SIMUSE: MODELING RECREATIONAL POLYDRUG USE THROUGH AN AGENT-BASED MODEL

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ABSTRACT
This paper describes an attempt to capture individual and social characteristics of poly-drug use in a generic agent-based model called SimUse. We consider poly-drug use and its social context as a complex phenomenon and use a generative framework to create an iterative dialogue between qualitative fieldwork, theoretical constructs and computer simulations. The structure of SimUse includes five levels of influence. In a first time the context of recreational polydrug use and the rationales of this research is introduced; then, the second part of the paper describes the overall structure of the model before detailing key aspects of SimUse: (1) the neurological engine and its behavioural consequences; (2) the decision process and its different elements; and (3) the intra- and extra-individual reevaluation processes. We conclude with two examples of how the model reacts to illustrative parameter changes and external shocks and their consequences for decision-makers.

Keywords: drug use, agent-based model, social simulation, sociology of deviance

1. INTRODUCTION

Drug use is a major concern of western modern societies: the latest reports from the United Nations Office on Drugs and Crime (UNODC) estimate the number of problematic and injecting users around 27-59 million individuals and occasional consumers to 155-250 million (UNODC 2011). Furthermore, drug trafficking and consumption trends are subject to frequent and rapid evolutions (UNODC 2011; EMCDDA 2013). Indeed, for approximately twenty years, the drug market context has been characterized by the endemic presence of classic illicit drugs (cannabis, cocaine, ecstasy, heroin, amphetamine-type and numerous hallucinogens) (Faugeron & Kokoreff 2002), associated with the constant appearance of new psychoactive substances (known as "designer drugs" or "legal high"), and the augmentation of pharmaceutical substance misuse (EMCDDA 2013). This particular context, combined with the 'normalization' of drug use (Parker et al. 1998; Parker 2005) has favored polysubstance use (Fontaine et al. 2001), practice leading to the consumption of at least two psychoactive substances, sometimes concurrently. According to the EMCDDA (European Monitoring Centre for Drugs and Drug Addiction), polysubstance use is the actual "dominant pattern of drug use" and appears as a major social issue due to increased hazard risks and health-related harms (EMCCDA 2009).

According to these previous reports, drug use appears to be a complex social problem that needs to be seen through a multi-disciplinary prism. International institutions have called for developments of technology able to encapsulate such a dynamic complex phenomenon and hence, being able to evaluate the relevance and accuracy of public policies relative to this matter (EMCCDA 2009). To tackle this social issue and capture the complexity of polydrug use, we propose to create an artificial society via an agent-based model, SimUse, to run *in-silico* social simulations. This model purpose is twofold: on the one hand, it is used as a *mediator* framework, enabling the dialogue between several disciplines; and on the other hand, as a *predict*ive tool for public policy makers. Indeed, SimUse, attempts to encompass several levels of understanding in order to create an ontology of recreational polydrug use.

This paper is organized as follows: Section II legitimizes our approach by introducing key-concepts from the scientific literature concerning drug use and addiction. We then refer to social simulations built on the topic in order to reinforce our stance. The second part (III) of the paper presents three levels of modeling in SimUse: (1) the decision process concerning the choice of substances; (2) the neurological engine representing the behavioural and physiological responses to the consumption of the chosen substances; and (3), the intra- and extra-individual re-evalutation process following consumption. The last section (IV) presents two *what-if* scenarios illustrating the type of results that SimUse can produce.

