Comprehensibility as a discrimination criterion for Agent-Based Modelling and System Dynamics: An empirical approach

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Agent-based modelling seems to be an alternative way of modelling to System Dynamics. Criteria for discriminating the methodologies, and criteria for the choice of which one to use, still remain vague. This study compares both approaches on an empirical basis, utilizing an exploratory experiment aimed at investigating the respective comprehensibility of each methodology. The gained results, considering all the observations, show no significant differences between the two treatments. Nevertheless if the subjects are grouped into SD students and non-SD students, differences are observed. Interestingly it shows an advantage of the AB approach for the SD student group, whereas the non-SD students seem to have an advantage with the SD methodology.

INTRODUCTION

Recent studies concerning System Dynamics and Agent-Based Modelling have compared them by conceptual criteria, discussing their ability to model specific problems. Although both methodologies can be complementary in the sense that they model different problems, there are several contexts in which both methodologies are applicable: one might be the Bass model[1], another one might be the modelling of supply chains[2]. So one question is, in contexts where both

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[1] Borshchev/ Filippov, From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools, Proceedings of the 22nd International Conference of the System Dynamics Society, 2004

[2] Schieritz/ Groessler, Emergent Structures in Supply Chains – A Study Integrating Agent-Based and System Dynamics Modeling, Proceedings of the 36th Hawaii International Conference on System Sciences, 2001;

methods are applicable, which one proves to be more useful? This is being defined by the purpose of the model. If a model is built to invoke learning, as is often done in SD, the comparison of the methodologies regarding their capabilities to clarify given problems is an interesting question, for which the authors could not get answers from the existing literature. Therefore an experiment was being constructed in order to compare the comprehensibility of System Dynamics and Agent-Based Modelling. This is reached by presenting the same problem with the two methodologies seen as treatment. The subjects have to manage a tourism facility, whose main resource is the attractiveness of the area. The task is to maximise the cumulative customers by building hotels. Delays and non-linearity have to be considered. Two different models and respective interfaces, as treatments, are created: a System Dynamic and an Agent-Based description of the task.

What is SD?

System Dynamics is a modelling approach developed by Jay Forrester[3]. Its focus lies on the structure of the system to be modelled. This structure is to be captured in a notation consisting of stocks and flows. As Sterman points out: "That structure consists of the feedback loops, stocks and flows and nonlinearities created by the interaction of the physical and institutional structure of the system with the decision-making processes of the agents acting within it."[4] System Dynamics may be particularly suitable for models with a high degree of aggregation. A second advantage is the possibility to always link cause and effect. Another advantage is the efficiency of the approach: usually SD models can be simulated faster than AB models and the modelling effort which is necessary to create a model seems considerably lower.

What is AB?

In Agent-Based Modelling, on the other hand, "the individual members of a population such as firms in an economy or people in a social group are represented explicitly rather than as a single aggregate entity."[5] "This massively parallel and local interactions can give rise to path dependencies, dynamic returns and their interaction."[6] Grebel and Pyka identify in addition three advantages of the AB approach, namely:

a) It can show how interaction of independent agents creates collective phenomena;

Akkermans, Henk, Emergent Supply Networks: System Dynamics Simulation of Adaptive Supply Networks, Proceedings of the 36th Hawaii International Conference on System Sciences, 2001

[3] Forrester, Industrial Dynamics, Cambridge, 1961

[4] Sterman, Business Dynamics. Systems Thinking and Modeling for a Complex World, Boston, 2000, p. 107

[5] Sterman, Business Dynamics. Systems Thinking and Modeling for a Complex World, Boston, 2000, p. 896

[6] Grebel/ Pyka, Agent-based modelling – A methodology for the analysis of qualitative development processes, 2004 in: Lombardi/ Squazzoni, Saggi di economia evolutiva , Franco Angeli, Milano, Italy (forthcoming). p. 10

b) It can identify single agents whose behaviour has a predominant influence on the generated behaviour;
c) It can identify crucial points in time, at which qualitative changes occur.

What is an Agent?
Following classical definition traditions we apply the genus proximus - differentiae specificae approach: the genus proximus would be "software-based computer system" for both notions[1], while for the differentiae specificae no sufficient characteristics have been found yet. Woolridge and Jennings[1] discriminate between two notions of agency, a weak one and a strong one. The authors offer the characteristics autonomy, social ability, reactivity and pro-activeness for the weak notion and also offer a stronger notion which adds anthropomorphic descriptions.

