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Agent-based Approach to Crime and Criminal Justice Policy Analysis

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1. INTRODUCTION

Agent-based Social Simulation (ABSS) has increasingly been proving to be successful for the study of crime and criminal justice policies[1]. The use of techniques belonging to the field of computer simulation in policy modelling is also actually increasing[2].

Early applications of simulative approach to crime analysis appeared in the field of Environmental Criminology[3]. In 2008, a special issue of the "Journal of Experimental Criminology" was entirely devoted to current applications of simulation methods to the study of crime and criminal justice policies[4]. As regards crime research, it was suggested how this technique

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[1] L. LIU, X. WANG, J.E. ECK, J. LIANG, *Simulation Crime Events and Crime Patterns in RA/CA Model*, in Wang F. (ed.), "Geographic Information Systems and Crime Analysis", Singapore, Idea Group, 2005, pp. 197-213; X. WANG, *Spatial Adaptive Crime Event Simulation with RA/CA/ABM Computational Laboratory*, Geography Cincinnati, University of Cincinnati, 2005; L. LIU, J.E. ECK (eds.), *Artificial Crime Analysis Systems: Using Computer Simulations and Geographic Information Systems*, Hershey, IGI Global, 2008; D.J. BIRKS, S. DONKIN, M. WELLSMITH, *Synthesis over Analysis: Towards an Ontology for Volume Crime Simulation*, in Liu L., Eck J.E. (eds.), "op. cit.", pp. 160-192.

[2] M.A. WIMMER, K. FURDIK, M. BICKING, M. MACH, T. SABOL, P. BUTKA, *Open Collaboration in Policy Development: Concept and Architecture to Integrate Scenario Development and Formal Policy Modeling*, in Charalabidis Y., Koussouris S. (eds.), "Empowering Open and Collaborative Governance", Berlin, Springer Verlag, 2012.

[3] P.L. BRANTINGHAM, P.J. BRANTINGHAM, *Computer Simulation as a Tool for Environmental Criminologists*, in "Security Journal", Vol. 17, 2004, n. 1, pp. 21-30; P.L. BRANTINGHAM, E.R. GROFF, *The Future of Agent-based Simulation in Environmental Criminology*, in "Proceedings of the American Society of Criminology Conference", Nashville, 2004.

[4] E. GROFF, L. MAZEROLLE, *Simulated Experiments and Their Potential Role in Criminology and Criminal Justice*, in "Journal of Experimental Criminology", Vol. 4, 2008, pp. 187-193.

could be useful to advance, test or refine theory[5], to anticipate consequences accruing from one type of intervention over another[6], and to provide new policy evaluation tools[7]. As a consequence simulation can also supply informed policy guidance to crime control agencies[8].

Recently several international conferences on artificial intelligence and multi-agent systems hosted lots of contributions about applications of computer simulation to the crime problem[9].

There are many reasons why it is appropriate to investigate the relationship between ABSS and crime analysis. The principal argument in criminology is the need for complementarities between the experimental or quasi-experimental approach and the simulation one[10]. The use of agent-based computational method would be considered particularly beneficial in cases where empirical research is limited by the inability to conduct field trials[11]. In some cases, simulation can be viewed as a sort of pre-test of certain crime

[5] E. GROFF, *Simulation for Theory Testing and Experimentation: An Example Using Routine Activity Theory and Street Robbery*, in "Journal of Quantitative Criminology", Vol. 23, 2007, n. 2, pp. 75-103; E. GROFF, *Adding the Temporal and Spatial Aspects of Routine Activities: A Further Test of Routine Activity Theory*, in "Security Journal", Vol. 21, 2008, pp. 95-116.

[6] R.A. BERK, J. BOND, R. LU, R. TURCO, R.E. WEISS, *Computer Simulations as Experiments: Using Program Evaluation Tools to Assess the Validity of Interventions in Virtual Worlds*, in Bickman L. (ed.), "Donald Campbell's Legacy (Vol. II): Contributions to Research Design", Newbury Park, Sage Publications, 2000.

[7] P. PEREZ, A. DRAY, *SimDrug: Exploring the Complexity of Heroin Use in Melbourne*. Drug Policy Modelling Project Monograph Series, Fitzroy: Turning Point Alcohol and Drug Centre, 2005, http://www.turningpoint.org.au/research/dpmp_monographs/dpmp_monograph11.pdf; A. DRAY, L. MAZEROLLE, P. PEREZ, A. RITTER, *Drug Law Enforcement in an Agent-based Model: Simulating the Disruption to Street-level Drug Markets*, in Liu L., Eck J.E. (eds.), "op. cit.", pp. 352-271.

[8] D. REIS, A. MELO, A.L.V. COELHO, V. FURTADO, *Towards Optimal Police Patrol Routes with Genetic Algorithms*, in Mehrotra S., Zeng D.D., Chen H., Thuraisingham B., Wang F.-Y. (eds.), "Intelligence and Security Informatics", Proceedings of the IEEE International Conference on Intelligence and Security Informatics, 2006, pp. 485-491.

[9] See the Proceedings of ACM Symposium 2007 http://www.acm.org/conferences/sac/sac2007/, AAMAS 2008 http://www.aamas-conference.org/Proceedings/aamas08/ and ICAART 2009 http://www.informatik.uni-trier.de/ ~ ley/db/conf/icaart/icaart2009.html.

