The role of deliberative agents in analyzing crises management in pre-modern towns

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Abstract. So far, the impact of deliberative interventions and actors' preferences in dealing with mortality crises in pre-modern European towns seems widely unexplored. For that purpose a multiagent-based model has been implemented in JAMES (A Java-Based Agent Modeling Environment for Simulation). In order to allow for heterogeneity three actor groups - merchants, craftsmen, laborers - and one planning agent - the local authorities - are distinguished. Actors are interacting as consumers and suppliers via several markets, e.g. grain market, consumer good market, and labor market. Within the course of simulation the local authorities is capable of intervening in market processes and implementing measures of crisis management, e.g. job creation programs. From simulation results a deeper insight into economic and demographic consequences of disasters and the effectiveness of crisis management can be obtained.

1 Introduction

Mortality crises are characterized by a massive loss of lives within a relatively short period of time and they are caused mostly by exogenous events such as natural disasters, epidemics, harvest failures, or wars. The salient features of mortality crises are a great loss of births, an abrupt fertility decline during subsequent periods [18] and a more or less severe paralysis of the local economy. The history of pre-modern Europe is very rich of such disastrous events, Black Death" (1347-1352) [7,23] and The Great Famine" (1315-1317) [16] being not only the most famous of these events, but having had an European-wide effect, too [8]. The permanence of mortality crises led Malthus [18] and the ongoing research based on his ideas to the conclusion that mortality crises in the pre-industrial era were natural checks that stopped mankind from stretching the limits of physical resources too far [25,20,34].

When looking at mortality crises from a pure macro-level perspective it seems as if European mortality crises were only historical episodes without any long-term effect both on the demography and the economy. The population of Europe and the economic markets always have been able to recover, reaching new and in fact higher level equilibria. Analyzing this issue from a micro-level perspective, things are looking very differently. Many large-scale disasters with only a region- or community-wide effect happened [22] and long-term consequences of such disasters cannot be denied. Across Europe demographic and economic consequences of mortality crises were indeed different, and not all communities managed to recover from such crises [13,24,1,33]. E.g., following numerous heavy storm tides between the 14th and the 17th century, the northern part of the Netherlands and the North Sea coastal areas of Germany stagnated demographically as well as economically during the late 17th century, whereas in other parts of Europe both population and economic growth started to accelerate at the same time [15]. But, it still remains unclear how strong the course of economic growth and demographic development was affected by the frequent occurrence of mortality crises [32]. Questions, that, e.g. with respect to the AIDS epidemic in Africa [4], could be of interest for the research on modern mortality crises and crisis management, as well.

The role of local authorities in preventing and overcoming economic and demographic crises caused by large-scale disasters is of particular interest in our application. The way how a crisis is managed determines the subsequent process of recovery. What was done in reaction to a famine, an epidemic or a fire in the town? The modern example of the earthquake in Kobe, Japan, in 1995, suggests, that careful chosen actions by the government could ease the recovery from disaster [14]. In the past, measures of crisis management such as interventions in economic markets or the implementation of job creation programs were typical actions taken by local governing bodies during the course of a crisis. Also, precautionary measures such as the hoarding and the public supply of grain in order to avert grain price increases or the closing of the town in order to prevent the spread of an epidemic were often in use [6]. It still remains unclear whether these actions were chosen carefully with respect to the current situation or whether they worked to perfection. Very often, intervening agents did not have complete information about the full scale of the disaster, they started intervention too late, they took inappropriate or wrong measures or their decisions were designed only to satisfy the interest of local pressure groups rather than being taken in order to prevent the town from severe long-run impacts.

By applying simulation methods to this issue we attempt to test whether a so-called “crisis management” implemented by local governing bodies in the course of disasters and mortality crises in pre-modern European towns was effective and efficient as well. A first step towards this goal is modeling and simulating the demographic-economic interactions following a disaster.

Most of the analysis of demographic processes is based on mathematical macro models many of which are solved analytically [17]. This is also true for the analysis of historical demographic-economic interactions [9,2,3,19]. In contrast, we will use a multi-agent approach to modeling and simulation. Multi-agent approaches provide a new perspective on modeling and simulating social communities. As do multi-level simulations in general, they turn the attention to interacting individuals and the emerging macro patterns on the institutional level. In addition they support modeling and simulating heterogenous social communities that embrace reactive and deliberative actors, likewise [11]. Thereby, the interrelations between decision processes based on norms and preferences and the dynamics of communities are moved into the focus of exploration.

