2.4. The project owner has no direct stake in the outcome of the auction because neither will they receive, nor pay for biddings of other people. However, given the nature of the project, it is likely (and probably even desirable) for the project owner to take on some tasks themselves in which case other people's bid may influence his personal gains as we will see in Section 3.2.1. Giving them insight into the biddings could lead to *shill bidding*, or project owners deleting bids that do not match their agenda.

Solutions to this would be to forbid the project owner from bidding on tasks within their own sphere of responsibility, or requiring multiple people to validate adjustments to placed bids.

3.1.3. Expanded model

Our expanded model (Figure 12) reflects the goals set by HOI[2] more precisely than the model in Figure 9. Because the model shows the timing of project phases, time-independent considerations concerning the design are not represented.

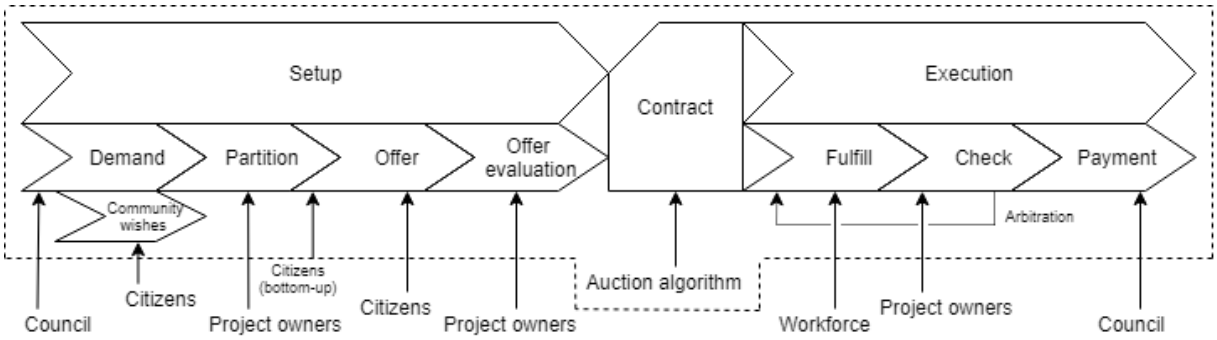

Figure 12 - Stakeholder involvement expanded in accordance with HOI[2] goals.

The expanded model shows where *community wishes* and *offer evaluation* come into play as well as *arbitration* in the execution phase. Also, the stakeholders concerned with each phase are adjusted to be in line with HOI[2]'s conception of the platform.

3.1.4. Conclusions

We have adjusted the model that we started this section with to incorporate more features of the HOI[2] platform that should support its durability. However, there some potential problems that require decisions outside the application. These decisions should ideally be made rationally, but given the current size of the project this is not self-evident.

3.2. Auction algorithms

In Section 2.2.5 we concluded that the use of a VCG mechanism-based combinatorial auction is best suited for our purposes and goals, but generally lacks computational feasibility. We may thus not be able to achieve optimality with such algorithms. However, we could argue that a close-to-optimal division of tasks, in terms of cost, is satisfactory to our case. The algorithm determines how bidders retrieve their tax money in exchange for labour. Sub-optimality would imply that tax money is wasted and hence that the citizens of Vasse pay and receive tax money that could be left out of the total sum. This extra money is not evenly spread amongst all citizens because it depends on how tasks are divided and at what rate.
Close-to-optimal allocation requires minimal 'extra' money and hence minimises uneven spread of these extras.

Our goal is minimising the total cost of performing all tasks. Let us assume a set T of tasks where $T = \{t_1, t_2, \dots, t_n\}$ and t_j denotes task j. Furthermore, we have a set of bidders B where $B = \{b_1, b_2, \dots, b_m\}$ and b_i denotes bidder i. For some collection of tasks s, which is a subset of T ($s \subseteq T$), bidder i allocates a value of $v_i(s)$. Hence, a simple algorithm could be $minimize \sum_{j=1}^{n} \sum_{i=1}^{m} v_i(s_i)$. However, this algorithm is not feasible because it does not consider the fact that tasks are not divisible and cannot be allocated to multiple bidders. In this section we look into alterations that make our simplistic algorithm computationally feasible while remaining close-to-optimal. We start by introducing the Vickrey-Clarke-Groves (VCG) mechanism that determines each bidder's gain after task allocation.

3.2.1. Vickrey-Clarke-Groves mechanism

A resource allocation mechanism that maximises total welfare and determines costs by charging bidders for the 'harm' they cause to other bidders, is called a VCG mechanism (Zhang & de Weerdt, 2007). This can be interpreted as the winning bidder receiving a discount on his bid that is related to the lower bids of his competition. In our situation, where we minimise costs, this translates to awarding the lowest bid with a bonus that increases the amount they receive with respect to their initial bid. We will look at this mechanism using both a mathematical explanation and a stylised example.