WHAT IS THE DIFFERENCE BETWEEN AB AND SD?

One approach, developing several criteria for discrimination, is discussed by Schieritz and Milling[7]. They propose the following table:

	System Dynamics	Agent-based Simulation
Basic building block	Feedback loop	Agent
Unit of analysis	Structure	Rules
Level of modelling	Macro	Micro
Perspective	Top-down	Bottom-up
Adaptation	Change of dominant structure	Change of structure
Handling of time	Continuous	Discrete
Mathematical formulation	Integral equations	Logic
Origin of dynamics	Levels	Events

Table 1: Criteria for discrimination between SD and ABM.

The discrimination on the basis of "basic building blocks" is a merely cosmetic one as we think, agents can be built out of feedback loops and feedback loops can include agents. Also the "unit of analysis" is mostly a cosmetic discrimination, but, as the authors mention themselves, it is not to be seen on absolute but only relative standards: "Compared to Agent-based Simulation however, they [SD models] are modeled structurally".[8]

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7 Schieritz/ Milling, Modeling the Forest or Modeling the Trees, Proceedings of the 21st International Conference of the System Dynamics Society
8 Schieritz/ Milling, Modeling the Forest or Modeling the Trees, Proceedings of the 21st International Conference of the System Dynamics Society, p.7

The discussion of "adaptation" is a point we consider as valid as well, but is probably owed to one of the strengths of SD, the simplicity of its language. With a more advanced syntax, more adaptation could as well be achieved. It is for example possible to implement different equations in SD models for the same variable changing due to the value of another variable via IFTHENELSE constructions. This is nevertheless a complicated way to really model adaptation.

Also the "handling of time", the "mathematical formulation" and the "source of dynamics", make out rather distinct tendencies in both approaches. In SD models are computed on the basis of differential equations with a tendency towards small time steps to simulate continuity. Dynamics are implemented through stocks that accumulate the flows. In ABM every agent reacts to certain events, which are discrete and normally formulated logically.

The "level of modelling" together with the discussion of the "perspective" tries to grasp the following point, which we consider to be lying a little deeper. Whereas it seems obvious that System Dynamics comes from a macro or top-down approach, and Agent-Based modelling approaches from the micro level via bottom-up, the authors themselves state that also in SD micro-level phenomena can be modelled. We consider the main discrepancy to lie in the difference of the modelling level and the analysis level. Whereas in SD, those two levels don't differ, i.e. it is being analyzed what was modelled before, there is a difference between those levels in ABM. Here, an agent is modelled and a society is analyzed, i.e. the modelling approach is more vertical than just flat or horizontal as in SD. In the same direction goes the discussion of Parunak, Savit and Riolo[9], when they argue about individuals and observables. SD, so their argumentation, connects observables via equations and can then compute them. AB on the other hand models behaviour through which individuals interact and analyzes the produced observables. This qualifies their conclusion, that ABM has the advantage of an additional level of validation.

Agent-Based Modelling, maybe having inherited this concept of object-oriented programming, doesn't grasp the whole system, but it defines simple agents and tries to explain the emergent behaviour out of their interaction. How an agent can be defined is still somewhat unclear. So as Milling et al. say it: SD models the forest, whereas AB models the trees, but as we want to stress, still analyzes as well the forest.

What we consider another point of discrimination is the assumption concerning the linkage between cause and effect. Whereas in SD a rather tight linkage between the structure and the

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[9] Parunak/ Savit/ Riolo, Agent-Based Modeling vs. Equation-Based Modeling: A Case Study and Users' Guide, Proceedings of Workshop on Modeling Agent Based Systems, 1998

resulting behaviour is assumed, this assumption is discarded in ABM in favour of the concept of emergence. This is certainly of less value in practical applications, but nevertheless a more cautious approach to model systems, which are not easily understood.