2. DRUG USE AS A COMPLEX ADAPTIVE SYSTEM

The literature on substance use, misuse and addiction reveals that drug consumption results from a large set of risk/protective factors influencing individuals in their choices to consume drug(s). West (2006) indicates that every discipline, from genetics to economy has conceptual tools and operative theories to study and explain drug use and abuse. He also notes that these disciplines do not interact with each other, leading to the situation where there are "many theories but little progress" (West 2006). Based on this point-of-view, several researchers have called for a multidisciplinary approach to capture these risk/protective factors and understand their interactions (Unger et al. 2004). The review of the scientific literature establishes five main levels of analysis, starting from neurology and finishing with symbolic macrostructure. These levels are named here: *drug, intrapersonal, interpersonal, context,* and *symbolic.*

At the *drug* level, the neurosciences have highlighted the crucial role of *neurotransmitters* in mechanisms of pleasure, memory and mood changes (Koob and LeMoal 2006). Because each drug has a specific impact on the brain, we have to take in consideration these neuropharmacological differences to understand changes in user behaviours. Add to this preceding point, repeated and frequent intakes modify brain structures due to synaptic adaptation that can lead to alteration of both physiological and psychological state (Julien et al. 2008). At the *intrapersonal* level, the beliefs and meanings attached by individuals to substances is conditioned by the set of *representations* constructed by these individuals through interactions and past experiences (Jodelet 2003). Therefore, user's beliefs and experiences about drugs influence and modify the decision process after each drug use' iteration. It also appears that users expect specific effects from psychoactive substances and infer these latter *functions* (Boys et al 1999). Moreover, each individual has a set of *capitals* (economic, symbolic and social) that affects his/her ability to find, afford and choose specific type of drugs (Boys and Mardsen 2003).

The *interpersonal* stratum should be understood as the level of interactions. Social learning theory indicates that individuals tend to mimic and incorporate behaviours they have witnessed. Concerning polysubstance use, this theory underscores the importance of *socialization* on drug social representations and opinions: parental drug consumption, *peer pressure,* and *peer influence* have been widely studied and appear to increase the risk of acute substance abuse. In the same way, belonging and identifying oneself with a drug user's group can induce a consumption reflecting group patterns (Sussman and Ames 2008). Furthermore, friends and acquaintances are generally the first sources of drug supply and are considered by neophytes as "safe keepers" insuring the safety of initiations.

On a *contextual* level, the intra- and interpersonal levels could be impacted by neighborhood conditions, economic deprivation, geographical relegation, economical and/or social inequalities (Rhodes et al. 2001). Obviously, *drug market structure* varies from one geographical area to another and facilitates or not the accessibility to certain drugs (Johnson et al. 1992). Consistent with these last two points, *geographical contexts* (specific suburbs, rural/urban areas, etc) give access to a more or less big panel of drugs. Some kinds of consumption can only take place in specific social context (Preble and Casey 1969).

Finally, the *societal* level condenses the legal and symbolic dimensions influencing the choices of drug users. *Legislation* and *global availability* define the ease of access to the licit and illicit drugs and, in turn, influence the price and penal risks of each drug (Sussman and Ames 2004). In a context of drug normalization (Parker 2005), *mass media*, *norms* and *social acceptance* play a major role on the beliefs of both users and non-users. Indeed, the repeated exposures to advertisements modifies preference and conduct (Theus 1994), movies or TV series could product a positive image of deviant behaviour (Villani 2005) and social goals such as cult of the performance or reconnaissance by wealth (Ehrenberg 1991; Simmel 1900) affect both consumer decisions and acts.

Polyuse accentuates the complexity of this social phenomenon. Indeed, most of the studies concerning polysubstance consumption are focused either on *simultaneous* polydrug use (SPU) as a social practice common to particular subpopulations (especially related to nightlife and rave groups) or on the adverse health effects of *concurrent* (life-based) polysubstance use (CPU) (Ives and Ghelani 2006). This research suggests that SPU and CPU are interdependent. This assertion is based on the fact that experiences arising from any drug(s) session could impact and transform representations attached by individuals to substances. These representations vary throughout the *career*, understood as the consolidated biographical experiences of polyusers, and orient the acts, which constitute the basis that orients further decisions related to substances use.

