Market Opportunities, Customer Desires and Purchasing Selectiveness Modelling in Multi-layered Cellular Automata:

A Study Case on Organizational Survivability

José V. Matos[1,2,3], Rui J. Lopes[1,2], Yasmin Merali[4]

[1]ISCTE-IUL Lisbon University Institute, Lisbon, Portugal
jlvmatos@gmail.com, rui.lopes@iscte.pt
[2]Instituto de Telecomunicações, Lisbon, Portugal
[3]Faculty of Sciences – University of Lisbon, Portugal
[4]University of Warwick – Warwick Business School, Warwick, United Kingdom
yasmin.merali@wbs.ac.uk

Abstract. The present work aims to contribute to a better understanding of the dynamics of organizational competition and survival in a supply chain network market context, while highlighting the potential of multi-layered cellular automata models as frameworks for accommodating increasing levels of complexity. More particularly, the implementation of inter-layer rules associated to k-bit words modelling of market opportunities, customer desires and purchasing selectiveness, and their impact on the dynamics of an evolutionary "ecology" of suppliers, competing organizations, and customers, following a complex adaptive systems approach is described and illustrated through a study case on organizational survivability. The implications of the study results — reflecting the interplay between market environment, competitors' strategic choice, and corresponding ability to succeed, survive crises and proliferate — are then discussed and the main aims of the work ahead highlighted.

Keywords: Cellular Automata, Complex Adaptive Systems, Crisis Management, Organizational Competition and Survival, Supply-Chain Network Modelling.

1 Introduction

To succeed in a globally linked business market environment, companies are required to compete effectively and efficiently while simultaneously having the ability to survive unexpected events and potential supply chain disruptions. The increasing structural and dynamical complexity of business networks combined with the need to keep modelling at the simplest level required to provide meaningful and general insights, recommends the adoption of an incremental and comprehensive framework. In this context, the potential provided by multi-layered Cellular Automata (CA) models to provide such framework is highlighted and illustrated through a study case which aims to contribute to a better understanding of the organizational competition and survival dynamics in a supply chain network market context. While benefiting from the analysis advantages of simple CA models, the adopted approach, using multiple CA layers — corresponding to different agent types — combined with the implementation of inter-layer rules, provides a well-suited and versatile modelling methodology able to incorporate the properties and mechanisms of a complex adaptive system [1].

After providing a conceptual introduction to the competition and survival problem in the business world and addressing the modelling challenges involved, as well as the process leading to the adopted multi-layered CA base approach, complemented by the integration of fundamental market dynamics elements, the performed study case is described, and the obtained results presented. The implications of those results are then discussed, and the main aims of the work ahead highlighted.

2 Problem Domain Context, Components and Dynamics

To stay in business, companies need to simultaneously sustain a competitive advantageous market position while being able to avoid, escape, contain and recover from unexpected and threatening events that may lead to crisis and highly damaging situations. Organizational survivability requires an effective and efficient competitive strategy in normal times, as well as an adequate resilient strategy to handle potential threats and overcome crisis (i.e. the capability to anticipate, avoid, escape, contain, and recover from potential business continuity threats). In a resource constrained context, efficiency and resilience requirements are often at odds with each other.

Crises can be defined as an unstable time or state of affairs in which a decisive change is impending, with the distinct possibility of a highly undesirable outcome (adapted from Fink [2]). Organizational survivability and the effectiveness of firms' crisis preparedness and response measures may, however, depend on the specific competitive market environment in which those measures are implemented. That environment often includes a complex network of suppliers, competitors and customers, with different attributes (population densities, economic capacities, changing desires, etc.), linked through increasingly global and intricate supply chains.

To understand an organization's competitiveness and ability to avoid and survive crises we need to consider, not only its strategic choices, but also how its competitors' strategies affect the overall process dynamics. In this context, the underlying problem that the present work aims to help understand is how organizational strategic choices, in both normal and crisis times, affect the ability of a firm to successfully compete, overcome crises and survive under different market environments.