In the following we will describe how we exploited an agent-oriented approach, i.e. JAMES (Section 2), to model and simulate the interactions of households being producers and consumers of goods and reacting differently to a crisis according to their current social and economic status (Section 3). Simulating reaction patterns during a crisis and during its aftermath helps in gaining a deeper insight into the economic and demographic dynamics as well as into how these processes were interrelated, although complete time series data are lacking for pre-modern European communities, which hampers a throughout and detailed validation of the model (Section 4).

2 James

JAMES, a Java-Based Agent Modeling Environment for Simulation, constitutes a framework for the modeling and simulation of multi-agent systems. Unlike other multi-agent simulation systems [27,28,21], JAMES supports different sequential and parallel execution strategies and is firmly rooted in a formal approach to discrete event simulation [30].

The model design in JAMES resembles that of parallel DEVS [36], enriched by means for changing the composition and interaction structure [30]. Dynamic systems are described as reflective automata whose transitions are triggered by external events and the flow of time. The original DEVS formalism has been extended to allow models to assess and access their own behavior and structure and to embed real-time processes within the simulation. This formalism has been implemented in JAMES, whose flexibility has already been put to test to construct different test scenarios, e.g. TILEWORLD, to describe *BDI* (belief, desire, and intentions) architectures [12], to analyze the performance of planning agents [26], and agents moving through a virtual network [29,31].

As does DEVS [36], JAMES distinguishes between *atomic* and *coupled models*. Coupled models are the means to develop complex models by hierarchical composition. A coupled model is a model consisting of different components and specifying the coupling of its components. Its interface to its environment is given by a set of external input and output events. An atomic model represents a time triggered state automaton with the ability to assess and access its own structure. It can be used as a frame for modeling an agent and its environment or components thereof [26] or as a representative and interface of a software agent which runs in parallel to the simulation system [31]. It embraces a set of input events, a state set, a set of output events, an internal and external transition function, an output and time advance function. The internal transition function dictates state transitions due to internal events, the time of which is determined by the time advance function. The external transition function is triggered by external inputs which are defined as bags over simultaneously arriving input events. Each model communicates with the external "world" through its input and output events, the latter of which it produces via its output function. The time advance function defines the reaction time between incoming events and outputs to be produced. In addition, it allows models to stay active without any incoming events, e.g. to launch messages and requests into the network from time to time. To facilitate the integration of real time processes, e.g. planning systems, and to support the execution of agents in the virtual environment as they are run in the physical one [31], each model is equipped with a peripheral port. The function `real-time-knob` enables the user to relate simulation time and time used by the real-time process explicitly as part of the model.

JAMES provides reflective mechanisms which empower the atomic model to change the composition and interaction structure of the model. Structural changes, e.g. the deletion and creation of models and couplings, are the building blocks to capture the phenomenon of agents roaming the Internet. These methods include methods to commit suicide, to remove themselves from their environment, to create or add other models within the embedding coupled model and to alter their interaction structure with their environment. To initiate structural changes outside their own range, models launch corresponding requests to models which have direct access to the region of interest.

3 Implementation in James

Actors and institutions are both described as atomic models in JAMES. Whereas the institutions are modeled as traditional dynamic systems the actors are equipped with deliberative mechanisms that guide their activity. Average citizens are assumed to choose their action based on preferences and the expected utility of an action. The local authorities is assumed to use plan steps to deliberatively control the pre-modern town and to achieve its goals. Institutions can be interpreted as corporative actors whose actions affect the citizens and the local authorities whose behavior also depends on the their own preferences or desires, norms, current situation, and their options. The cumulative effect of all the actors' activities is reflected at the level of the institutions.

3.1 Citizens

The population of a pre-modern town is divided into three actor groups (merchants, craftsmen, laborers) and one planning agent (local authorities).

These actor groups are part of the coupled model POPULATION. They constitute atomic models but internally comprise groups of homogeneous actors. Actors choose their action depending on earlier observations and their own state which embraces beliefs, preferences and intentions. They execute an action, and if no reaction of the environment asks for correcting the flow of activities, after a time they continue with their planned activity. Otherwise they start to re-evaluate their situation.