[10] J.E. ECK, L. LIU, *Contrasting Simulated and Empirical Experiments in Crime Prevention*, in "Journal of Experimental Criminology", Vol. 4, 2008, n. 3, pp. 195-213.

[11] E. GROFF, L. MAZEROLLE, *op. cit.* For a review, see also V. PUNZO, A. FICI, *Modelli ad agenti e sociologia del crimine e della devianza. Aspetti teorici e metodologici*, in Faro S., Lettieri N., Tartaglia Polcini A. (eds.), "Diritto e Tecnologie. Verso le scienze sociali computazionali", Napoli, Edizioni Scientifiche Italiane, 2011, pp. 271-294.

prevention programs, able to suggest any changes before their empirical test[12].

There is also a strong evidence that agent-based simulation allows to implement the Coleman's casual macro-micro-macro "transitions"[13]. It allows researchers to create artificial societies[14] and to explore how individual-level criminal action might translate into observable macrolevel crime patterns. An important challenge within the field of criminology is to investigate the spatio-temporal dynamics of crime[15]. Within this area, the key object is the study of crime, criminality, and victimization as they relate to particular places and how offenders, targets (victims), and guardians (control agents) shape their activities spatially[16]. For example, a relevant question is which factors influence the emergence of so-called hot spots – areas in which many crimes occur[17] – and how the displacement of criminal hot spots can be predicted and prevented[18]. Computer simulation of criminal patterns is implemented to identify potential hot spots and flashpoints. It can be usefully used for supporting police forces which can allocate resources to areas where particular crimes are most likely to occur[19].

[12] E. GROFF, L. MAZEROLLE, *op. cit.*

[13] F. SQUAZZONI, *The Micro-Macro Link in Social Simulation*, in "Sociologica", Vol. 1, 2008, n. 8.

[14] J.M. EPSTEIN, R. AXTELL, *Growing Artificial Societies: Social Science from the Bottom-up*, Cambridge, MIT Press, 1996.

[15] L. LIU, J.E. ECK (eds.), *op. cit.*; T. BOSSE, C. GERRITSEN, *Social Simulation and Analysis of the Dynamics of Criminal Hot Spots*, in "Journal of Artificial Societies and Social Simulation", Vol. 13, 2010, n. 2, http://jasss.soc.surrey.ac.uk/13/2/5.html.

[16] S. JOHNSON, *Repeat Burglary Victimisation: A Tale of Two Theories*, in "Journal of Experimental Criminology", Vol. 4, 2008, pp. 215-240.

[17] L. SHERMAN, P. GARTIN, M. BUERGER, *Hot Spots of Predatory Crime: Routine Activities and the Criminology of Place*, in "Criminology", Vol. 27, 1989, n. 1, pp. 27-55; J.E. ECK, S. CHAINEY, J. CAMERON, M. LEITNER, R. WILSON, *Mapping Crime: Understanding Hot Spots*, National Institute of Justice, U.S. Department of Justice, 2005, http://www.ojp.usdoj.gov/nij/pubs-sum/209393.htm.

[18] T. BOSSE, C. GERRITSEN, *op. cit.*; V. FURTADO, A. MELO, A. COELHO, R. MENEZES, *A Crime Simulation Model Based on Social Network and Swarm Intelligence*, Proceedings of the 2007 ACM Symposium on Applied Computing, Seoul, 2007.

[19] See for example the IBM system known as CRUSH - *Criminal Reduction Utilising Statistical History*, http://www-03.ibm.com/press/us/en/pressrelease/32169.wss. The software is being tested in UK and has been tested in Tennessee, where the police department credits CRUSH as the key factor behind a 31% reduction in overall crime and a 15% fall in violent crime.

The knowledge and techniques that can be ascribed to ABSS are, in effect, demonstrating a significant capacity to contribute to criminal justice policy making.

This paper aims at presenting the potential intersections between ABSS and crime research by focusing on policy making issues. The goal is to clarify how ABSS can specifically support the elaboration of criminal justice policies by making the policy evaluation tools more effective.

2. Agent-based Modeling and the Bottom-up Approach to Computer Simulation

The employment of Agent-based Social Simulation (ABSS) in the social sciences has increased over the past ten years[20] and has proved as a powerful computational tool to formalize models of social outcomes and to modelling crime[21]. The main purpose of agent-based modelling is to analyze the properties of social systems by explicitly representing individuals (called "agents"), interactions between them and the (geographical, spatial, economic, institutional) environment in which they are situated[22].

In crime modelling, agents represent offenders, potential victims, police and/or others informal control agents. Agents make decisions about movement and actions in a local environment (e.g. a street network, social network or some other representation of space). The environment can include features such as buildings, where potential victims might be situated, or barriers to movement or communication.

The bottom-up approach to computer simulation on which agent-based social simulation relies means that starting from a few, simple, theory-based rules that inform the behavior of individual agents (and their interactions), the model generates macro-level patterns (they often acquire the property of emergence which refers to unexpected consequences)[23].

The interactions of agents with each other and the environment are governed by set of rules, following a sequence of the "what if" – questions. As

[20] N. Gilbert, K. Troizsch, *Simulation for the Social Scientist*, Maidenhead, Open University Press, 2005; N. Gilbert, *Agent-based Models*, London, Sage, 2008.