Therefore, the present research has studied these interconnected forms of polyuse by combining concepts coming from neuroscience (to capture the behavioural changes during SPU) to findings produces by a sociological investigation (to apprehend the changes that occurs throughout CPU). The former is informed by the literature on the subject (Solomon 1980; Koob and LeMoal 2006; Julien et al. 2008) and the latter by qualitative interviews conducted during fieldwork.

Considering the complexity and dynamics of drug use, several researchers have already proposed to study drug use as a *Complex Adaptive Systems* (Gorman et al. 2004; Perez et al. 2005) and to model this phenomenon through agent-based social simulations. Agar and Wilson created the first of these simulations. *SimTalk* was designed to capture the communication process existing between heroin users based on an ethnographic investigation amongst heroin injectors in Baltimore (Agar and Wilson 2004). Chattoe, Hickman & Vickerman have complexified *SimTalk* by inserting *non-users* agents inside the model: their model, *DrugChat,* introduces the role of network peers in agent's decisions (the communication in *SimTalk* was based on the spatial proximity). On the topic of heroin, Perez et al (2005) have built an agent-based model, *SimDrug,* to replicate the Melbourne heroin drought of 2000-2001. Agents in SimDrug are integrated into an informed spatial environment and other classes of agents (i.e. constables, dealer, outreach workers, wholesalers) were created to reproduce the social environment in which heroin users normally evolve into. Perez and colleagues (2012) have also developed an agent-based model concerning the consumption of amphetamine amongst young Australians, based on quantitative and ethnographic material. In *SimAmph,* the decisions of agents were shaped to acknowledge the key roles of individual perception, peers influence, and subcultural settings. Gorman and colleagues (2006) have produced a simulation on alcohol consumption in general population. Their model aimed to analyze the role of agent-environment interactions in the development and the continuation of alcohol use. Simulations have also been designed to study drug distribution markets (Agar and Wilson 2002; Romano, Lomax, and Richmond 2005; Hoffer, Bobashev, and Morris 2009).

However, most of these models focused on a single substance. Given the fact that our objective is to recreate the career of recreational polydrug users, by taking into account the five levels of analysis previously described, we needed to introduce several new features into our model. The next section details some of the novel components.

3. BUILDING SIMUSE: A MULTILAYER MODEL

SimUse has been developed in NetLogo 4.1.3 (Wilensky 1999). Social simulations enable us to carry out artificial social experiments to investigate the consequences of pre-defined conditions on a range of specific social and environmental conditions. SimUse investigates how agents take their decisions, consume recreational drugs, interact with other users and (a) evaluate their own actions and/or (b) judge the behaviours of other users. By doing so, SimUse aims to assess the impact of these drug practices on the social life of recreational consumers.

Agents representing recreational polydrug users are characterized by neurological, behavioural and social attributes. These attributes generate the agents' choices, actions and interactions, informed by qualitative interviews findings. These agents act in a preprogrammed routine inside a drastic simplification of an urban environment aggregating specific settings (Bar, Club, Bottle-Shop, etc). Other types of agents were included in the simulation (i.e., drug dealers, wholesalers and law enforcement) to recreate the context the in which the polyusers evolve.

From prior work and analysis of the interviews, carried out in Australia and France by the first author, it appears that the decision process regarding drug use is comparable to a "practical reasoning" (Bratman 1987). Indeed, the interviews reveal, consistently with other research (Boys et al. 1999; Boys and Mardsen 2003), that polydrug users have expectations regarding their consumption and infer "functions" and roles to the different substances they consume. These "functions" could be regrouped into four meaningful categories, namely "Sociable", "Relax", "Energy", and "Intoxicate". In brief, drugs providing the "Sociable" function are considered by interviewees as facilitating the communication with others and increase "fun" with peers. Substances with the "Relax" function attached to them are used for their analgesic or sedative properties and to establish a boundary between working and leisure time. "Energy" drugs are consumed for their stimulant effects allowing their users to stay awake longer and boost their physical capacities. Users that target the "Intoxicate" function generally cited drugs that produce intense rushes, hallucinations or analgesia.