With the exception of the local authorities all other citizens base their decision on an economic utility model. Living in an economic world, actors attempt to maximize their utility which they derive from consumption and have to decide what type of goods to acquire. As goods are assumed to be so-called "normal" goods, the tendency to consume these goods increases with the income and decreases with raising prices.

The Cobb-Douglas-type utility function determines the utility of a certain bundle of goods based on the preferences. The optimal amount of a certain good x_i is constrained by the income and the prices p_i for this good and all alternative goods. The preferences are encoded for a certain good i as β_i. If we assume that a consumer has to buy a certain minimal amount of goods γ_i and that the utility is measured on a logarithmic scale then we arrive at the following equation which is known as the "Klein Rubin Utility Function".

$$U(x_1, ..., x_n) = \ln\left(\prod_{i=1}^{n}(x_i - \gamma_i)^{\beta_i}\right) = \sum_{i=1}^{n}\beta_i \ln(x_i - \gamma_i)$$

The Lagrange method is used to maximize the utility given a limited budget, i.e. y. The "optimal" amount of a certain good to be ordered can be calculated depending on the minimal demand of that good and a quota that

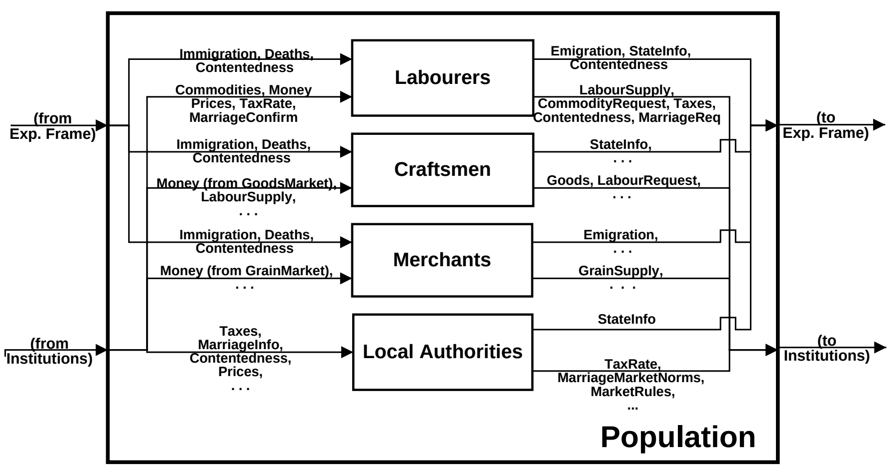

Fig. 1. The population

depends on the preference system and the income of the actor and on the price of the good and on prices of alternative goods.

$$x_i = \gamma_i + \beta_i \frac{y - \sum_k p_k \gamma_k}{p_i}$$

Actors do not only consume but also produce goods for the markets. The actors in our model of a pre-modern town are playing the role of consumer and/or producer depending on the market. Laborers offer their labor on the labor market. The labor is requested by the craftsmen and merchants. Depending on the situation the local authorities releases some of the grain, it has bought and laid in stock before, so the local authorities represents a consumer and producer of the grain market. Merchants sell grain to the other inhabitants of the pre-modern town. Goods are only produced by the craftsmen and requested by laborers and merchants. Thus, the parameter values between population groups vary, e.g. the preference and the minimal amount of needed commodities (see table 2).

	laborers	craftsmen	merchants
γ_{grain}	30	30	30
γ_{goods}	10	10	10
γ_{labor}	0	100	100
β_{grain}	0.3	0.2	0
β_{goods}	0.7	0	0.4
β_{labor}	0	0.8	0.6

Fig. 2. Parameter values used to determine the requests of goods, grain, and labor in the experiments

The following reflections apply to the exploitation of labor and how Merchants and Craftsmen determine the economically rational amount of grain and goods to be produced.

We assume the production process of the output Q of consumer goods to be a function of only labor input:

$$Q = f(L) = AL^{\alpha}$$

L is the amount of labor required, α represents the productivity elasticity and A is an efficiency rate.