To address the present problem, the following components and dynamics of interest were considered: (1) supply-chain actors (suppliers, focal firms, and customers); (2) interactions between them, considering agent-centred limited knowledge about the market; (3) agents market-positioning behaviour reflecting Porter's five forces that shape industry competition (rivalry among existing competitors, bargaining power of buyers, bargaining power of suppliers, threat of new entrants, and threat of substitute products or services) [3]; (4) a set of generic strategies followed by competitors; (5)

product/service opportunities and customer desires driving the demand and supply dynamics; (6) customers' purchasing behaviour based on product/service utility added-value; (7) downstream product/service and upstream revenues flows.

3 The Modelling Approach

3.1 Multi-layered Cellular Automata as a Supply Chain Modelling Framework

A three-layered CA was used as a supply-chain modelling framework, expanding the rule-based interactions from within to across populations (i.e. intra and inter-layer based rules). Aggregating the supply-chain actors in three individual population sets — suppliers, competing focal firms (or competitors), and customers (with different economic capacities and desires) — the rules driving their market position selection at each population layer are influenced, not only by the current attributes of the actor's neighbour sites on that layer, but also by the current attributes of the corresponding neighbour sites of the adjacent layers. As shown on Figure 1, a competitor's functional (non-disrupted) supply chain implies the existence of at least one supplier and one customer on the same (x-axis) competitor's position, or adjacent positions, of the corresponding layers. A disrupted supply chain implies the interruption of the corresponding deliverable/revenue flows. In their pursuit of the corresponding delivery/revenue flows maximization through functional supply chains, the behaviour of suppliers (top layer) is influenced by the suppliers' and competitors' layers, the behaviour of competitors (middle layer) is influenced by all three layers, and the behaviour of customers is influenced by the competitors' (product/service deliverables) and customers' layers. In particular, the suppliers' positioning rules are driven towards the maximization of product/service demand from available supply chains' competitors — three at most, corresponding to the selected supplier's x-axis position X, and two (X-1 and X+1) neighbouring ones — while minimizing other (competing) suppliers in vicinity; competitors' positioning depends on their applicable strategy (as illustrated on Fig. 2); and customers' continuously seek the empty position on their layer that is best served by available competitors' deliverables[1].

[1] More specifically, with the introduction of market opportunities and customer desires, as later described on Section 3.2, customers will continuously seek the empty position that corresponds to the available deliverable that best matches its current desire.

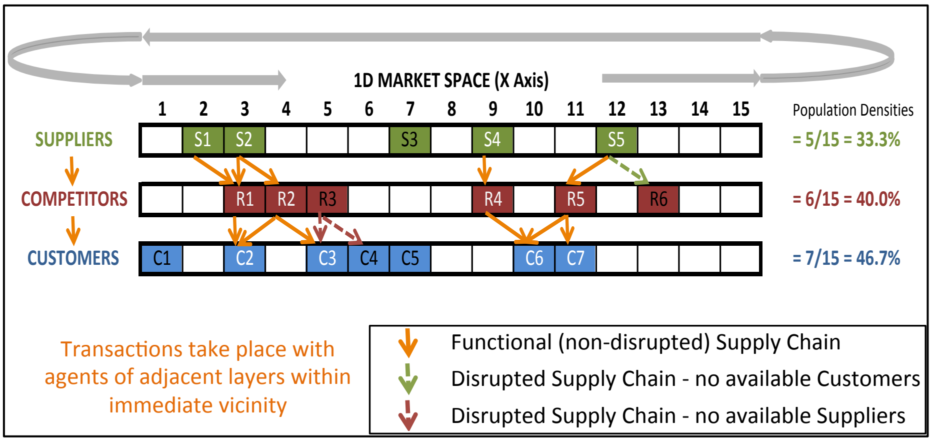


Fig. 1. A three-layered 1D Cellular Automata as a Supply Chain Modelling Framework

The adopted intra- and inter-layer neighbourhood rule-based CA model allows for the translation of the aspects related to Porter's five forces that shape industry competition [3] into the corresponding tension that drives suppliers, competitors and customers interests, as reflected in their market positioning selection rules. This modelling approach also provides a simple and comprehensive framework for the implementation of "structuralist" strategies. As defined by Kim and Maugborne [4], "structuralist" strategy types "assume the operational environment is given" (and have a bias to stay and defend their current positions). As such, their market positioning strategy is mainly driven by their market environment structural configuration, considering their current position, other competitors (particularly the most direct ones), potential customers, and business partners.