Comparing findings from the qualitative interviews with the neuropharmacological consequences of each drug suggests that the substance choices of recreational polyusers are consistent with the functions they target. In other words, psychoactive substances, through their actions on the different neurotransmitter systems, are means employed by polyusers to obtain particular physiological and/or psychological effects and, in turn, achieve social-oriented functions. Considering the importance of the neurological properties of each substance on user decisions, SimUse needed to include a neurological component. This "NeuralBox" functions as an algorithm, where drugs are the inputs and behaviours are outputs. The translation between "drugs" to "behaviours" is taken care of by a set of modeled neurotransmitters. By drilling down to the neurotransmitter level, this model which we call the *neurological engine,* permits treating several substances at the same time and, therefore, to mimic polydrug use.

Given the neuropharmacology of the drugs most currently used, we decided to model eight neurotransmitters:

- **Dopamine** is involved in feelings of reward, self-confidence, talkativeness and happiness (Arias-Carrion and Pöppel 2007). It is also considered as the main cause of addiction (Wise 2002);
- **Cannabinoid** is a neuroregulator inhibiting the release of other neurotransmitters. It induces an analgesic effect, sensation of well-being, decreases in body temperature and potentiates opioid effects (Ashton 2001);
- **Opioid Peptides** generate analgesia and depression of the respiratory functions (Santiago and Edelman 1985);

- **Gamma-Amino-Butyric Acid (GABA)** is the principal inhibitory neurotransmitter in the brain reducing and regulating the activity of other neurons and neurotransmitters (Kuffler and Edwards 1957);
- **Glutamate** is the main excitatory neurotransmitter. It is involved in all aspect of brain function, including movement, language, learning, and memorization (Riedel 1996; Riedel, Platt, and Micheau 2002);
- **Norepinephrine** produces a host of changes including increasing arousal and attention, increasing body temperature, motor activity (Schwarze, Bingel, and Sommer 2012), respiration rate, blood pressure (Julien, Advokat, and Comaty 2008);
- **Serotonin (5-HT$_{1A}$ and 5-HT$_{2A}$)** Serotonin is involved in mood regulation and memory. Mild enhancement of 5-HT$_{1A}$ receptors brings euphoria and a sentiment of happiness. This neurotransmitter is implicated into prosocial behaviour (Crockett et al. 2010). A large dose of 5-HT$_{2A}$ in the brain leads to disorientation, confusion, and visual hallucinations (Manford and Andermann 1998).

Table 1 lists the substances considered, together with their related functions, and the neurotransmitters activated by each psychoactive substance.

Each drug carries a set of eight indicators (named, NeuralAction) characterizing the way they impact the corresponding eight neurotransmitters. By impacting specific neurotransmitter receptors, each drug induces a series of behavioural changes embedded in the "Behaviours" attribute of the user class. To trigger such reactions, the amount of neurotransmitters in the brain needs to exceed their "Tolerance-Threshold". These behavioural reactions vary accordingly to the level of neurotransmitters in the brain and important amounts of neurotransmitters lead to unexpected and unwanted behaviours and physiological/psychological damages. This functioning is illustrated with the following activity diagram (Figure 1):

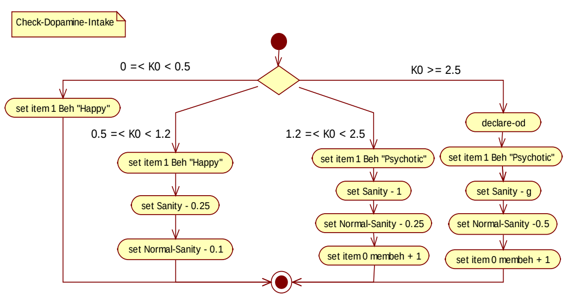

Figure 1: Impact of Dopamine dose Activity Diagram

The K value represents the difference between the actual amount of neurotransmitters and the "Tolerance-Threshold". The higher the value, the more likely the user will experience acute and severe reactions: for example, just reaching the Tolerance-Threshold turns the agent behaviour to "Happy", while a large difference between these two levels leads to "Psychotic" behaviour (here, "declare-od" means that the user is overdosing). SimUse "neurological engine" involves several other components (e.g., tolerance, comedown, and craving) that cannot be developed here.