Finally an additional criterion for discrimination is to be investigated here: the comprehensibility of the methodology. If we consider as one purpose of a model to serve as a playground to learn about the complexity of the real world[10], then comprehensibility plays a major role. There are some points that hint towards an easier understanding of agent-based models, as individuals and events are the concepts that are commonly used in the construction of worldviews. SD on the other hand has explicitly distanced itself from this event-based worldview with its fundamental attribution error[11]. In addition it has created a highly formalized language – stocks and flow notation – which doesn't seems easily accessible at the first glance. This formalization nevertheless enforces a more rigorous description and structuring of a given problem. Which of these approaches facilitates problem understanding, is to be investigated here.

[10] Sterman, Business Dynamics. Systems Thinking and Modeling for a Complex World, Boston, 2000, Chapter 1 (esp. p.34/35)

[11] Sterman, Business Dynamics. Systems Thinking and Modeling for a Complex World, Boston, 2000, p.28

EXPERIMENT

The hypothesis, which shall be defended here, is that there is a difference in the understanding of complex problems, based on whether they are presented in an Agent-Based or System Dynamics manner.

Design of the experiment

Several approaches were being considered in the beginning of the designing process of the experiment. Particularly demanding was the choice of the tool to be utilised. Whereas SD can offer a set of formalized construction tools for model-development, AB is still mostly based on libraries[12], for which a certain skill in programming is necessary. A step towards a user-friendly integrative formalized tool is made by AnyLogic[13], which also contains the basic SD features. Nevertheless the adoption of AnyLogic was rejected for the reason that Vensim, an SD software, facilitates the construction of an ILE to a very high degree. Another point of discussion was whether to build an Agent-Based model at all. For the purpose of investigating the abilities in problem structuring, an Agent-Based description of a System Dynamics model would have been sufficient. Nevertheless it seemed more valuable to implement the underlying structure for the experiment as Agent-Based in order to test the limits of traditional SD software towards that new paradigm. Result of the latter is in our eyes, that it is possible to implement simple agents, but interaction between the agents seems very hard to model elegantly. In addition, one of the more obvious advantages of Agent-Based Modelling, spatiality, seems out of reach for the traditional SD software and it is as well not included in the core of the SD-paradigm.

Models

Both the SD and the ABM model have been built with Vensim[14]. The acceptance of the AB model obviously depends on the chosen definition of an agent.

The main structure is the same for both models. There is an aging-chain for the hotels, which define the hotel capacity. The hotel capacity and the tourists in the area then define the attractiveness of the resort. The number of tourists that want to visit the place is computed according to the attractiveness of the area. In the AB case this number is based on the individual

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[12] Woolridge/ Jennings, Intelligent Agents: Theory and Practice, in: Knowledge Engineering Review, Volume 10 No 2, June 1995

[13] XJ Technologies: http://www.xjtek.com/anylogic/

[14] Ventana System Inc.: http://www.vensim.com/

decisions made by the agents, while in the SD case it is defined by a nonlinear function. The outcome of both models doesn't show significant differences.