We assume that the aim of a venture is to maximize its profits. Since the labor input itself depends on the wage ($L = f(p_l)$) the most rational amount of consumer goods (Q^*) to be produced is calculated based on the amount of production ($f(L)$), the market price (p_c) and required work effort ($p_l L$)

$$U(Q) = p_c f(L) - p_l L \longrightarrow Max!$$

which gives

$$\ln Q^* = \frac{\ln A + \alpha \ln \alpha}{1-\alpha} - \frac{\alpha}{1-\alpha} \ln \frac{p_l}{p_c}$$

3.2 Institutions

Markets, the public opinion and the taxes are part of the institutions. The markets embrace the good markets, the grain market, and the labor market. All of them follow the same pattern. They react to requests from the citizens by transferring commodities to the citizens. Market prices are formed in accordance with the ratio of demand to supply. To avoid abrupt changes a parameter damping the price mechanism is introduced in the dynamics of the market. The local authorities can directly influence the market process by setting an upper bound for prices.

The way how the current state is perceived and evaluated by the community is stored in the public opinion which affects the migration dynamics. The public opinion is the aggregate of all households' contentedness, contentedness being measured as a combination of change in the households' own economic status over time and of change in comparison to the average economic status of households in other social groups. The information about the current public opinion triggers the intervention by the local authorities.

All corporative actors are grouped into the coupled model INSTITUTIONS and interact only indirectly via the citizens and the local authorities (Figure 3).

3.3 Authorities

Whereas the laborers, craftsmen and merchants are realized as utility based agents, the local authorities is modeled as a so-called BDI (beliefs-desires-intentions) agent. The local authorities has certain beliefs about the situation and the interrelation of the markets, tax rate, stock of grain, budget, emigration and the citizens' contentment. These beliefs are partly inherited and partly derived by observing the environment and the own activities and by condensing quantitative information into qualitative "beliefs". As described above, the public opinion is designed to trigger actions by the local authorities.

The responsibility of the local authorities is to regulate markets e.g. by raising or lowering wages, by raising consumer taxes, lowering hearth taxes, installing guild limits or job creation programs. The authorities associates with its activities certain preconditions, effects and time horizons, which allow to derive automatically given a certain situation, and certain goals, i.e. desires, the intentions of the local authorities. In our implementation we employed GRAPHPLAN [5] as part of the cognitive component the local authorities is equipped with.

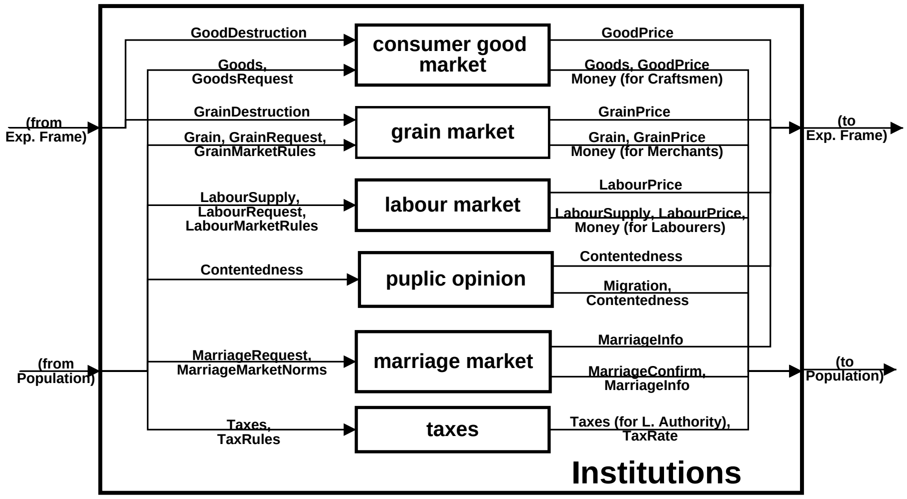

Fig. 3. The institutions

The implementation of actors is based on class `Agent` (Figure 4), which provides all DEVS-methods necessary for interaction with the simulation system. But while all agents use the same interface for perceiving and acting each type is equipped with a unique kind of cognitive component, responsible for dealing with perception and calculating appropriate actions. `GroupCC` realizes the functionality for calculating perceptions and actions of a whole group of agents with homogeneous behavior pattern but heterogeneous states. `CitizenCC` implements the shared properties of all citizens and `WorkerCC`, `CraftsmenCC` and `MerchantsCC` the specific behavior of each actor group. The cognitive component for actor groups uses a state class consisting of multiple instances of class `SimpleAgentState`. `SimpleAgentState` represents the situation of one civil household in the simulation by storing all information and intentions in numerical variables. In contrast `PlanningAgentState` is structured into beliefs, desires and intentions, which are stored in knowledge bases. Because the simulation system operates mainly with numerical values and the external planers with symbolic variables, cognitive components for planning agents have to provide the facilities for transforming quantitative into qualitative information and vice versa. E.g. the contentedness of an individual is calculated as a weighted sum of the own wealth in relation to the wealth of the actor group to which the individual belongs, the own wealth in relation to its prior wealth and the own wealth in relation to the wealth of the other actor groups. The average contentedness values of actor groups which are gathered in the model public opinion reveal the current sentiment of the different actor groups to the local authorities. A value less than 0 being interpreted as low satisfaction which requires the authorities attention.