Table 1: Relation between Substance, Targeted Functions, and Neurotransmitters

Substance	Function	Neurotransmitters
Alcohol	Sociable	Dopamine+ / 5-HT$_{1A}$+
	Relax	GABA+ / OpioidPeptide+ / Glutamate -
	Intoxicate	GABA+ / OpioidPeptide+ / Glutamate -
Cannabis	Sociable	Dopamine+ / 5-HT$_{1A}$+
	Relax	GABA+ / Cannabinoid+
	Intoxicate	GABA+ / 5-HT$_{2A}$+
Cocaine	Sociable	Dopamine+ / 5-HT$_{1A}$+
	Energy	Norepinephrine+ / Glutamate+
Crack	Intoxicate	Dopamine+
MDMA-type	Sociable	Dopamine+ / 5-HT$_{1A}$+
	Energy	Norepinephrine+ / Glutamate+
Opiate-type	Relax	OpioidPeptide+
	Intoxicate	OpioidPeptide+ / Dopamine +
Amphetamine-type	Energy	Norepinephrine+ / Glutamate+
Hallucinogens	Intoxicate	5-HT$_{2A}$+

Nevertheless, the decision process does not stop at the choice of substances based on their expected effects. The interviews showed that the representations users have of drugs condition their choices. Therefore, the interviews investigated these representations and their transformations taking into account that representations are socially constructed. These "Social representations" constitute the stock of information, beliefs and opinions that actors have produced about precise objects through their experiences and interactions (Jodelet 2003; Moscovici 2011). In SimUse, these social representations are modeled and formalized through numerical values representing the user attitudes towards each drug. The range of values goes from -5 to 5: a drug with a negative social representation will not be selected by the agent; neutral representation (0) could lead to consumption if the peers of the agent have a global positive representation of the drug; and a positive representation entails the selection of the related substance. This decisional process is modeled in SimUse as shown in figure 2:

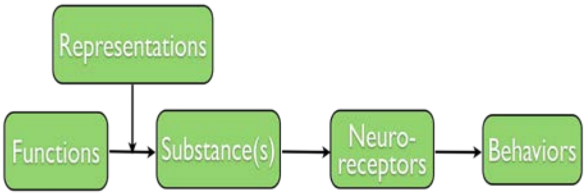

Figure 2: SimUse Drug Decisional Process

In the interviews, the respondents explained that their representations tend to be modified based on the behaviours they observe on themselves retrospectively and by judging the behaviours of other consumers. Indeed, the respondents indicate that they "measure" and balance the positive and negative effects substances have on them. Positive and expected effects appear to reinforce positively the social representation users have attached to the substances (e.g. becoming energetic and alert after the intentional consumption of amphetamine). Conversely, side effects and inappropriate behaviours entail a negative re-evaluation of the representation (e.g. displaying aggressive behaviours after the consumption of amphetamine), which in turn affects future drug-based decisions. Figure 3 provides a flowchart describing this process.