Consider again the sets of tasks and bidders on the previous page, where bidder i allocates a value of $v_i(s)$ to set s. If this is his true value and he wins the auction with a bid of $p_i(s) = v_i(s)$, his utility u_i would be $u_i = p_i(s) - v_i(s) = 0$. In other words, if he wins the auction at a price for which he is indifferent between either outcome of the auction, he does not benefit from it and he may as well not take part in the auction at all. This bidder, however, was not alone. His bid increases the total social value (non-winning bids have zero utility) and so he is rewarded for that, based on the other's bids. In fact, the actual price depends on other's bids only. His gain g_i equals the total social value if he did not bid, the minimum of $\sum_{m\neq i}^{m-1} b(s'_t)$, minus the social value that other bidders added to the total, namely $\sum_{m\neq i}^{m-1} b(s_t)$. Hence, bidder i's utility will be $u_i = min \sum_{\mathrm{m}\neq i}^{m-1} b(s'_t) - \sum_{\mathrm{m}\neq i}^{m-1} b(s_t)$. Consider the example in Figure 13 on the next page.

In the example, the lowest cost combination possible is $v_1(t_2) + v_2(t_1) = 65 + 90 = 155$. To determine the actual price that both bidders will receive, we determine for each bidder the winning price if he did not bid, and the social value added by other bidders. If bidder b_1 would not have participated in the auction, the lowest bid to perform all tasks would be $v_2(t_1 + t_2) = 160$. This is the first term in the equation for u_i given above. Next, we subtract the social value that other bidders add. In this example, bidder b_2 wins task t_1 with his bid of 90. Bidder b_3 does not win anything and so his added value is 0. The total value added by other bidders is thus 90, which is the second term in the equation for u_i. The same calculations are done for bidders b_2 and b_3.

We see in the example that both winning bidders receive more than their original bid was[18] and thus have been rewarded for increasing total social value. Notice that because bidder b_3 does not win anything, his utility is zero. The zero-values are left out of the equations for clarity reasons.

[18] Bidder b_1 offers 65 and receives 70, bidder b_2 offers 90 and receives 105.

Example:

There are two tasks t_1 and t_2, and three bidders b_1, b_2 and b_3. They value the tasks as follows:

$v_1(t_1) = 120$	$v_1(t_1 + t_2) = 170$
$v_1(t_2) = 65$	
$v_2(t_1) = 90$	$v_2(t_1 + t_2) = 160$
$v_2(t_2) = 90$	
$v_3(t_1) = 200$	$v_3(t_1 + t_2) = 380$
$v_3(t_2) = 200$	

The lowest cost combination is $v_1(t_2) + v_2(t_1) = 65 + 90 = 155$ to have both tasks done. Now we calculate the gain of all bidders.

b_1	$min \sum_{i \neq 1}^{2} b(s'_t) = v_2(t_1 + t_2) = 160$ $\sum_{i \neq 1}^{2} b(s_t) = v_2(t_1) = 90$	$u_1 = 160 - 90 = 70$
b_2	$min \sum_{i \neq 2}^{2} b(s'_t) = v_1(t_1 + t_2) = 170$ $\sum_{i \neq 2}^{2} b(s_t) = v_1(t_2) = 65$	$u_2 = 170 - 65 = 105$
b_3	$min \sum_{i \neq 3}^{2} b(s'_t) = v_1(t_2) + v_2(t_1) = 65 + 90 = 155$ $\sum_{i \neq 3}^{2} b(s_t) = v_1(t_2) + v_2(t_1) = 65 + 90 = 155$	$u_3 = 155 - 155 = 0$

Figure 13 - Example of task valuations (top) and payment calculation (bottom) by the VCG mechanism.

Notice that if either winning bid $v_1(t_2) = 65$ or $v_2(t_1) = 90$ are increased by less than 5, the respective bidders do not increase their gain. They do decrease the gain of the other bidder, however. If we would increase $v_1(t_2)$ from 65 to 66, b_1 still receives $u_1 = 160 - 90 = 70$. Bidder b_2 now receives $u_2 = 170 - 66 = 104$.

3.2.2. Task allocation algorithms and computational feasibility

The example above shows 2 tasks and 2 bidders. Furthermore, the numbers are so that an optimum exists. In reality there may be hundreds of tasks and a couple of hundred bidders. In such cases it may not be as easy to find an optimal allocation. In fact, the VCG mechanism appears to result in NP-hard calculations for combinatorial auctions (Nisan & Ronen, Algorithmic mechanism design, 2001) which means that they may remain undecidable. Furthermore, the VCG mechanism requires all bidders to make valuations for all possible bundles to approach optimality closely. Given that the number of possible bundles increases exponentially with the number of tasks (See Section 2.2.4.), requiring valuations for all bundles is undesirable. In this subsection we look into methods to help us achieve close-to-optimal feasible solutions.