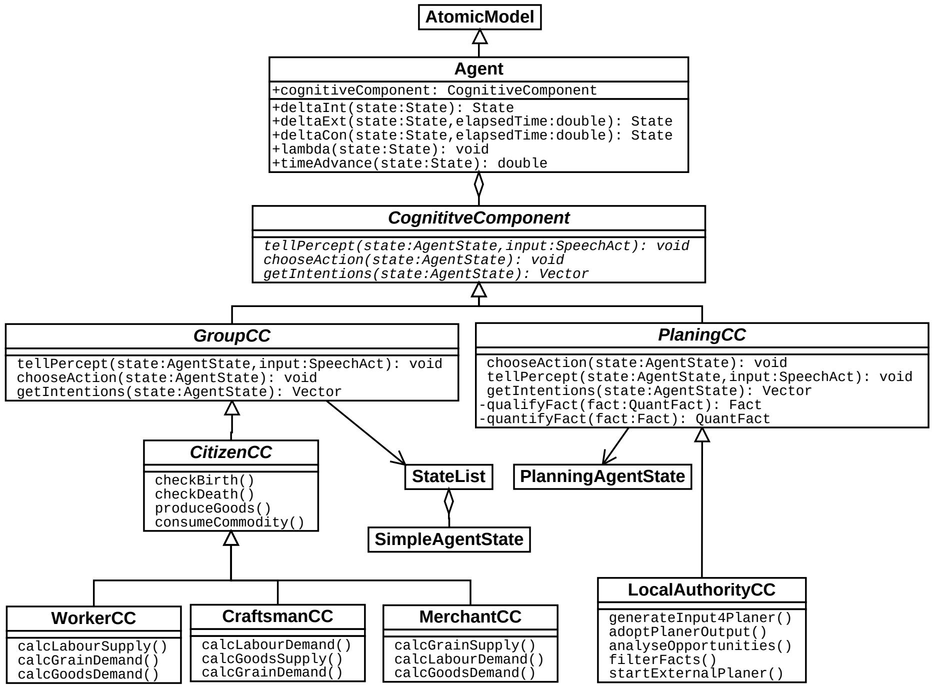

Fig. 4. Overview about the agent classes implemented

4 First Experiments and some preliminary results

We have performed first experiments, some results of which we will discuss in the following sections.

4.1 25 years without a crises

As a very first step market dynamics and demographic developments in the pre-modern town are simulated without a crises. To support the planned simulation experiments, first, the basic simulation has to run stable throughout a longer time horizon. Each simulation step represents one week of real time. We choose a time horizon of 25 years. For each actor group we specify death rates due to malnutrition, assuming that merchants and craftsmen in general have a better chance to survive periods where they do not meet the subsistence level. The model includes natural reproduction and death rates. Merchants and craftsmen have lower birth and death rates than laborers but that the overall net growth rate is lower for the laborers. Since in the current version of the model natural changes in population and changes caused by immigration and/or emigration are not distinguished, birth and

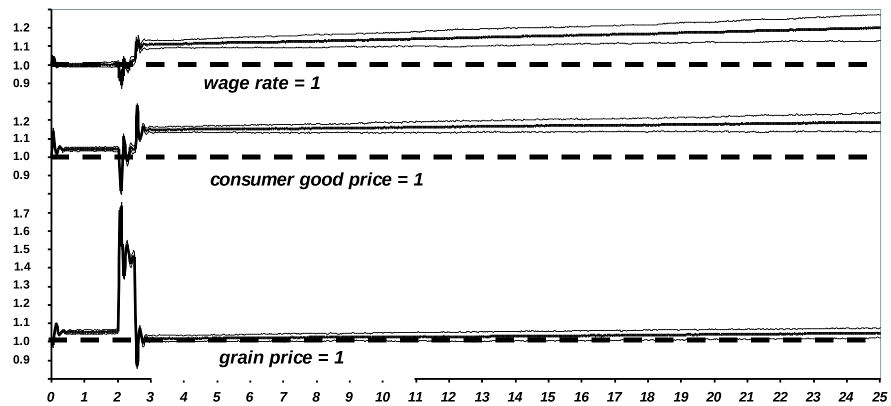

Fig. 5. Development of prices with a famine during the simulated period of 25 years (averaged over 25 simulation runs, thin lines represent upper and lower bounds of a confidence interval). All prices have been initiated with value "1".