[21] D.J. Birks, S. Donkin, M. Wellsmith, *op. cit.*

[22] J.H. Miller, S. Page, *Complex Adaptive Systems. An Introduction to Computational Models of Social Life*, Princeton-Oxford, Princeton University Press, 2007; F. Squazzoni, *op. cit.*; N. Gilbert, *Agent-based Models*, cit.

[23] J.M. Epstein, R. Axtell, *op. cit.*; N. Gilbert, K. Troizsch, *op. cit.*

underlined by Elffers and Van Baal it means: what happens if "acts" ("behavior") of a number of "agents" are fully governed by certain "law-like processes"? These law-like processes state completely which specific act an agent will perform, in a given situation[24]. For example, a rule such this could state: "If an offender agent occupies the same location as a target agent, then the offender robs the victim", otherwise "If a police agent is within a set distance of an offender agent then no crime occurs". Rules govern the transition from one state to another – for example, the state with no crime to the state with a crime.

Usually these law-like processes are specified by means of a mathematical formula (a decision rule that in many cases includes probabilistic elements) that identifies what behavior will be performed by that actor, given his situation (often the situation is characterized by the availability of other actors).

Moreover, the environment may change during the simulation according to a related law-like process as well (under the influence of higher order rules for adapting, such as learning models, neural network models, etc.) and agents may be capable of evolving, based on experience, allowing unanticipated behaviors to emerge.

Simple problems of this type sometimes can be analytically solved through mathematical analysis. However, simulation becomes indispensable as soon as the complexity of the problem is analytically intractable with mathematical or statistical models. As already Squazzoni highlighted, social scientists can grasp within a formalized model those relevant features of the complexity of social systems: autonomy and heterogeneity of agents, adaptive rationality, spacial and local interactions, non-equilibrium dynamics[25]. Even a simple agent-based model can exhibit complex behavior patterns and provide valuable information about the dynamics of the real-world system that it reproduces[26].

In the field of crime research, for example, the spatial nature of crime and interaction between agents (criminal, police, victim, etc.) often requires

[24] H. ELFFERS, P. VAN BAAL, *Spatial Backcloth Is Not That Important in Simulation Research: An Illustration from Simulating Perceptual Deterrence*, in Liu L., Eck J.E. (eds.), "op. cit.", p. 20.

[25] F. SQUAZZONI, *op. cit.*

[26] F. SQUAZZONI, R. BOERO, *Towards an Agent-based Computational Sociology: Good Reasons to Strengthen Cross-fertilization between Complexity and Sociology*, in Stoneham L.M.(ed.), "Advances in Sociology Research", New York, Nova Science Publishers Inc., Vol. 2, 2005, pp. 103-133; J.H. MILLER, S. PAGE, *op. cit.*; N. GILBERT, *Agent-based Models*, cit.

the agent-based models to include space and time[27]. It becomes important overcoming some of the limitations which characterize the traditional research methods in criminology bounded both temporally and spatially. In this framework, simulation method represents a third way between the more established research approaches[28] of carrying out social science, in addition to argumentation and formalization. In contrast to other methods "with computer simulations, it is possible to carry out experiments and observe the occurrence of emergence"[29].

3. Agent-based Modeling and Crime Analysis: Using Simulated Experiments in Crime Prevention

For the purpose of this paper we focus our attention on agent-based simulation as a different, but complementary approach, to existing methodologies applied in the study of crime. Especially we refer to the use of agent-based modelling as a virtual laboratory to conduct "virtual experiments"[30]. In regard, Eck and Liu[31] stated that simulated experiments of crime prevention interventions are an important class of research methods that fits within the empirical experimental paradigm widely used in criminology.

A simulation works as a computational laboratory when you manipulate a, so-called, experimental condition[32]. Agent-based models can be used

[27] D.G. Brown, M. North, D. Robinson, R. Riolo, W. Rand, *Spatial Process and Data Models: Toward Integration of Agent-based Models and GIS*, in "Journal of Geographical Systems", Vol. 7, 2005, n. 1, pp. 25-47; E. Groff, *Characterizing the Spatio-temporal Aspects of Routine Activities and the Geographic Distribution of Street Robbery*, in Liu L., Eck J.E. (eds.), "op. cit.", pp. 226-251.

[28] N. Gilbert, *Simulation: A New Way of Doing Social Science*, in "American Behavioral Scientist", Vol. 42, 1999, n. 10, p. 1487.

[29] N. Gilbert, P. Terna, *How to Build and Use Agent-based Models in Social Science*, in "Mind & Society", Vol. 1, 2000, p. 58.

[30] L. Liu, J.E. Eck (eds.), *op. cit.*; M. Townsley, D.J. Birks, *Building Better Crime Simulations: Systematic Replication and the Introduction of Incremental Complexity*, in "Journal of Experimental Criminology", Vol. 4, 2008, n. 3, pp. 309-333.

[31] J.E. Eck, L. Liu, *Contrasting Simulated and Empirical Experiments in Crime Prevention*, cit.

[32] C. Dibble, *Theory in a Complex World: GeoGraph Computational Laboratories*, Santa Barbara, University of California, Department of Geography, 2001, p. 165; D.C. Parker, T. Berger, S.M. Manson, *Agent-based Models of Land-use/land-cover Change*, LUCC Report Series No. 6, LUCC Focus 1 Office Anthropological Center for Training and Research on Global Environmental Change, Indiana University, 2001; L. Tesfatsion, *Guest Editorial:*

to investigate the relative impact of one or more components of a system through several manipulations. Simulations implemented in the framework of a computational laboratory offer the advantage of being able to control aspects of interest about agents and/or the landscape, varying the values of the parameters related to one or both of them[33].