Bundle restrictions

Let us consider a situation where 10 tasks must be fulfilled. The number of possible bundles that can be created is $2^{10} - 1 = 1023$. If we restrict the number of items that are allowed in a bundle, the

order changes to $\frac{n!}{r!(n-r)!}$ or $\binom{n}{r}$, where n is the total number of items and r is the number of items allowed per bundle. If only 2 items are allowed, the number of possible combinations is 45. Restricting the number of items per bundle dramatically reduces the number of required valuations.

Another method would be to restrict the number of combinations that can be made. For example, we could present 10 tasks as 5 groups of 2 tasks. People can hand in valuations for bundles of tasks within a group, but not between groups. The number of possible combinations is then $5 \times (2^2 - 1) = 15$.

Reducing the number of bundles that need valuation could be feasible if the total number of tasks remains relatively small. If we would double the number of tasks from 10 to 20, the total number of possible bundles becomes approximately 1 million, restricting the number of items per bundle increases the number of bundles from 45 to 190, and restricting to specific combinations of 2 tasks increases the number of bundles from 15 to 30 (linear). Using such methods restricts the possibility for people to express valuations for any bundle they prefer and requires careful considerations from the entrepreneur. Furthermore, if the number of tasks becomes very large, the number of possible bundles may still be too high to evaluate. We could keep the number of tasks low by increasing task size. This may eventually lead to tasks being too large to perform by individuals.

We observe a trade-off between the freedom of bundle creation and the feasibility of valuation. Tennenholtz (2000) shows that bundles that are restricted to 2 items are both computationally feasible and optimal. If the bundles are allowed to consist of 3 items, feasibility is no longer guaranteed. Incentive compatible approximations are feasible for larger bundles when bidders are assumed to be single-minded, meaning that they only allocate value to a single bundle (Mu'alem & Nisan, 2008).

Relaxation and randomised rounding

An extensively researched method is using a relaxation of the model constraints and rounding the results. Dughmi *et al*. (2016; 2011) have explored this method specifically aimed at combinatorial auctions and public projects. First, the constraints of the allocation mechanism are neglected. This means in our case that tasks are considered divisible and can be allocated to multiple bidders. The result is then rounded to integers so that each task is assigned only to one bidder. All other bidders are now left with a bundle that does not contain the specific task, which is only valid if they expressed a value for this bundle.

Demand and value oracles

Dobzinski *et al*. (2010) note that randomised rounding in combinatorial auctions yields solutions that are far from optimal. They propose an extension to the allocation that results from relaxation and randomised rounding by using valuation and demand oracles while maintaining incentive compatibility. An oracle, in computability theory, is a black-box device that makes decisions in problems of any complexity class. Naturally, such a device does not appear out of nowhere to solve our problem. Dobzinski *et al*. (2010) indicate, however, that the required oracles can easily be simulated when valuations[19] are convex and subadditive. We could argue whether that is reasonable to assume for our problem[20].

The oracles can be simulated using the non-zero-utility biddings. This solution still depends on a large number of subset valuations which is not feasible in our project. When the scale of the project increases, for example to a large city or metropolitan area, this solution may be worth investigating.

[19] Because we use an incentive compatible reward allocation scheme, we assume the biddings to be equal to the valuations.

[20] See Figure 11a on page 23.

Greedy algorithms
Greedy algorithms are a class of algorithms that solve problems by choosing the optimum at each stage it encounters. The solution found then consists of local optima and does not necessarily match the global optimum. The main advantage of using greedy algorithms is that they are fast and easy to apply. In combinatorial problem solving, greedy algorithms are based on the matroid of the problem. A matroid is a structure that defines sets as combinations of independent subsets. A greedy algorithm could start at the branch with the largest subset[21] and choose subsequently the largest subset that remains.
There are many different greedy algorithms that can be thought of. Dobzinski & Mor (2018) present an algorithm that improves the approximation ratio[22] from earlier developed greedy algorithms, but such algorithms lack incentive compatibility as Borodin & Lucier (2010) prove.

Shortest Path
Amir *et al*. (2015) explored the use of a multi-agent pathfinding (MAPF) algorithm to solve combinatorial auctions. Each bundle is represented as a path along coordinates (items). The algorithm is meant to find a path for each bidder so that the total path length among bidders is minimalised and paths do not cross.
They propose an iterative algorithm consisting of three steps: participants place bids on their preferred bundles, the algorithm finds a feasible solution, bundle valuations are updated after which the participants can update their bids. Their algorithm does not coincide with the VCG payment scheme, but is incentive compatible. Two major drawbacks of their MAPF implementation are that it may be time consuming to iterate multiple times and the fact that the algorithm does not guarantee a complete or feasible distribution of tasks.