natural death rates also incorporate rates of immigration and emigration, respectively. Net growth rates for all actor groups are greater zero, because in pre-modern towns high death rates due to bad living conditions usually were compensated by high immigration rates. With a slightly growing population the system runs stable over the course of 25 years. All prices are slightly growing within the span of 25 years. A simulation run of 25 years of simulated time takes around 10 minutes on a personal computer (666 MHz, Pentium III, 128MB RAM). In our experiments simulation runs started with 2000 laborers' households, 400 craftmen's households and 250 merchants' households, which by pre-industrial standards represents a fairly big town.

4.2 A major crises without intervention

In order to show what happens to the town in the aftermath of a large-scale disaster we simulate the baseline scenario described above including a major harvest failure that starts after two years of simulated time. This harvest failure is represented in the model by a very limited distribution of grain to the citizens during half a year which in turn produces a severe famine killing almost half of all laborers. Economically, the crisis is reflected by strong variations of the grain price during the periods of grain scarcity (Figure 5). In the long run this famine seems to cause a permanent upward shift of wages because after the death of almost 50% of all workers labor becomes

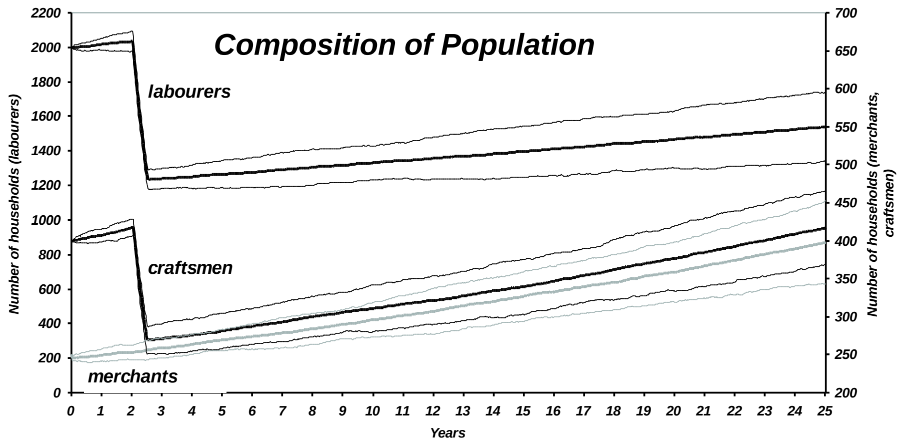

Fig. 6. Development of actor groups with a famine during the simulated period of 25 years (averaged over 25 simulation runs, thin lines represent upper and lower bounds of a confidence interval)

a scarce good and a permanent downward shift of grain prices is the result. A variation of this famine scenario is characterized by high death rates due to malnutrition for merchants and craftsmen as well. A considerably large proportion of craftsmen dies from starvation which has a considerable effect on the economy, because the supply with consumer goods runs short (Figure 6). The figure shows also, that with a 25 times replication of the experiment results do not show much variation.

In contrast to the baseline scenario where malnutrition did not affect the course of demographic and economic processes, the propensity to die because of malnutrition matters in the crisis, of course. During the remaining 22 1/2 years of simulation - almost equal to the span of one generation - the loss of population cannot be fully compensated with the net growth rates of the baseline scenario. This means, that in order to speed up population growth in the town, fertility, but more likely, immigration has to be increased.

4.3 The authorities intervenes

Given the situation of grain scarcity and a developing famine the local authorities has to decide which measure of crisis management are to be deployed in order to avert negative medium-term and long-term consequences of the disaster. In (Figure 7) the intentions the local authorities decided upon to intervene are shown. As we have only started with experimenting with the planning agent "local authorities" in our system, it is not surprising that the crisis management plan developed by GraphPlan has neither the intended nor overall plausible effects on the system. Our analysis suggests a careful refinement of the current time horizon associated with each of the single actions. But nevertheless, starting with a situation, were all actor groups are dissatisfied, this preliminary plan shows, that managing a crisis is a fairly difficult task. One easily sees the complexity that is created by attempts to regulate markets. Single actions, such like the reduction of the intensity of the famine by providing citizens with the hoarded grain or the protection of craftsmen against immigration by installing a guild limit, actions that are designed to satisfy interests of single actor groups usually only have short-term consequences and will lead to dissatisfaction of other actor groups.