This feature provides a level of control difficult to achieve using traditional social science methods[34]. First of all, the combination of heterogeneous agents which interact in different local environments enables the researcher to conduct several "virtual" experiments in different experimental conditions (also applying various prevention scenarios) and then evaluate the simulated outcomes[35]. Simulation "offers social scientists an analogue to controlled experiments for examining social phenomena. In a simulation researchers can alter factors normally beyond their control, implement interventions perfectly, and explore dose–response relationships beyond logistic and financial constraints"[36].

By contrasting empirical and computational experimentation within criminology, Eck and Liu[37] state that simulated experiments provide a bridge between theoretical explanations and empirically inferred representations of crime patterns[38]. Simulated experiments help criminologists to face the weakness of theoretical explanations of crime (mainly written in common languages and often subjected to multiple interpretations), because they provide a rigorous formalization of a certain theory for empirical testing and experimentation. Indeed simulation requires that the theory's assumptions must be operationalized as a computer algorithm that is consistent with the theory. The result is a more formalized theory[39]. In other words, agent-

Agent-based Modeling of Evolutionary Economic Systems, in "Computation", Vol. 5, 2001, n. 5, pp. 437-441.

[33] E. GROFF, L. MAZEROLLE, *op. cit.*

[34] J.M. EPSTEIN, R. AXTELL, *op. cit.*; N. GILBERT, *Simulation: A New Way of Doing Social Science*, cit.

[35] E. GROFF, *Simulation for Theory Testing and Experimentation: An Example Using Routine Activity Theory and Street Robbery*, cit.; E. GROFF, L. MAZEROLLE, *op. cit.*

[36] M. TOWNSLEY, D.J. BIRKS, *op. cit.*, p. 310.

[37] J.E. ECK, L. LIU, *Contrasting Simulated and Empirical Experiments in Crime Prevention*, cit.

[38] *Ivi*, p. 196.

[39] I. BENENSON, P. TORRENS, *Geosimulation: Automata-based Modeling of Urban Phenomena*, New York, Wiley, 2004; J.M. EPSTEIN, *Generative Social Science: Studies in Agent-based Computational Modelling*, Princeton, Princeton Univ. Press, 2006; P. HEDSTRÖM,

based simulation requires the researcher to specify the causal mechanisms[40] by which a hypothesized independent variable gives rise to the dependent variable, according to the theory incorporated into the simulation model.

The process of decomposing theories into computational formalisms "such as the rules that govern agent behaviour, is useful in that it provides researchers greater insight and demands that they specify theories and concepts in explicit terms. This can highlight potential inconsistencies or shortcomings and, by doing so, contributes to the subsequent strengthening of theory[41].

Once the theory has been operationalized as a computer code, the next step is to observe whether the model (and then the theory on its basis) is sufficient to generate an outcome that looks like the empirical distribution of the dependent variable observed. According to the principles of the generative explanation[42]: if the simulation outcomes do not match the empirical data related to the phenomenon in question, the theory is falsified, otherwise we have identified at least one process that grows the phenomenon (and how theory explains it).

It is for its ability to falsify that simulation might help improving theorizing in criminology[43]. As stated by Eck and Liu "because simulations can falsify theory, they are not simply a method for theory elaboration but can also be used for experimentation"[44]. Criminological theories can be made testable.

Unlike statistical explanations of crime, generative explanation reached through the mean of agent-based simulation focuses on the mechanisms that give rise to the phenomenon. Specifically, crime pattern simulations allow researchers to examine not only the mere distributions of crime patterns (e.g. the dislocation of hot spots within a certain spatial environment) but also how they develop (the mechanisms that give rise to crime patterns or that prevent crime from clustering)[45].

Anatomia del sociale. Sui princìpi della sociologia analitica, Milano, Bruno Mondadori, 2006; J.H. MILLER, S. PAGE, *op. cit.*.

[40] P. HEDSTRÖM, *op. cit.*

[41] M. TOWNSLEY, D.J. BIRKS, *op. cit.*, p. 311.

[42] P. HEDSTRÖM, *op. cit.*; J.M. EPSTEIN, *op. cit.*

[43] D.J. BIRKS, S. DONKIN, M. WELLSMITH, *op. cit.*

[44] J.E. ECK, L. LIU, *Contrasting Simulated and Empirical Experiments in Crime Prevention*, cit., p. 198.

[45] *Ivi*, p. 196.

The utility of applying simulated experiments in crime research also derives from data limitations. Crime studies rely on poor and misleading empirical data. This is a matter of fact. Data sources are in fact highly unreliable where people involved with crime know little about what occurred or have a self-interest to say nothing about it (for example in the case of offenders) or to misrepresent the truth in particular circumstances. Inductive reasoning, based on inherently faulty data, is likely to lead to invalid explanations[46]. In the case of crime there is also the problem of the so-called "dark number" which implies that a certain amount of crimes are inherently undetectable.