Preference elicitation
As we mentioned in Section 2.2.4., the VCG mechanism requires bidders to place a bid for every possible bundle if we want to be able to achieve optimal results. Given the exponentially growing number of bundles with linear increasing number of tasks, this is not feasible. Conen & Sandholm (2001) propose an algorithm that does not only require bundle valuations, but asks complementary questions about the preference for certain bundles or individual tasks. Their algorithm is aimed at finding Pareto-optimal[23] allocations and maintaining incentive compatibility through VCG payments. An additional benefit could be that the *elicitor*, as the algorithm is called, is able to recognise which bidder may be willing to fill-in gaps and essentially guide the community towards a complete and welfare-maximising allocation.

3.2.3. Conclusions
Most applications for combinatorial auctions are found in the field of information technology and hence, most literature is aimed at solving problems in this field. The shortest path algorithm, for example, may work very well when the bidding agents are nodes in a network that are able to bid rationally hundreds of times within seconds while in our case people may not be inclined to spend much time on the setup phase (Figure 12 in Section 3.1.3). Restrictions on bundles could ease the burden on potential bidders (in terms of time and choice overload) while remaining incentive compatible. Restricting bids is on itself no allocation algorithm, but can prove useful for increasing the optimality. As mentioned on the previous page, the use of demand oracles is worth exploring for larger scale projects.

[21] In terms of number of tasks, total value, value over number of tasks, etc.
[22] The approximation ratio is an indication of how close the solution is to the optimal solution.
[23] Pareto optimality means that no agent can improve on its current state without worsening the state of any other agent (Barr, 2012).

3.3. Application of blockchain technology

In this section we propose a simple application of blockchain technology for recordkeeping of contracts. The objective is to create a low-cost and safe storage for the contracts without violating the privacy of individual community members. The design is based on the concepts presented by Naivecoin (Hartikka, n.d.) and tailored to the requirements set by HOI[2]. We will occasionally compare design choices with the design of current blockchain applications like Bitcoin to emphasise the difference between public and private blockchain applications and to substantiate why we do not choose to apply existing solutions.

3.3.1. Generating blocks and distributing the ledger

Section 2.3.1 explained how blocks in a blockchain are connected to the previous block through block hashes. The first block, obviously, has no predecessor and does not follow this rule. It is hard-coded as the origin of the chain and is called the *genesis block* (Nash, 2017). The genesis block contains an index, a timestamp, data, and a hash that is generated, based on the data. Successive blocks also contain a connection to the previous block. A visual representation is shown in Figure 14.

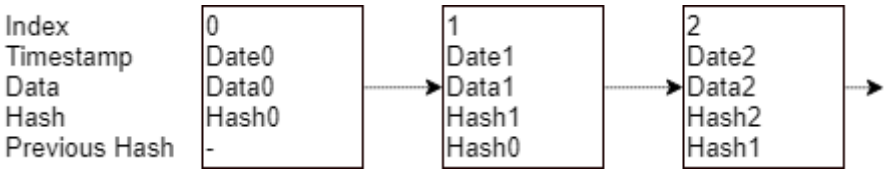

Figure 14 - Successive blocks in a blockchain. The genesis block has index 0.

The hash function generates a key based on the contents of the block. In contrast to these contents, the key is very short which makes verification convenient. When data in block 1 (in Figure 14) are forged, *Hash1* changes and no longer matches *Hash1* in block 2. In turn, *Hash2* changes and no longer connects to the 4th block and so on.

In the Bitcoin protocol, blocks are closed, and new blocks are generated automatically on a time basis (roughly every 10 minutes). This means that, theoretically, new transactions are recorded every 10 minutes. This fast transaction speed and security render it useful as a currency. Our blockchain implementation is not meant to create a new currency, and continuously creating new blocks is not necessarily required. Once the auction and allocation are finished, contracts are created automatically in bulk. It would be more efficient to have the application create a new block when it requires one to store the contracts.

In a private chain, like ours, we keep control over who is allowed to add new blocks. However, we can allow multiple parties to view the contents of the blocks. In our case, we would like the HOI[2] application to be the single entity that can create blocks and store data (the master node) and all other parties involved (council, contractors, arbitration committee) to only verify that their contract is indeed stored (slave nodes). When the master node adds a new block, it broadcasts it to other nodes. The other nodes accept the new block if the index number is exactly 1 higher than the last block. If, for some reason, someone has been able to forge previous blocks and recreate the chain, it will not be accepted by the network because the index number of the forged block already exists.

Alternatively, bidders place their bids directly (and hashed) on the blockchain. This would increase security dramatically because it would make it impossible to tamper with the bids between the bidder and the blockchain. This would require that every participant runs a node in the network which can be cumbersome and increases complexity of the HOI[2] platform. It also increases the complexity of the blockchain code because it is then not only a means to safely store data, but also to handle bids and run the auction algorithm. It also increases storage capacity requirements because all information on tasks, bundles and bids is stored with every participant.

3.3.2. Storing contracts

As mentioned in Section 3.2.1., demands for some tasks within the public domain (especially in care taking) are considered to be sensitive information. In such cases it would be undesirable that such information is publicly stored in a blockchain. In fact, we could argue that the contents of *any* contract are private between the contractor and contractee.