3.2 Market Opportunities and Customer Desires Modelling as a Driver of Agents' Co-evolutionary Dynamics

While the aforementioned model design can accommodate the implementation of a "structuralist" strategy type, it falls short on describing adequately both the demand/supply dynamics and to model "reconstructionist" strategy types, which seek to shape the operational environment, actively pursuing innovation and new opportunities [4]. In order to overcome these shortcomings the model should be enhanced with the introduction of product/service market opportunities and customer desire features. Thus, product/service opportunities and customer desires are modelled using a similar k-bit word structure in which each bit represents a specific product /service attribute (that may, or not, match a customer's desire).

In this context, a k-bit opportunity word sub-model was implemented, associating a specific product/service opportunity to each site of the competitors CA layer (as represented in Figure 2). These k-bit words distribution within that CA layer promotes opportunity diversity while allowing for competitors' possible exploitation of product/service similarities as well as local vicinity benefits. To accommodate those requirements, opportunity cardinal points — k-bit with words with Hamming distance of one between them — are regularly spaced on the corresponding CA layer[2], and the intermediate words allowed to vary (based on Hamming distance criteria), with the level of variation defined as intended. The articulation between those k-bit opportunity words (translated to specific product/services offers when that opportunity is taken by a competitor) and the implementation of individual customer agents' k-bit desire words (which may evolve over time) fosters the model dynamics in terms of customers' desires and focal firms' products/services fitting objectives.

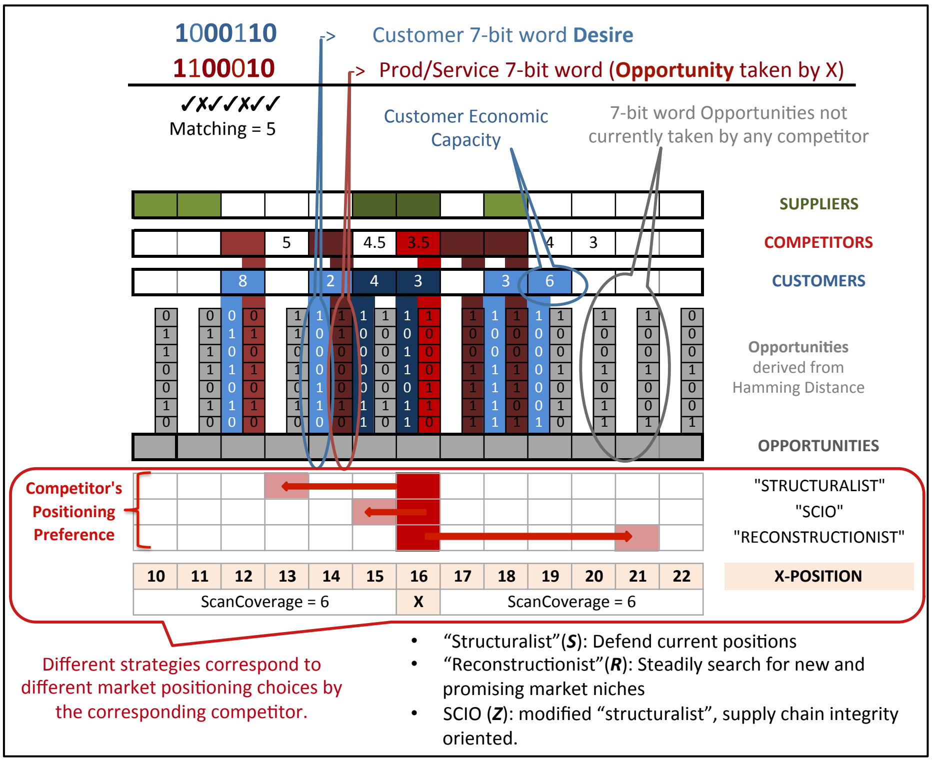


Fig. 2. Opportunities and desires as drivers of the co-evolutionary dynamics (excerpt representing positions 10 to 22 of the entire x-axis market space, corresponding to the local neighbourhood of competitor currently placed at position 16).