Data and theory limitations show the weakness of many criminological theories[47]. In addition, computer experiments provide us with an approach that overcomes some of the current limitations of the traditional research methods which deal with real-world settings, real subjects or even with laboratories. There are indeed many limits to manipulate multiple independent variables through field experiments or test their effects independently. In field experiments it is difficult to create many experimental conditions. Where field experiments in crime prevention or criminal justice are difficult and highly costly, "simulations allow the testing of innovative interventions prior to their being taken into the field"[48]. With simulations, an extensive range of interventions can be applied by varying parameters. As underlined by Townsley and Birks "Simulation models allow repeated experiments under identical conditions, save for differences selected by the researcher"[49]. Moreover, each experimental condition can be replicated hundreds or thousands of times[50] and once the model has been built, further adjustments are simple to perform.

Simulations can then be used to select the range of conditions and in some cases they may be usefully employed as pre-tests in order to screen out the least plausible innovations[51].

[46] *Ivi*, p. 201.

[47] D. WEISBURD, A.R. PIQUERO, *How Well Do Criminologists Explain Crime?*, in Tonry M. (ed.), "Crime and Justice: An Annual Review of Research", Chicago, University of Chicago Press, Vol. 37, 2008.

[48] J.E. ECK, L. LIU, *Contrasting Simulated and Empirical Experiments in Crime Prevention*, cit., p. 198.

[49] M. TOWNSLEY, D.J. BIRKS, *op. cit.*, p. 311.

[50] J.M. EPSTEIN, *op. cit.*

[51] E. GROFF, *Simulation for Theory Testing and Experimentation: An Example Using Routine Activity Theory and Street Robbery*, cit.; J.E. ECK, L. LIU, *Contrasting Simulated and Empirical Experiments in Crime Prevention*, cit.

There are also moral boundaries to empirical experimentation that operates with human subjects. Simulations might then be considered when ethical issues preclude random assignment of people to certain control conditions. For example, while police might not "strike" for long periods of time in real life, they can do so in an artificial society.

Simulated experiments could also shed light on some important police functions that are very unlikely to be studied with field experiments, for example the effect of police rapid response on crime[52].

Finally, computational laboratories allow to change the physical environment, that is not possible in real-world settings, for example it is thus possible to alter street patterns experimentally, on a large scale, to see their effects on crime patterns[53].

A critical note with regard to simulated experiments relates to the actual implementation of an intervention in a real environment. Only after the actual implementation of a policy intervention indeed it will create the post-implementation data used in empirical experiments. In simulated experiments the implementation data of a certain intervention are hypothetical, created in a "virtual" setting. On the one hand this fact reduces the credibility of simulated experiments, on the other "it has the advantage that we can 'bench test' policies prior to their implementation, or even test arrangements that cannot be tested in the field"[54].

Next Section will focus on the advantage of crime simulation for criminal justice policy modeling. We will review several agent-based models implemented for this purpose.

4. Agent-based Models of Crime Prevention and Criminal Justice Policies

Criminologists have recently been exploring how agent-based simulation models can inform the study of crime[55].

[52] J.E. Eck, L. Liu, *Contrasting Simulated and Empirical Experiments in Crime Prevention*, cit.

[53] *Ibidem*.

[54] *Ivi*, p. 204.

[55] P.L. Brantingham, P.J. Brantingham, *op. cit.*; P.L. Brantingham, E.R. Groff, *op. cit.*; L. Liu, J.E. Eck (eds.), *op. cit.*

The early works are the studies by Epstein and colleagues[56] on civil violence and by Wilhite[57] on crime protection. Both studies show how interactions between individual agents appear to be linked to the emerging pattern of violence or protection at the collective level. Crime simulations allow researchers to examine how crime patterns develop and to explore the mechanisms that give rise to crime patterns[58].

It is possible to distinguish different types of agent-based models on crime, starting from their purposes. They range from theorizing, to policy testing and program planning[59]. Starting from assumptions drawn from different criminological theories, several simulations explore theoretical problems in crime[60]. In each case, researchers are interested in determining whether commonly observed crime patterns could arise from simple processes. If the simulations can mimic real world phenomena, by using a limited set of simple processes, this suggests that the theories encapsulated into the software may be sufficient to explain the phenomena.

Experimenting with these artificial crime models may help formulate hypotheses about how crime is produced[61]. After theoretical hypotheses/ex-

[56] J.M. EPSTEIN, J.D. STEINBRUNER, M.T. PARKER, *Modeling Civil Violence: An Agent Based Computational Approach*, Washington D.C., Center on Social and Economic Dynamics, Brookings Institution, 2001, working paper.

[57] A. WILHITE, *Protection and Social Order*, in "Computational Economics and Finance Meeting", Yale University, 2001.

[58] L. LIU, J.E. ECK (eds.), *op. cit.*

[59] J.E. ECK, L. LIU, *Varieties of Artificial Crime Analysis: Purpose, Structure, and Evidence in Crime Simulations*, in Liu L., Eck J.E. (eds.), "op. cit.".