We propose to store all contracts as hashes, based on the contract's contents like blocks are hashed on basis of their contents. The contract in Figure 12 in Section 3.1.3. is a result from the auction algorithm that matches a bid with the corresponding task and its specifications. The agent that placed the bid agrees that he or she will perform the task if their bid is accepted. When a bid is accepted by the algorithm[24] it is therefore automatically signed by both ends of the contract. Both parties receive their contract containing their names, the specification and the agreed price. The HOI^2 application creates a hash from the contract and stores it in a block. Hashes are easy to calculate, but very difficult to reverse. Contract owners can thus easily verify that their contract is stored in the blockchain, but parties who do not own the contract cannot view its contents by having access to only the hash. Should disagreement occur between the two parties, the arbitration committee can easily verify the validity of the contract and act as they see fit.

In this fashion, each end of the contract is personally responsible for safely storing the contract, but validity and possible forging are out of the question. Furthermore, contract contents are kept private and storage requirements are kept to a minimum.

3.3.3. Using the blockchain

The currently most well-known, and in Section 2.3.1. mentioned, blockchain technology use case, Bitcoin, is quite infamous for the energy consumption used to guarantee security (Popper, 2018). Its energy consumption is so high because all the nodes of the network are performing calculations in order to validate transactions. The private blockchain that we have proposed at the start of this section does not require mining by all nodes. Only the master node creates blocks and stores transactions while the slave nodes are merely there to verify legitimacy. Running a slave node requires the HOI^2 application, access to the network (provided by HOI^2) and a device to run it on. Because the slave nodes perform no calculations and the storage requirement is low because only contract hashes are stored, there are no high-grade devices required and energy requirements are kept to a minimum.
This private chain does not provide the same security level that is ensured with the Bitcoin blockchain. Bitcoin is a digital currency with a market cap of billions of dollars. Cracking the Bitcoin network would make it possible to divert large amounts of value-representing coins, thereby harming the rightful owners. On our private chain, there is no transaction of value between peers. The contract hashes that are stored represent no value in the physical world and their contents remain inaccessible independent of the blockchain. Implementing the same level of security that Bitcoin has would therefore be excessive. The private chain is, however, immutable and thus cannot be altered unnoticed.

In practice, the inhabitants of Vasse that want to participate in the project will need the HOI^2 application[25] to bid on tasks or bundles and to check off tasks that they have fulfilled. Running a blockchain node is optional. They do not need to interact with the blockchain itself unless they want to be absolutely sure that their contract is stored.

[24] After eventual intervention from the project owner.
[25] Either as a computer program or an app, or any way the board desires.

3.3.4. Blockchain and the HOI^2 application

In this section we show how the blockchain is connected to the other elements in the project. The representation of a blockchain as a chain of blocks is very intuitive, but in reality it is not a pleasantly readable ledger. Instead of trying to read the blockchain, we can make use of the graphical user interface of the HOI^2 application.

Figure 15 shows how the users only interact with the central server and how the master and slave node(s) interact for both possible implementations from Section 3.3.1. The council, as a user, delivers the task specifications to the central server after which the entrepreneur (user) can divide the specification into smaller tasks. The inhabitants (user) place bids on bundles, all through the application and stored in the central server. When the due date arrives, the auction algorithm allocates the tasks to the respective auction winners and stores the contracts in the master node. The master node broadcasts the created blocks to the slave nodes that inhabitants can run optionally. There will be at least a few slave nodes, namely, with the council and with the HOI^2 board.
In the situation depicted on the right of Figure 15, all interactions run on the blockchain. Still, the HOI^2 application can provide a user interface so that users do not need to interact with the blockchain by running code.

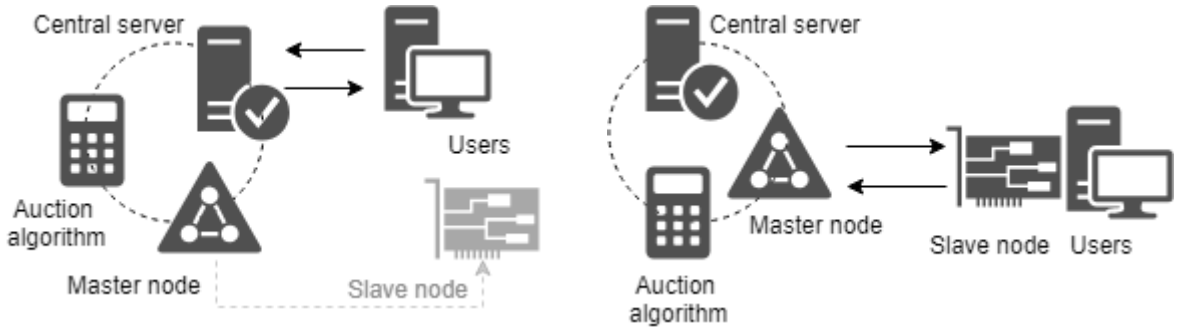

Figure 15 – Indirect interaction between the users and the blockchain with optional slave node (left) and direct interaction with obligatory slave node (right).