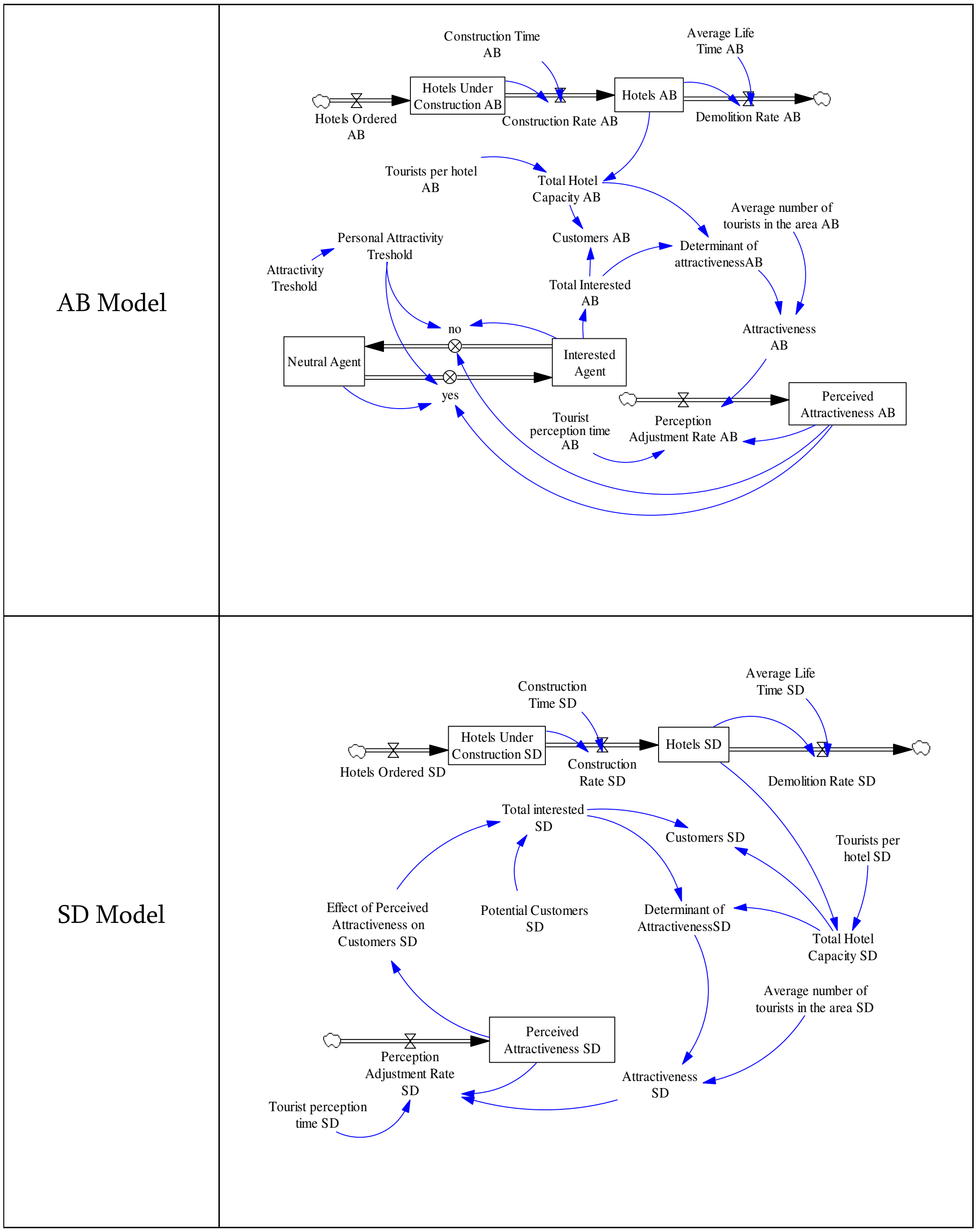


Figure 1: structure of the AB and SD models.

The AB models may need special attention. Four sub-ranges named vector 1, vector2, vector3 and vector4 have been created, each of them having ten elements. This makes a total of 10.000 agents available. The stock Neutral Agent is initialized with 1, the stock Interested Agent with 0. The two flows switch then from the usual continuous perspective to a logical one via IFTHENELSE functions. The resulting formulation is:

Yes[vector1, vector2,vector3, vector4] =IF THEN ELSE(Perceived Attractiveness AB>=Personal Attractiveness Threshold

[vector1,vector2,vector3,vector4] :AND: Neutral Agent[vector1,vector2,vector3,vector4]>0, 1 , 0)

The "yes" flow sends a pulse as the perceived attractiveness exceeds the Personal Attractiveness Threshold, while the "no" flow sends a pulse as the perceived attractiveness falls below the Personal Attractiveness Threshold.

If this simple approach can already be called an agent, is worth some discussion. Schieritz and Milling[15] propose a scale of agency instead of a simple binary criterion and offer an insightful table, which puts forward the following criteria:

- Proactiveness, Purposefulness;
- Situatedness;
- Reactiveness, Responsiveness;
- Autonomy;
- Social Ability;
- Anthropomorphity;
- Learning;
- Continuity;
- Mobility;
- Specific Purpose.

In order to defend the agent-based character of the model underlying the experiment, a check (which criteria are met), seems to be necessary. Each agent is identified with a so-called "Attractiveness Threshold", an individual parameter, read in from an Excel-Spreadsheet, containing 10.000 normally distributed values approximately from -1 to 1 (the mean is equal to zero and the standard deviation is equal to 0,3).

The criteria satisfied by the simple version of an agent that is implemented in the model, are:

- Situatedness. The stock "Perceived Attractiveness" implemented in the model creates a perceived environment. This stock might, as a future step, be also individualized by adding subscripts. As the necessary calculations already take a significant amount of time, this idea has nevertheless been disposed here.