[60] X. WANG, L. LIU, J.E. ECK, *A Spatial Dynamic Simulation of Crime Using Agent-based Modeling*, Proceedings of the Association of American Geographers Conference, Philadelphia, 2004; E. GROFF, *Simulation for Theory Testing and Experimentation: An Example Using Routine Activity Theory and Street Robbery*, cit.; E. GROFF, *Characterizing the Spatio-temporal Aspects of Routine Activities and the Geographic Distribution of Street Robbery*, cit.; T. BOSSE, C. GERRITSEN, M.C.A. KLEIN, *Agent-based Simulation of Social Learning in Criminology*, Proceedings of the International Conference on Agents and Artificial Intelligence (ICAART), Porto, 2009; V. PUNZO, B. SONZOGNI, F. CECCONI, *Social Networks and Deviant Leisure Choices. An Agent-based Simulation Model*, in Lo Verde F.M., Modi I., Cappello G. (eds.), "Mapping Leisure across Borders", Cambridge Scholars Publishing, forthcoming; D. BIRKS, M. TOWNSLEY, A. STEWART, *Generative Explanations of Crime: Using Simulation to Test Criminological Theory*, in "Criminology", Vol. 50, 2012, n. 1, pp. 221-254.

[61] X. WANG, *op. cit.*; X. WANG, L. LIU, J.E. ECK, *Crime Simulation Using GIS and Artificial Intelligent Agents*, in Liu L., Eck J.E. (eds.), "op. cit.", pp. 209-225; E. GROFF, *Characterizing the Spatio-temporal Aspects of Routine Activities and the Geographic Distribution of Street Robbery*, cit.

planation mechanisms have been identified they must then be tested using empirical data[62].

Other studies acquired a simulative approach to examine prospectively the likely effects of policy changes[63].

Some authors suggested the use of agent-based simulation as a policy evaluation tool[64]. Deepening the aspects related to the impact of various anti-crime policies, Wilhite and Allen[65] for example showed that, although the intensification of the anti-crime measures tends to reduce crime, the impact of incarceration is ambiguous, as a high rate of detention may lead to increased crime in the long term. In general, the increase in time of incarceration can reduce crime, as a mechanical effect, but this reduction may be due to a steady increase in the prison population, and this may suggest that incarceration may not be a solution in a long-term perspective. The results achieved by Wilhite and Allen show that the deterrent effect of the anti-crime (in particular the increase in length of the penalties) and incarceration varies between short and long term.

Other studies employed agent-based models to test policies or to compare crime prevention strategies[66]. Szakas and colleagues, for example, illustrate a simulation of police patrolling that would allow to test various police patrol methods[67]. Simulations such as presented by Szakas and colleagues could help in planning a certain intervention (in the case study it is a police intervention) by narrowing the range of options available and aiding in the selection of the options with the greatest promise. Specifically, the authors suggested that police simulations might be particularly useful for planning police interventions for emergency situations (e.g. natural disasters, terrorist

[62] J.E. ECK, L. LIU, *Contrasting Simulated and Empirical Experiments in Crime Prevention*, cit.

[63] K. AUERHAHN, *Using Simulation Modeling to Evaluate Sentencing Reform in California: Choosing the Future*, in "Journal of Experimental Criminology", Vol. 4, 2008, n. 3, pp. 241-266.

[64] P. PEREZ, A. DRAY, *op. cit.*

[65] A. WILHITE, W.D. ALLEN, *Crime, Protection, and Incarceration*, in "Journal of Economic Behavior and Organization", Vol. 67, 2008, pp. 481-494.

[66] T. BOSSE, C. GERRITSEN, *Comparing Crime Prevention Strategies by Agent-based Simulation*, 2009 IEEE/WIC/ACM International Joint Conference on Web Intelligence and Intelligent Agent Technology, 2009.

[67] J. SZAKAS, C. TREFFTZ, J.R. RAMIREZ, E. JEFFERIS, *Development of an Intelligent Patrol Routing System Using GIS and Computer Simulations*, in Liu L., Eck J.E. (eds.), "op. cit.", pp. 339-351.

attacks, and mass accidents). Similarly, the agent-based model described by Bosse and colleagues illustrates the usefulness of simulation as an analytical tool to investigate the effectiveness in crime prevention of various guardianship policies and to develop policing deployment strategies, the so-called hot spot policing[68].

According to Eck and Liu "planning simulations are very similar to the use of simulations to test policies, but they are less specific about the changes being implemented"[69]. For example, a planning simulation might ask what would happen to court backlogs if arrests were increased (but would not specify how arrests are increased). Instead, a policy testing simulation might ask whether changing a particular policing practice results in more arrests[70].

An approach similar to the planning simulations relates to the use of simulations to test the impact of programs prior to implementation[71]. In this framework, simulations form the basis of decision support systems (DSS)[72], a popular class of computer-based information or knowledge based systems that support decision making activities. Specifically, Intelligent DSS often use multiple intelligent agents interacting based on decentralized coordination models to assist decision makers in analyzing a situation[73].

Contextualizing its interest to a specific policy sector, the agent-based model developed by Dray and colleagues[74] examines the likely impact of crime-prevention interventions looking at the effects of forms of policing on heroin related harms. The study describes an agent-based model that aims

[68] T. Bosse, H. Elffers, C. Gerritsen, *Simulating the Dynamical Interaction of Offender, Targets and Guardians*, in "Crime Patterns and Analysis", Vol. 3, 2010, n. 1, pp. 51-66.

[69] J.E. Eck, L. Liu, *Varieties of Artificial Crime Analysis: Purpose, Structure, and Evidence in Crime Simulations*, cit., p. 416.

[70] *Ivi*, p. 416.

[71] P.L. Brantingham, U. Glässer, P. Jackson, B. Kinney, M. Vajihollahi, *Mastermind: Computational Modeling and Simulation of Spatiotemporal Aspects of Crime in Urban Environments*, in Liu L., Eck J.E. (eds.), "op. cit.", pp. 252-281.