3.3.5. Collaborative groups in social applications

As was mentioned in Section 2.1.2., social collaboration can be stimulated by introducing a reputation component. We know that blockchain networks can be used to transfer value when the network generates tokens. The network that we imagine does not rely on digital currency or assets to be of use. However, we could introduce a system where the network generates tokens that are distributed to digital addresses (on the blockchain) called *wallets*. After all, every participant is known in the HOI^2 platform. Furthermore, the contract that each participant receives contains information on total reward, number of undertaken tasks etc. A very simplistic implementation of a reputation system would be to award people with tokens that represent how much someone has done for the community.

3.3.6. Conclusions

The implementation of a distributed ledger for recordkeeping instead of using an ordinary database poses some difficulties. First of all, appropriate ready to use solutions do not yet exist which means that implementation requires development. Furthermore, the use of a distributed database requires an infrastructure whereas centralised applications do not. The main benefit is the immutability that blockchain technology offers. The other properties such as privacy and autonomicity are not unique to blockchains.

3.4. Implementation

In this section we look into constraints for practical implementation of the platform in Vasse. We will also identify potential bottlenecks and investigate pragmatic alternatives to the design choices we have made so far. The intended scale of the project comprises all tasks that the local government performs within the villages' borders[26]. For the start-up phase, the cooperative's board decided to limit itself to maintaining the green areas only.

3.4.1. Limitations

Legislation

The short-term scope of the project is the larger parts of the green area. These are maintenance of ditches and banks along the main roads and trimming the trees in both the inner and outer regions of Vasse. The maintenance of ditches requires specialised equipment and the trimming of trees (especially alongside roads in the outer region) requires certification. Furthermore, the cooperative decided that it does not want to be involved with individuals for liability and taxation reasons. Only legal entities can qualify for these tasks and hence, the cooperative is seeking support from local farmers, gardeners and sports clubs, the latter of which could ask volunteering from its members. The limitations that occur from legislation could prove to be a significant bottleneck.

Truthful bidding

Considering this, we have only a few bidders and few tasks to auction off, some of which cannot be fulfilled by each bidder. An auction does not work well in such cases, especially when the bidders are able to recognise that they are the only bidder. After all, they can specify any price and still win. Also, a VCG-mechanism does not fit its purpose in such cases. With only a few bidders, a wide bid-spread is more likely and could make the use of this mechanism backfire. Consider again Figure 13 and let us assume that bidder b_2 does not exist. In this case, bidder b_1 wins both tasks and his utility is now given by $u_1 = 380 - 0 = 380$ which is considerably more than his true valuation of 160. The VCG-mechanism could thus increase the price dramatically. Another reason to require a large pool of bidders is the fact that a combinatorial auction poses an NP-hard problem. With increasing number of bidders, the number of combinations increases as well which, in its turn, increases the possibility of complete solutions. With increasing number of tasks, the number of possible bundles increases exponentially. Close-to-optimal solutions under a VCG pricing scheme require valuations of all bundles by all bidders. Conitzer & Sandholm (2006) address that under such circumstances, first-price payment schemes perform better in terms of optimality.

Furthermore, the HOI^2 board determined that it needs income as well to cover the costs involved with the development of the platform. They propose to retain ten percent of all cash flows through the platform. This decision has effect on the meaning of *true value* of bidders and how they will bid. Depending on where the ten percent is charged, it may affect the initial biddings or only the final price of the tender.

Decentralisation

The HOI^2 board emphasises the importance of using blockchain technology in this project, even in the start-up phase. One of the reasons, they say, is the fact that this is demanded by the council for the basis of trust. On the other hand, they acknowledge that it is difficult to establish decentralisation with so few parties involved and hence, they propose to implement a ledger with only one or two nodes. Although a centralised blockchain application can provide the same functionality as a decentralised one, the argument of trust vanishes and would not comply with the council's request.

[26] The intention to expand further is beyond the scope of this project.

3.4.2. Constraints and points of action

Under current circumstances, an auction is not likely to yield a financially optimal allocation. In practice, the HOI^2 board will negotiate an allocation with the interested contractors.
We have already addressed how the board will deal with the restrictions concerning liability and taxation. The board will not contract individuals, only existing legal entities. This is also the reason that individual negotiations are practically possible; there are very few parties to negotiate with at this stage. Furthermore, the current scope of the project does not enable cross-domain task combination benefits.
The application is built according to the model in Figure 12. It allows different user types to perform actions according to their type and the timing of the project. Furthermore, the HOI^2 board hires an entrepreneur to divide tasks and recruit contractors.