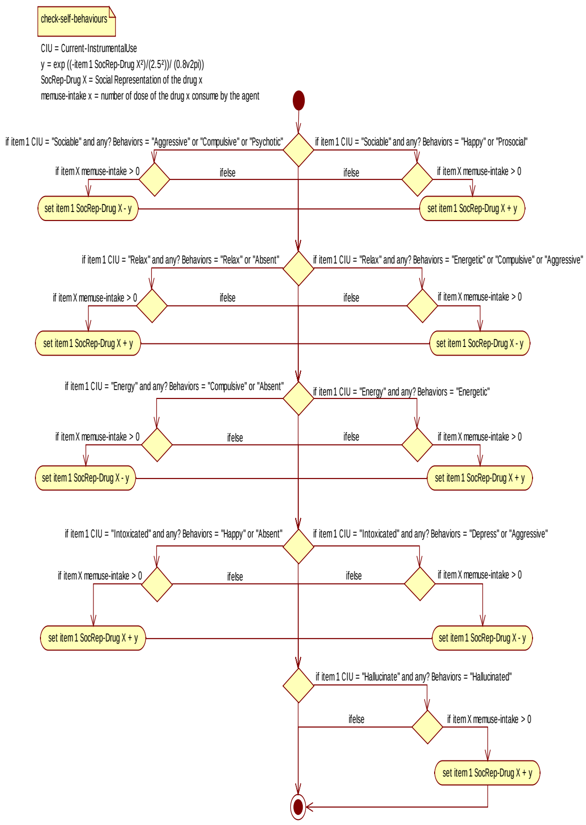

Figure 3: SimUse Activity Diagram for Social Representations Re-evaluation based on the Self Behaviours

The y value displays in this activity diagram is the result of a Normal distribution of mean 0, of variance 1.25 with x equal to the value of the social representation attached to the drug. In other words, agents with social representation values close to the extremes (either -5 or 5) see their representations feebly modified, while agents with a neutral representation (equal to 0) change substantially the way they perceive the drug incriminated.

However, self-reevaluation is not the only process that affects social representations. Based on the Symbolic Interactionist perspective, we consider that meanings, and so social representations, attached to objects are also modified throughout the interactions (Blumer 1998). Interview respondents explained that their opinions on particular drugs could change if they witness inappropriate behaviour from other users under the influence of these substances. Indeed, uncontrolled usage (i.e. compulsive use, being sick) and/or anti-social behaviour (e.g. aggressiveness) are negatively judged and stigmatized by recreational users. Conversely, witnessing expected effects and prosocial behaviours seems to modify positively user's representations. SimUse takes this second form of re-evaluation into account by modeling this process the following way (see Figure 4):

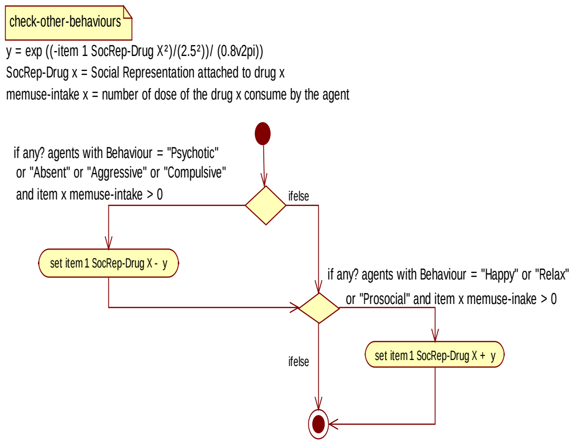

Figure 4: SimUse Activity Diagram for Social Representations
Re-evaluation based on Others Behaviours

It is important to note that repeated consumption of similar substance induce a neurologic *tolerance*. This tolerance reduces the response intensity from the neuroreceptors: in term of consumption, the higher the tolerance, the more users will need to consume to obtain the expected effects. Increased doses generate more intense side effects leading to inappropriate behaviours or unpleasant outcomes, modifying in turn the representation associated with the drug. Taking into account the re-evaluations processes and neurological tolerance, the decisional process shown in figure 1 is updated as follows (see Figure 5):

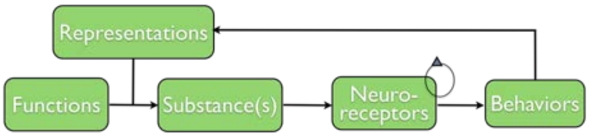

Figure 5: SimUse Iterated Decisional Process

The final model contains a larger quantity of operations and classes, but the complete description of SimUse would exceed the scope of this paper.