[72] L. Fang, K.W. Hipel, D.M. Kilgour, X. Peng, *A Decision Support System for Interactive Decision Making. Part I: Model Formulation*, in "IEEE Transactions on Systems, Man and Cybernetics", Part C, Vol. 33, 2003, n. 1, pp. 42-55; L. Mikhailov, M.G. Singh, *Fuzzy Analytic Network Process and Its Application to the Development of Decision Support Systems*, in "IEEE Transactions on Systems, Man and Cybernetics", cit., pp. 33-41.

[73] J.N.D. Gupta, G.A. Forgionne, T.M. Mora (eds.), *Intelligent Decision-making Support Systems: Foundations, Applications and Challenges*, New York, Springer, 2006.

[74] A. Dray, L. Mazerolle, P. Perez, A. Ritter, *Drug Law Enforcement in an Agent-based Model: Simulating the Disruption to Street-level Drug Markets*, cit.

at comparing three different law enforcement strategies (policing strategies), exploring the relative impact of each (standard patrol, hotspot policing, and problem-oriented policing) on an archetypal street-based illicit drug market. Researchers simulate the relative effectiveness of these different drug law enforcement approaches, analyzing several outcome indicators (such as the number of committed crimes, dealers' and users' cash, overdoses and fatal overdoses). Simulative results show that problem-oriented policing is the most effective approach to disrupting street level drug markets in a simulated urban environment[75].

The study shows how simulated policy experiments can examine situations that are impossible to be examined using empirical research methods. In fact an experiment on three types of policing strategies simultaneously throughout the same city would be impossible to conduct in the real world.

Within the field of Criminology, the spatio-temporal dynamics of crime are an important subject of study. Typical questions, in this area, are how the emergence and displacement of criminal hot spots can be explained and predicted. In this regard, an interesting question is whether simulation models of criminal displacement can be useful for anticipatory policies strategies (e.g. to increase the number of guardians at locations where hot spots are likely to emerge, instead of at the present locations of hot spots). Some agent-based models have been implemented to this purpose, comparing between a number of policy strategies (varying from merely reactive to more anticipatory policies)[76]. In all these cases researchers highlight the implications of simulated experimentation in terms of policy indications.

An interesting and recent approach that looks at the use of computer simulation in policy modelling is the so-called *participatory agent-based social simulation*[77]. Participatory modeling aims at closely involving potential users and stakeholders in model specification, design, testing and use. The development of agent-based social simulation models is realized in conjunction with users and stakeholders. They can repeat decisions made under

[75] *Ibidem*.

[76] T. BOSSE, C. GERRITSEN, *Comparing Crime Prevention Strategies by Agent-based Simulation*, cit.

[77] A. RAMANATH, N. GILBERT, *The Design of Participatory Agent-based Social Simulations*, in "Journal of Artificial Societies and Social Simulation", Vol. 7, 2004, n. 4, http://jasss.soc.surrey.ac.uk/7/4/1.html; M.A. WIMMER, K. FURDIK, M. BICKING, M. MACH, T. SABOL, P. BUTKA, *op. cit.*

differing scenarios and strategic conditions[78]. This method can provide support for decision making in a relatively cost effective way[79]. A group of researchers at the University of Koblenz (Germany) have recently been designing and implementing a software tool to support participatory simulation and policy modeling[80]. The software is intended to provide a platform for formalizing various kinds of agent behavior representations[81] and to support models of political negotiations between different groups of stakeholders[82]. The use of participatory simulation as a technique that enhances understanding of tasks and communication among stakeholders is also receiving increasing attention in the field of criminal justice policy research[83].

5. Conclusions

In the present paper we have discussed how agent-based social simulation (ABSS) can address the study of crime and how it can support criminal justice policy making. Crime simulation is a methodological approach to formalizing and testing criminological theory and to conducting "virtual" experiments on crime-prevention strategies.

One of the advantages of simulated experiment is its ability to create a counterfactual (it does not have to use randomization because it can go back in time and recreate the same society upon which to apply a different intervention)[84].

[78] E. Bonabeau, C. Meyer, *Swarm Intelligence: A Whole New Way to Think about Business*, in "Harvard Business Review", Vol. 79, 2001, n. 5, pp. 107-114; B. Hannon, M. Ruth, *Dynamic Modelling*, 2nd ed., New York, Springer-Verlag, 2001.

[79] T. Wickenberg, P. Davidsson, *On Multi Agent Based Simulation of Software Development Processes*, in Sichman J., Bousquet F., Davidsson P. (eds.), "Multi-Agent-Based Simulation - MABS 2002", Bologna, 2002, pp. 104-113.

[80] See the "Open Collaboration in Policy Modelling - OCOPOMO" project, funded by the EU under the FP7.

[81] U. Lotzmann, R. Meyer, *A Declarative Rule-based Environment for Agent Modelling Systems*, in "Proceedings of the 7th Conference of the European Social Simulation Association, ESSA 2011", Montpellier, September 2011.

[82] OCOPOMO is currently developing a methodology to convert the mental models of stakeholders (which usually come as verbal description of their world views) into formal models, accumulated in a DRAMS description of a simulation model.

[83] See the "The Global Dynamic of Extortion Racket Systems - GLODERS" project, funded by the EU under the FP7.