Creating a platform that complies with the set goals requires the following steps to be taken:

- ☐ To comply with the goals of keeping governmental meddling out and create a platform that allows people to experiment and be creative, it is important to increase the scale of the project by incorporating more public task domains. This requires trust and a lenient attitude from the council which can be difficult because they remain responsible. Adding more domains increases the possibility of creative and efficient solutions by the community.
- ☐ To enable inhabitants to take responsibility and ownership, they must be allowed to do so. The most direct solution would be alternative legislation concerning employment and liability. A more pragmatic solution could be to find a business structure for HOI^2 that is able to cover liability and insurance for its employees.
- ☐ The HOI^2 application must be developed and a blockchain implementation must be developed. Depending on the desired use for the blockchain, the application is merely a user interface for the blockchain, or a separate application that can be run independently from the blockchain.
- ☐ The HOI^2 board must appoint entrepreneurs for the division of tasks and a arbitration committee must be appointed to see to correct execution of task division, allocation and completion.

These steps must be taken to be able to run the project as it is envisioned by the board and are independent of the implementation of the combinatorial auction algorithm. The auction algorithm is meant to maximise social welfare while minimising costs to make the project feasible and socially sustainable. Additional constraints for feasible implementation of the auction algorithm are:

- ☐ A large pool of participants is required in order to minimise the risk and effectiveness of collusion and to increase the chances of finding optimal and complete solutions.
- ☐ Implementation of additional algorithms that allow for optimal and complete solutions without the need of complete valuation by all participants.

These constraints are not easily met, especially for a small community project as HOI^2 currently is. However, a large bidder pool is not unlikely once the project increases scale as is envisioned. Policy and legislation is a matter for the national (or even international) government. As stated in Section 1, the project is inspired by the national government's decision to make local governments financially responsible for social care taking. We could argue that it is thus not unreasonable to ask for legal adjustments that enable local governments to address this issue.
The tasks in the project could potentially be within the entire range of professions and a supposed business under which all contractors are appointed should thus be able to cover all legal and financial requirements for the employees. Alternatively, the contractors act as freelancers and are individually responsible for these requirements.
In either situation, the contractors determine their own (minimum) price and because of that, there is no clear distinction between paid work and voluntary work. Currently, the labour law dictates minimum wages, working conditions and regulations considering voluntary work. The contracts that

arise from these auctions should abide by these laws or the laws should be widened in order to make this structure possible.
Because tasks from different public domains can be combined into bundles, it can become difficult, if not impossible, to determine how the municipal budget is composed. This requires a different approach towards budgeting and may no longer allow for separate entries, but rather a lump sum budget to perform all public tasks.

Finally, the decentralisation constraint is imposed by the council. It is possible to decentralise the ledger at a later stage by adding nodes. In that case, the implementation of blockchain technology is merely proof-of-concept.

3.4.3. Conclusions

In its current state, the project is not able to comply with all goals set (Section 1.1). The current scale does not allow for the exploitation of modern technologies and legal restrictions prevent individual community members from participating and thus, from taking ownership and responsibility. Scaling only does not solve the legislation issue and could even impose new issues concerning optimality.

4. Conclusion

Our aim was to design a platform through which public tasks can be split and allocated to members of a local community in exchange for payment in order to increase wellbeing and wealth in that community. Additionally, the platform should apply blockchain technology as a basis for trust.
The platform will be managed by a cooperative called HOI^2, which facilitates the infrastructure and communication between the local government, entrepreneurs and inhabitants of Vasse, the village where the project is set up. The aim is to bring these together in an application.

To achieve optimal social welfare, and avoid misuse and enrichment of individuals, the allocation and payment system should be incentive compatible. In incentive compatible systems, individual agents maximise social welfare by doing what is best for them personally as well. Prevention of misuse is an important aspect for the fairness, and thereby the sustainability of the project.

Our next goal was to decide how individual tasks should be valued. We found that administrative pricing schemes require the entrepreneur to determine demand and according to that, establish a price for each task. This is cumbersome and prone to arbitrariness. Auctions let people announce their private value for a task. A specific type, a combinatorial auction, gives the inhabitants of Vasse the opportunity to value combinations of tasks. This gives us the opportunity to create bundles with tasks from different domains, and benefit from subadditivity of task valuations.
We can make the combinatorial auction system incentive compatible by introducing a Vickrey-Clarke-Groves (VCG) payment scheme that determines the price on a basis of the valuation of other bidders. Under this payment scheme, bidders achieve maximum welfare by bidding their true value for a bundle of tasks. A major disadvantage of the VCG scheme is that it requires bidders to give valuations for all possible bundles, which may be infeasible because there are exponentially many bundles given a number of tasks. A preference elicitation algorithm takes this requirement away and instead asks additional questions in order to achieve an optimal allocation. For large-scale projects, the use of demand and value oracles is promising as well.