As illustrated on Figure 2, each of the corresponding bits of the competitor offering (opportunity taken by the competitor) and customer desire words are compared. Customers have different economic capacities (providing different levels of attractiveness for the competitors) and seek offerings that best match their desires. Competitors following a "reconstructionist" strategy type steadily search for possible oppor-

[2] With all-zero and all-one k-bit opportunity words acting respectively as the "North" and "South" poles at the opposite positions of the (circular) one dimensional CA layer.

tunity available market positions within their site neighbourhood that correspond to new and promising market niches (based on available opportunities, existing customers economic capacities and desires, and other competitors' offerings). Thus, the implementation of customer desires and market opportunities allows for distinct competitors' market positioning preferences, depending on their adopted strategy. As customers respond to changes in available offerings, and suppliers reposition themselves based on competitors' upstream demand and other suppliers positioning in their vicinity, downstream supplies and competitors' revenues change. This changing situation leads competitors to keep reassessing their current market positions in a continuous co-evolutionary process linking together suppliers', competitors', and customers' actions and outcomes.

3.3 Utility Added-value and Customers' Purchasing Behaviour: Modelling Product/Service Selectiveness

As a last model feature implemented to drive the required supply and demand market dynamics, a competitor-customer inter-layer demand rule, based on an over-added utility parameter that characterizes customers' product/service selectiveness, is implemented. After comparing available product/services specific attributes' matching with customers' desire k-bit words, this over-added utility (OAU) parameter between -1 and +1 (-1 totally undervalues; 0 proportional to utility; 1 totally overvalues) is used to define the level of demand from the corresponding product/service providers.

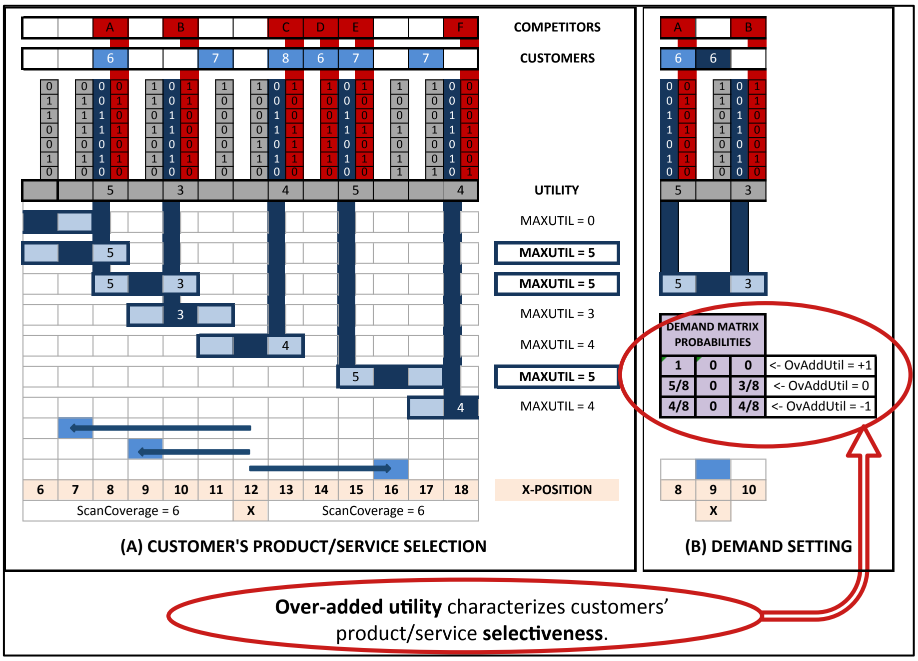


Fig. 3. Utility and selectiveness

Figure 3 provides an example illustrating a situation of a customer placed at position X=12 with a 7-bit word desire “1000110”. Considering a defined scanning coverage (SC) of 6, which allows the customer to check its x-axis neighbourhood from X=6 to X=18, the customer first assesses the available empty positions (as well as its current position) that are expected to allow it to obtain a product/service from a competitor that best matches its desire. In the provided example available positions at X=7, 9 and 16 are expected to provide it with the best viable maximum utility (MAXUTIL) of 5, so it will choose one of these positions randomly.

Once at a specific position (in the example it is assumed that X=9 was chosen) the customer can demand product/services from every available competitor (at X-1, X, and X+1) to a total amount corresponding to its economic capacity. In case OAU=0 the customer will randomly demand product/services from the different available competitors with probabilities proportional to their relative desire matching. In Figure 3 example it will demand with probability of 5/8 from competitor at X=8 (desire matching=5) and 3/8 from competitor at X=10 (desire matching=3). If OAU=1 it will demand the total amount only from the competitor that best matches its desire (in this case at X=8). When OAU=-1 demand will be set with equal probability from all available competitors. In this way, OAU characterizes customers' product/service selectiveness.