[84] R.A. Berk, J. Bond, R. Lu, R. Turco, R.E. Weiss, *op. cit.*

As far as the field of criminology is concerned, agent-based social simulation is useful in many circumstances, specifically when opportunities to conduct empirical experiments with real subjects are challenging or impossible[85]. For example, simulations might be considered when ethical concerns prevent the random assignment of people to the so-called "control conditions". Simulations are also useful as a comparatively inexpensive way to evaluate a certain program and suggest some changes before it is properly tested empirically. The cost of running 'virtual' experiments is inferior of the costs involved in empirical field trials. Simulation may play a significant role in vetting and strengthening programs prior to their empirical testing[86], "then we may be able to weed out interventions prior to their application in the field for empirical testing"[87].

Within criminology, ABSS has been usefully employed to projecting the likely impact of crime-prevention interventions[88] and to evaluating the potential of a certain criminal justice policy strategy[89].

As far the application of crime simulation to policy making, several researchers have been developing agent-based models to study policy problems in different policy sectors and with different purposes. In Fig. 1 we synthesized the way in which agent-based social simulation can be usefully applied within the policy process, showing, for each stage of the policy cycle, the specific purposes of agent-based models.

As already seen in previous Sections, agent-based social simulation can support the overall policy making process along its different stages: from the original problem definition; to the phase of implementation (in which agent-based models can be used to test the relative impact of a certain policy and to highlight what is going wrong); to policy evaluation, in which agent-based models can be used to test the overall impact of a certain policy.

During the first phase of the policy cycle (problem definition), for example, simulations could help improving the theoretical explanation (which justifies the definition of a certain issue as a problem that needs to be solved),

[85] E. GROFF, L. MAZEROLLE, *op. cit.*

[86] *Ibidem*; J.E. ECK, L. LIU, *Varieties of Artificial Crime Analysis: Purpose, Structure, and Evidence in Crime Simulations*, cit.

[87] J.E. ECK, L. LIU, *Varieties of Artificial Crime Analysis: Purpose, Structure, and Evidence in Crime Simulations*, cit., pp. 209-210.

[88] A. DRAY, L. MAZEROLLE, P. PEREZ, A. RITTER, *Drug Law Enforcement in an Agent-based Model: Simulating the Disruption to Street-level Drug Markets*, cit.

[89] T. BOSSE, H. ELFFERS, C. GERRITSEN, *op. cit.*

by requiring a higher degree of theory formalization. Formalization reveals logical inconsistencies of a theory that must be eliminated before planning useful policy interventions. If crime prevention interventions can be simulated, then we may be able to weed out interventions prior to their application in the field for empirical testing. Several agent-based models address this question and allow for the examination of the outcomes of different crime-prevention interventions (e.g. police patrolling strategies).

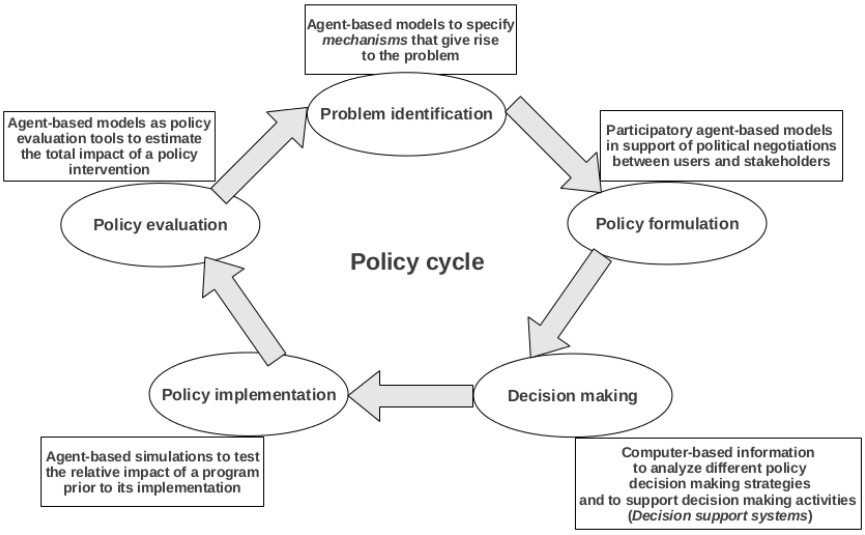

Fig. 1 – The employment of agent-based simulations along the policy making process

Moreover simulations could reveal how much time must pass between the implementation of a policy intervention and the appearance of its outcomes, for example in terms of crime reduction or increase of the safety of the population. This also means that simulation helps us to measure the impact of a policy intervention. This could also allow to improve the planning of empirical experiments and avoid using experiments that measure impact prior to its occurrence[90].

Finally, simulations could help us estimate the conditions in which a certain intervention is likely to wear off[91]. It is then possible to use simulated

[90] J.E. ECK, L. LIU, *Varieties of Artificial Crime Analysis: Purpose, Structure, and Evidence in Crime Simulations*, cit.

[91] *Ivi*, p. 210.

experiments to estimate the total impact of the intervention, by using various experimental scenarios in which you manipulate parameters related to the social, cultural or economic environment in which the policy is implemented and then to observe the consequences in the model. It may allow to give realistic measures of a program's impact and to provide effective, reliable, and replicable instruments for evidence based policy making.