[15] Schieritz and Milling, Modeling the Forest or Modeling the Trees, Proceedings of the 21st International Conference of the System Dynamics Society, p.7

- Responsiveness. The agent changes his state according to his environment, namely to the relation between "Perceived Attractiveness" and "Attractiveness Threshold".
- Anthropomorphity. The agent has an intention, i.e. to travel if the attractiveness is adequate according to his preferences.
- Continuity. The decision, whether the place is attractive is re-evaluated every time step.
- Specific purpose. The agents are designed for one specific task, namely the decision if the place is attractive to them or not.

So the agents here certainly do not meet the advanced characteristics of a full-fleshed AB-Model created in one of the programming languages designed specifically for constructing agents. Nevertheless, the basic characteristics of an agent have been implemented.

Interfaces

The interfaces for the experiment have been built with Venapp, which allows the easy construction of ILE's with Vensim models. The introductory screen was the same for both treatments, it proposed a general outline of the problem and a characterization of the delays for the ordering of hotels, the wording was:

"You are confronted with the task to run the tourism facilities of a geographically distinct place. Competition is not involved. At the beginning of the game the area is characterized by the absence of tourism facilities which makes the place attractive. As the experiment starts, the population will realize that your area is not crowded. The interest in your resort will then increase. Nevertheless, you should consider that it takes approximately four years before the tourists adjust their perception to the actual attractiveness of your resort. Your task is to maximize the total number of customers over time (maximize the cumulative number of tourists): There is only one decision parameter you have to manage: the number of hotels you decide to build. The construction of a new hotel takes four years, but is considered to take place over time, i.e. in the year after construction you already have a part of the hotel available. The average construction time is assumed to be four years, so in the first year, after your order, 25% of your ordered hotels arrive. In the second year after your order, 25% of the still existing gap are completed, so 18,75% arrive. A hotel lasts for 25 years, i.e. every year 4% of the existing number of hotels is discarded."

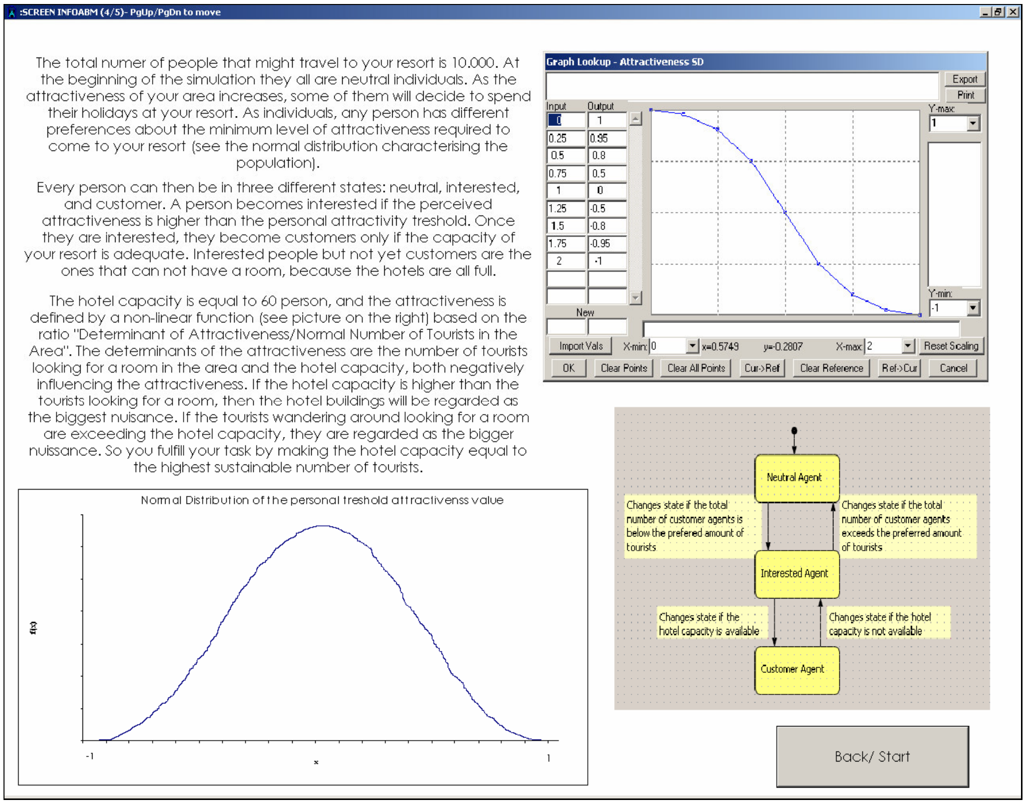


Figure 2: AB user instructions.