4 Model Implementation: A Study Case on Organizational Survivability

4.1 The Organizational Survivability Study and Implemented Strategy Types

A model was developed and implemented — using Java with NetBeans IDE and the Repast [5] agent-based simulation platform — to better understand the relationship between strategic choice (in normal times and when in crisis) and organizational survivability under different market environment contexts. For this purpose, three agent type spaces (suppliers, competitors and customers) were implemented as individual layers, whose size reflects the common one-dimensional market, plus an underlying opportunity space. The implemented interaction between those spaces illustrates the integration of the multi-layered CA base solution with the additional modelling features previously described to ensure the competition and survival market co-evolutionary dynamics.

The added effort placed by organizations on ensuring the effectiveness of their supply chains, avoiding any disruption or disturbance that can perturb the swift flow of goods and services from their primary producers to the final customers, was also considered. In the present model, a modified “structuralist” strategy was also implemented to reflect these organizations that are willing to sacrifice a greater slice of their short-term operational results for the sake of a more robust position in terms of their business continuity objectives. Thus, besides a “reconstructionist” and a “structuralist" strategy, the model also uses a more "Supply-Chain Integrity Oriented" (SCIO) modified "structuralist" strategy[3].

4.2 Competitors' Genetic Codes and Selection of the Fittest

To assess the impact of strategic choice on organizational survivability, each competitor agent is characterized by a genetic code that defines which strategy it follows in normal times and when in a crisis situation (which may be the same in both situations). This genetic code may be any of the nine possible outcomes from the permutation with repetition of the three ("reconstructionist", structuralist" and SCIO) strategies to the two applicable situations (normal times, and crisis).

Based on how good, or bad, a competitor is performing in terms of average revenues when compared to other competitors, its strategic genetic code may be selected (i.e. copied) by new market competing entrants[4], or the competitor may be led to crisis (and eventual dismissal) respectively Competitors whose average revenues position them on the worst performers percentage, as defined by ICT (In-Crisis Threshold), are led into a crisis status. If agents in crisis are not able to improve their average revenues during a specified number of CE (Crisis Endurance) run steps, so that they become positioned above the defined OCT (Out-of-Crisis Threshold) percentage and return to a normal status, they will be dismissed and replaced by a new competitor. While a randomness factor (RSP[5]) is also incorporated in the selection of new entrants strategy defining genetic code, the selection of the fittest is implemented in an evolutionary process where the competitors' population genetic codes distribution tends to reflect the adaptation of the corresponding strategy pairs to the modelled market environment. As a specific genetic code population depends on the ratio of new entrants versus dismissed agents carrying that code, its evolution depends on the average revenues of their agents (to increase their chances of being selected for reproduction, and avoid crises) as well as their ability to survive crises when they occur.

4.3 Model Flows and Parameterization

For the present work, the following main flows were considered: The upstream flow (from customers to suppliers) of product/service orders (demand), and the consequent downstream product/service flow (from suppliers to customers), with the corresponding upstream revenues flow.

---

[3] The way these three strategies may lead to different competitors' market positioning choices is illustrated on Figure 2.

[4] A TPP (Top Performers Percentage) parameter defines the percentage of agents with best average revenues whose genetic code will be eligible for transmission to a new entrant (probability of selection depends on agent's average revenue).

[5] RSP (Random Strategy Probability) defines the probability that a new competitor's strategy defining genetic code is chosen randomly. Consequently, there is a probability of 1-RSP that its genetic code is selected from the top performing competitors.

Using different agents' population densities (PD), supplier/customer agents' replacement probabilities (RP) by new-borns, market scanning coverage (SC)(range of each agent local analysis neighbourhood), customers over-added utility (OAU) and desire change probabilities (DCP)[6], as well as other user-defined variables to characterize different market environments, the market positioning rules followed by each agent at each step (integrating the basic elements of Porter's five competitive forces) shape the overall process dynamics. After a random definition of competitors' genetic codes at each run initialization, the competitors' genetic code distribution along the co-evolutionary process is analysed.