4. SAMPLE RESULTS

This section presents the results of two *what-if* scenarios aiming to test the reactions of the model to parameter variations and external shocks. These two scenarios share common initial parameters. Each simulation contains 500 agents and was run for 2400 ticks (which represents 200 virtual days).

The first scenario "EcstasyPrices" tests the impact of substance prices on the consumption rate of that substance. Five prices — 1, 10, 30, 60, and 100 — were tested to assess if the impact of price increases on consumption rates. To create equal conditions and reduce the impact of the irregular drug distribution, each agent knows a dealer of ecstasy at the initiation of the simulation. The first graph shows the impact of Ecstasy price on its consumption rates (cf. Figure 6):

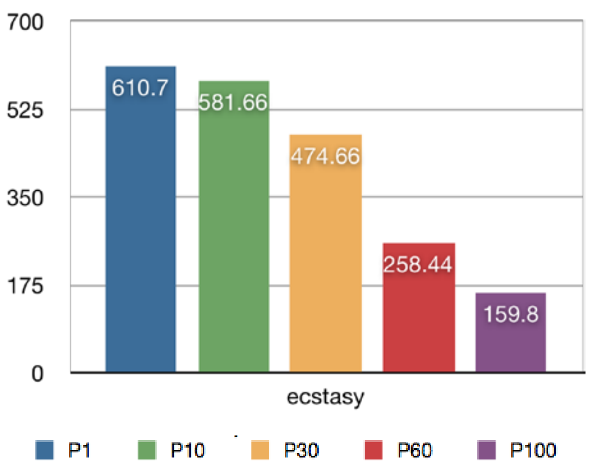

Figure 6: Impact of Ecstasy Price on its consumption rate

In Figure 6, the ordinate represents the number of Ecstasy dose consumed during the simulation. As it could be expected the ecstasy consumption decreases with increasing prices and, as indicated by (Figure 7), the rates of experimentations and regular uses diminish as well:

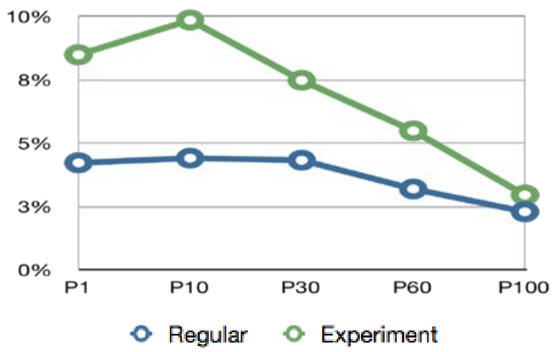

Figure 7: Impact of Ecstasy prices on experimentation and regular use frequencies

If increasing the price of Ecstasy induces a decrease in the rate of consumption, it also induces, in turn, a reduce number of positive experiences felt and reevaluated by potential consumers. Therefore, the ecstasy representation does not increase through the "check-self-behaviour" method, and, at the same time, the absence of visible users does not allow non-users to judge positively the substance through the "check-others-behaviour". In other words, the global social representation is less likely to increase if only a few agents can afford and test the drug. The results from the simulation tend to indicate that lowering the affordability of the drug reduces the number of regular users (certainly due to the financial aspect) but could also affect the number of future users.