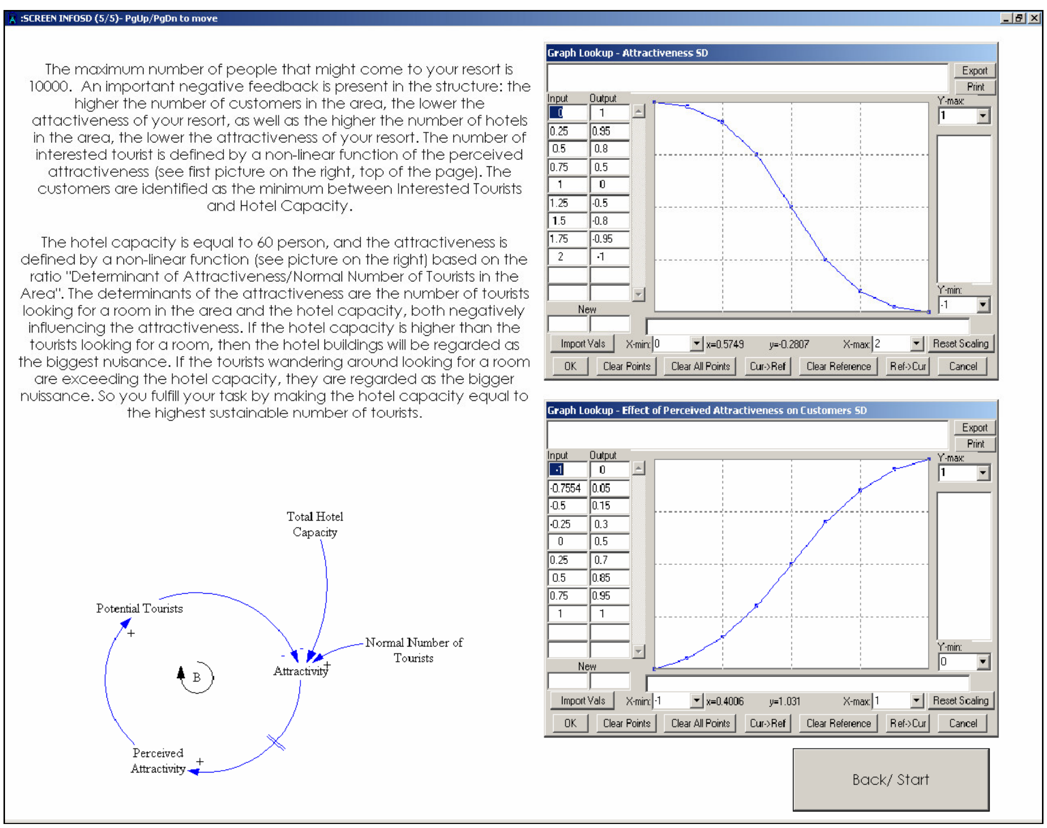


Figure 3: SD user instructions.

The differing instructions are considered to be equally complex. In the AB case a normal distribution and a state chart have to be understood, in the SD case the subjects are confronted with a causal loop diagram and a nonlinear function. The main difference as seen above is, that instead of a state chart of an agent and the distribution of the individual "Attractiveness Threshold", the SD explanation holds a second nonlinear function.