5 Results, Analysis and Implications

Based on the populations co-evolution during multiple runs of 15,000 steps each, the competitors were analysed by genetic code in terms of their average revenues and probability of being selected for possible genetic code transmission, percentage of agents in crisis, number of steps in crisis, crises survival ratio, dismissed agents ratio and total revenues. This analysis was performed under distinct PD ratios and different market environment volatilities, characterized in terms of different RP, SC, OAU, and DCP parameters (Table 1).

Table 1. Simulation runs parameter values

PDR (Comp)	Competitors Population Density (Ref.)	35%
MEC (Cust)	Customers Maximum Economic Capacity	8
K	Nr of bits opportunity/desire k-bit words	7
CE	Crisis Endurance	6
ICT	In-Crisis Threshold	10%
OCT	Out-of-Crisis Threshold	15%
TPP (Comp)	Competitors Top Performers Percentage	60%
RSP	Random Strategy Probability (new borns)	10%

	Scenario's Market Volatility				
	Low	LM	Medium	MH	High
SC (Supp/Comp/Cust)	5	8	10	13	15
RP (Supp/Cust)	0.00	0.05	0.10	0.15	0.20
DCP	0.00	0.01	0.02	0.35	0.05
OAU	-1.0	-0.5	0.0	0.25	0.5

Analysis of the obtained results (Fig. 4) reveals that: (1) the survivability of each "genetic code" varies significantly with environment volatility and population density

6 These parameters are defined as follows: PD = Percentage of s occupied by suppliers, competitors and customers on their corresponding layers; RP = Probability that each supplier/customer is dismissed at the end of each run step and replaced by a new similar agent (but with a new random desire, in case of a customer); SC = Number of positions to each side of its current position that an agent is able to collect market information at its and adjacent layers; OAU = (see Section 3.3); DCP = Bit "mutation" probability (from "0" to "1", or from "1" to "0"), per run step, of each bit of customers' k-bit desire words.

ratio changes; (2) while in low volatility environments the strategy employed in normal situations tends to be more determinant to survivability than the strategy adopted in crisis, as environment volatility increases the strategy employed in crisis tends to gain relevance in terms of relative survivability performance; (3) in low volatility and supply scarce/customer plenty environments, the highest levels of survivability are achieved by competitors using the "SCIO" as their normal strategy; (4) while the full "SCIO" (ZZ) strategy is very well adapted to low volatility and supply scarce contexts, and the full "reconstructionist" (RR) strategy dominates in high volatility or plenty supply scenarios, the "SCIO-reconstructionist" (ZR) strategy mix presents balanced results across the different scenarios and volatilities.

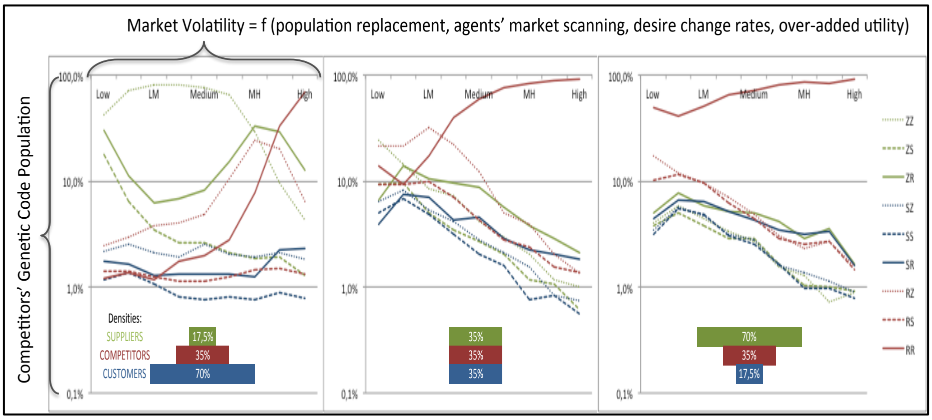
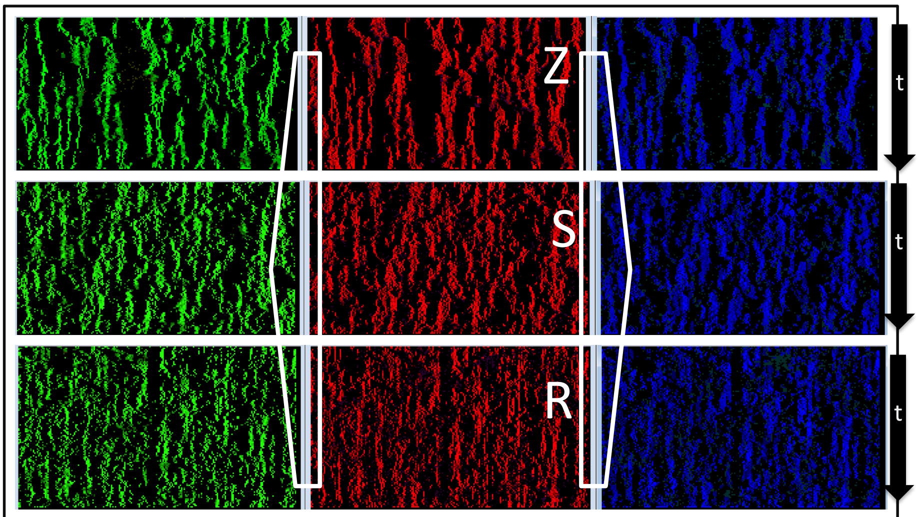