The second scenario evaluates the plausibility of model reactions when a large augmentation in the potency of a particular substance is created. This scenario wants to mimic the arrival on the drug market of an "uncut" drug (with a high degree of purity) to assess the reactions of the *users* to that kind of shock. To mimic this sudden increase of potency, the purity of Cocaine is almost tripled after 1200 ticks. Purity is not modeled in SimUse, but could be reproduced by changing the values of the Cocaine's NeuralAction attribute. To judge the impact of this increased potency, we have run a "Standard" scenario (in blue) in which the NeuralAction of Cocaine remains unchanged. As indicated in the following graph, the quantity of cocaine consumed in the "CocainePurity" scenario is lower than in the Standard one (Figure 8):

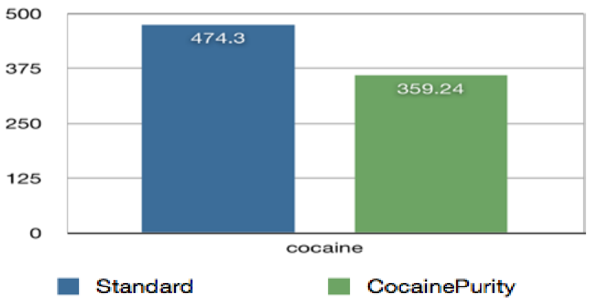

Figure 8: Impact of Increased Cocaine Purity on the Cocaine Consumption

This decrease could be explained by two facts: (a) *users* require lesser dosages to obtain targeted effects due to the increased potency of the substance, and; (b) this decrease could also be explained due to the accumulation of problematic situations or dramatic events following the purity augmentation (see Graph 4 below). Indeed, the number of "hazardous-acts" (i.e. irrational behaviours: putting oneself in danger, drive while intoxicated, attempt impossible actions), brawls ("assaults"), and users entering treatment ("treatnum") affect negatively the social representations of the agents experiencing these adverse reactions, as well as agents witnessing cocaine adverse consequences (Figure 9).

As shown by these preliminary results, changes in a single parameter at one level (price, purity) could entail modifications on several elements in the model directly or indirectly related to the parameters (for example, the diminution of the overall social representations or on the negative events experiences by the agent). Creating this type of ontology permits modeling this type of Complex Adaptive Systems. Indeed, by combining several levels of understanding, and, more importantly, by capturing their interactions and influences, this kind of agent-based model allows testing *what-if* scenarios.

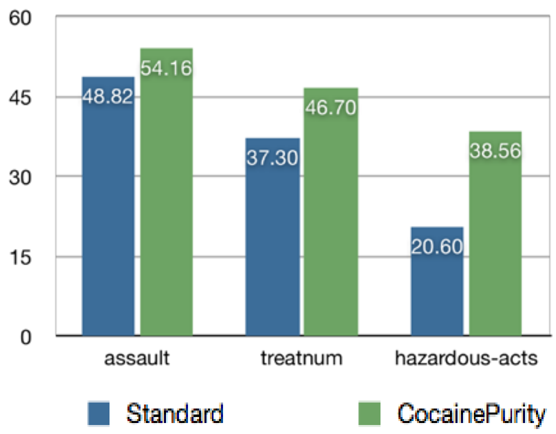

Figure 9: Impact of Increased Cocaine Purity on Negative Events

5. CONCLUSION

Again, as pointed by several institutions, drug policy is a complex topic due to the large number of protective and risk factors that can influence the choices and actions of drug users. This paper argues in favor of the utilization of social simulation to assist policy-makers in their choices, first because it helps to encompass and make interact different levels of analysis, and second because it could be used as a tool to test *what-if* scenarios.

This social simulation incorporates an original model of agent neurological reactions to psychoactive substances and allows encompassing polydrug use. In this paper, we have presented a decisional model of drug choice that consider both instrumental expectations and social representations attached to different substances, and a model of peers influences regarding drug users decisions.

SimUse is subject to numerous limitations (low number of agents, drastic simplification of neurological components and of the geographic area) and still needs further calibration regarding population statistics. However, given this complex agent response to polydrug use, we argue that the emergent social effects can be captured using an agent-based model. The experiments presented here offer an example of *what-if* scenarios and public policies testing achievable with this kind of agent-based social simulations.

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