To keep track of all contracts between the local government and the contractors, we can make use of a blockchain based distributed ledger. We proposed to create a new blockchain so that it can be tailored to the specific needs of the HOI^2 platform. Blocks do not need to be created on a time basis. Rather, the master node can create a new block to store contracts only when it has contracts to store. To create trust, new blocks are broadcasted to other peers in the network for verification. This creates a decentralised ledger that can be verified be anyone, while no one can alter it. Because the nature of some contracts is privacy sensitive, the contracts are hashed before they are stored. Because only hashes need to be stored rather than entire contracts, storage capacity requirements are kept to a minimum.

The proposed systems are aimed at guaranteeing trust and cooperative behaviour. There are, however, some issues that must be dealt with outside the scope of the application. These are: achieving consensus on shaping the neighbourhood before it can be put up as task, dealing with the possibility of an untrustworthy auctioneer (entrepreneur) and dealing with tasks of uncertain size.
Another obstacle is the current size of the project. With very few bidders and tasks, auctions do not work well in terms of maximising social welfare. Even more so, the VCG payment scheme is likely to increase prices dramatically when there are very few bidders. Furthermore, current legislation makes it difficult to enter into contracts with individuals for liability and taxation reasons. This pressures the possibility to create a market with many bidders even more.

Given these circumstances, the proposed design of the platform is currently not feasible and requires increased scale and an adjusted approach and/or legislation towards public-domain community employment.

5. Discussion and further research

In this section we look back on the work, the choices made and the conclusions that transpired from them. This section also contains suggestions for further research.

In the main question, social sustainability is mentioned as requirement platform design. It is meant to be achieved through the application of welfare maximising mechanisms, but is not measurable as such. There is no time horizon and we could argue that sustainability means perpetuity. The design is then either sustainable or not, which is unmeasurable. This is a very theoretical point but forces us to ask at what point the project is considered unsustainable and if, at some point, it is, is the design flawed, or are its constraints no yet, or no longer, met?

In Section 1.5., I pointed out that out of the many disciplines involved with the problem, only those concerned with value and risk would be addressed. Doing so creates a sandbox where only difficulties concerning valuations, and risks involved with those valuations, are recognised. This is, in my opinion, a direct cause for the fact that the design is not currently usable.

Concerning the design itself, combinatorial auctions are a popular mechanism in commercial resource allocation or IT applications like network routing. Literature on these matters assumes rational agents to make proper valuations. Can we assume individuals to be rational to the point where they are able to determine their *true* value for a task or set of tasks? If not, how does this affect the incentive compatibility property of the auctions? If incentive compatibility no longer holds, or is not perceived as such, this could harm the social sustainability as people may feel disadvantaged and less inclined to commit themselves to a task again.
Considering the notion of *experienced utility* (Kahneman *et al*., 1997), which they address as a "hedonic quality", we should consider the fact that people, as emotional beings, may feel displeasure beyond rationality. The utility they experience can even differ from time to time for reasons such as emotional state or opinions of others. It may be interesting to explore whether it is possible and desirable to aid individuals in making their valuations.

Although it became clear that auctions do not work well with few bidders, it is not clear how many potential bidders are desirable to make an auction work well (in terms of cost minimisation). Literature is sparse in this area. One reason for that may be that there are many auction mechanisms that are tailored to specific goals of the given market and that the number of presumed participants is incorporated within the mechanism, like setting a reservation price to prevent significant losses. It would be interesting to investigate whether it is possible to determine and set a critical mass of number of bidders that, upon achievement, enables us to put the auction mechanism to use. Alternatively, one could investigate the possibilities to tailor the current design to the current circumstances in order for it to be viable.
Larue *et al*. (2013) found that in sequential multi-unit auctions of livestock, an increasing number of bidders can decrease the average auction price. Because the auction type is different and not strategy-proof, their findings are not directly applicable to our study. Still, it may be interesting to see whether similar effects are apparent for the mechanisms in our design.

Current blockchain technology applications focus on decentralisation and efficiency in public markets. Private blockchain applications are less common, or at least less covered in (scientific) literature. The proposed blockchain design does not yet exist and requires development from scratch. Experience with this type of blockchain would be an interesting area for research and reporting.

HOI^2 envisioned a platform through which individuals can fulfil public tasks. Current legislation renders this infeasible, or at least undesirable. I would propose to investigate the possibilities of another legal

structure for HOI[2] that makes it easier to deal with many long and short-term employees that perform all kinds of tasks. A structure that immediately comes to mind is an employment agency.

Finally, the forthcoming problem of increased health care cost for the local government without additional funding from the central government was cause to this initiative. However, actual costs and savings are at no point considered. We can identify a lot of overhead induced by this project that is not considered in the actual question at hand, namely, is it possible to create a solution for the implied budget deficit? Costs involved with this project, besides remuneration for task fulfilment, are development and maintenance of the application, remuneration/salary for additional employees such as the entrepreneur and the arbitration committee, employment insurance, etc. The actual gain for the community, independent of the success of the project, is highly uncertain.

Given the current circumstances concerning the project and economic climate, this work should be viewed as an explorative design for inspiration in future developments.

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