Fig. 4. Simulation results (supplier-to-competitor and competitor-to-customer density ratios of 1:2, 1:1, and 2:1)

Scenarios with different environment volatilities and population densities were also run with competitors following only one strategy type. The effects induced on the business market by the competitors' strategy were then compared. The resulting patterns of suppliers, competitors and customers positioning evolution show that "SCIO" strategies tend to generate the more stable and concentrated market environments, while "reconstructionist" strategies present the more disperse and less stable ones (Fig. 5).

The obtained results suggest that: (1) as market environments become more volatile (more globally linked, with changing actors and customers' desires) the more critical to organizational survivability becomes the adoption of an effective crisis strategy; (2) as supply sources grow or market environments become more volatile, "reconstructionist" strategy types tend to have higher chances of success; (3) the proliferation of "reconstructionist" strategies, constantly pursuing new opportunities and shaping market trends, tend to induce higher instability in the market environment.



Top row – “SCIO” ; Middle – “Structuralist”; Bottom – “Reconstrucionist”

Fig. 5. Competitors’ (agents in red) strategies effect on market environment, including suppliers (agents in green) and customers (agents in blue)

6 Conclusion and Future Work

The present study case on competition and survival modelling in a supply-chain market context illustrates: (1) multi-layered CA models potential as frameworks for accommodating increasing levels of complexity in terms of different agent populations’ intra- and inter-layer (market) positioning-oriented rule-based modelling in a mutually shared space; (2) how the adopted approach does not hamper the clear, structured, and incremental implementation of those added levels of complexity, while withholding the desired CA modelling advantages in terms of a comprehensive understanding and analysis of the positioning dynamics at the individual and aggregate levels; (3) how the addition of market opportunities and changing customer desires, represented as k-bit words, in connection with an over-added utility algorithm to define the customer’s purchasing selectiveness on the modelled supply-chain, plays a decisive role in the overall co-evolutionary market model dynamics.

The principal aims of the work ahead are as follows: (1) fine-tuned characterization of each variable effect on the obtained results; (2) applying information theory measures to analyse the model’s phase-transition behaviour and quantify the system’s sustainability [6]; (3) taking the model to empirical data.

Acknowledgments

Special thanks to the support provided to this work by FCT project Pest-OE/EEI/LA0008/2011.

References:

1. Holland, J. H.: Hidden Order: How Adaptation Builds Complexity. Reading, MA, Addison-Wesley (1995)
2. Fink, S.: Crisis Management: Planning for the Inevitable. Lincoln, NE: iUniverse (1986)
3. Porter, M. E.: The Five Competitive Forces that Shape Strategy. Harvard Business Review, 86 (1), 79-93 (2008)
4. Kim, W. C., Mauborgne, R.: How Strategy Shapes Structure. Harvard Business Review, 87 (9), 72-80 (2009)
5. Repast (http://repast.sourceforge.net/)
6. Ulanowicz, R. E., Goerner, S. J., Lietaer, B., Gomez, R.: Quantifying sustainability: Resilience, efficiency and the return of information theory. Ecological Complexity , 6, 27-36 (2009).