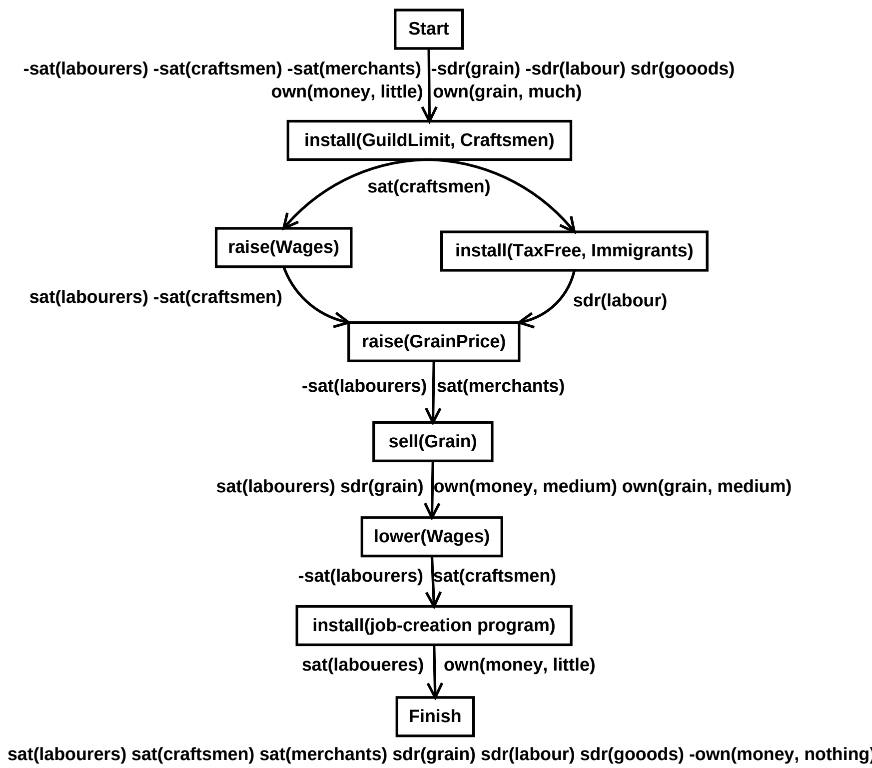

Fig. 7. Intentions of the local authorities triggered by a rebellious population

5 Conclusions

The aim of our research project is to analyze the impact of deliberative intervention in overcoming disasters in pre-modern towns. Actors are affected quite differently by the disaster and will react in many different ways. Many will not even survive the disaster. Of the survivors many will be set back to a difficult economic status. But some of them can become real "winners" of the current situation, e.g., if they did not lose their property or if they are involved in the reconstruction. Thus it seems natural to resort to an agent-oriented approach [10,35] rather than e.g. a macro-level simulation model in which the key features of our application, e.g. the actor's preferences and a price dynamic that results from individual micro-macro-level interactions, could not be adequately accounted for.

This approach enables to model a rather complex society of a pre-modern European community including utility-based actors as well as actors that depend on the BDI architecture. The derived model is used to simulate reactions to a large-scale disaster and the course of demographic and economic developments in the aftermath of such crisis. The macro-level outcome of the simulation - market prices, aggregate population figures and per capita savings - portrays these developments of the town in the course of time. Different sorts of disasters causing mortality crisis in the town can be tested by exposing the system to external perturbations.

In addition, further work is required to refine and validate the activity of the authorities and to include additional markets, e.g. the marriage market. Thereafter, the model shall be validated empirically as far as the sketchy and incomplete historical real data will us allow to do. This empirical validation will complement plausibility tests and sensitivity analysis used so far in developing the model. The current model looks back at a significant number of ancestors from which the current one was developed by successive refinements and extensions. This process was facilitated by the flexibility and the modular model design of the underlying simulation system JAMES - properties which will help in fostering the descendants.

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