Treatment	Given information	Necessary Deduction
Both	The hotel capacity is equal to 60 persons.	
	Perceived Attractiveness is the attractiveness after a delay of four years.	
	Determinant of Attractiveness / Normal Number of Tourists defines the attractiveness	
	If the hotel capacity is higher than the tourists looking for a room, then the hotel capacity will be regarded as the biggest nuisance.	If hotel capacity> tourists, hotel capacity = determinant of attractiveness
	If the tourists wandering around looking for a room are exceeding the hotel capacity, they are regarded as the biggest nuisance.	If tourists > hotel capacity, tourists = determinant of attractiveness
	Make the hotel capacity equal to the highest sustainable number of tourists.	
	Nonlinear relationship between determinant of attractiveness/ Normal number of tourists and attractiveness	If determinant of attractiveness = Normal number of tourists, attractiveness = 0
SD	Number of potential customers = 10.000	
	The higher the number of customers, the lower the attractiveness	
	Customers are defined as the minimum between Interested Tourists and Hotel Capacity	
	Nonlinear relationship between the perceived attractiveness and the customers	At Perceived Attractiveness = 0 marginal increase of tourists decreases
AB	Maximum number of people is 10.000	
	Normal distribution of Attractiveness Thresholds	At Attractiveness Threshold = 0 marginal increase of tourists decreases
	State-chart: Interested Agents can only become customers if the hotel capacity is available	
Both		If the hotel capacity is double the normal number of tourists, the attractiveness will be minimal and no tourists will be attracted in the long run.
		If the number of tourists is zero, the attractiveness will be one and all the potential 10.000 people would be attracted in the long run.
		The normal distribution as well as the nonlinear function is symmetric, so 5000 might be the normal number of tourists.

Table 2: Information and Deduction, interfaces.

The single information missing in both instructions is the normal number of tourists, which needed to be guessed.

Conduction of the experiment

The goal was to maximize the cumulative tourists over time, an output variable not directly accessible for the subjects. According the ranking after the experiment prizes were given out. Thereby the following prerequisites are fulfilled:

- Salience
- Monotonicity
- Dominance
- Privacy
- Risk

Salience is reached by clearly stating, that the task is to maximize the cumulated tourists, monotonicity is reached by distributing different prizes for the different ranks. Dominance is harder to reach as sufficient funding was not available, but privacy was secured by seating the subjects at individual computers and maintaining silence. The risk can be considered as the opportunity costs of coming and joining the experiment which is arguably low for students but nevertheless existent.

The experiment was run with two different groups, one which consisted of students of the Master-program in System Dynamics and another one which consisted of none System Dynamics students. In total 24 subjects played the experiment, 10 of them were part of the System Dynamics Master program. The experiment was slightly modified after the run with the System Dynamics group, a questionnaire after the experiment was added and the graphics were adjusted. In addition to that prizes were given out to the non System Dynamics group. The content was not changed. The questionnaire was added to understand the thinking process throughout the experiment more clearly. It consisted of the following questions:

1. What do you consider to be the maximum sustainable hotel capacity?
2. When did you realize this?
3. Did you have a strategy or did you just try?
4. If you had a strategy, what was it?
5. Did you feel like understanding the model?
6. Did you take the delays into account?

7. Which delay would you consider the most important?

For the System Dynamics students those questions were reconstructed out of interviews after the experiment.

RESULTS OF THE EXPERIMENT

The following table shows the treatments, the results for the total cumulated tourists, whether the subject is member of the SD master program, and several other characteristics (gained out of the questionnaires for the non-SD students and elicited through interviews for the SD students). Problem identifications states whether the task has been thoroughly understood, optimum identification states the optimum identified by the subject, if it did at all, and defined strategy shows whether the subject followed a strategy or just tried (stated in the next column). The last two columns are dedicated to the understanding of the structure, the consideration of delays as well as the consideration of the structure.

Treatment	Result	SD Student	Problem identification	Optimum identification	Defined Strategy	Trial and Error	Delays	Structure consideration
SD	4010	x	x	600	x		X	
SD	7181	x		none	x			
SD	18423			2500	x		x	x
SD	25675	x	x	4000		x	x	x
SD	26434			none		x		
SD	28910		x	6500	x			
SD	30454		x	5000	x		x	x
SD	44120		x	5000	x		x	x
SD	45769		x	6000		x	x	
SD	47088		x	none		x	x	
SD	53321	x	x	5000	x		x	x
SD	55392	x	x	4000	x		x	x
AB	8589		x	3000		x	x	
AB	8891			600		x		
AB	13994		x	none		x		
AB	25567		x	3000		x		
AB	27535		x	5000		x	x	x
AB	33525	x	x	2000	x		x	x
AB	37937	x	x	3000		x	x	x
AB	39878		x	6000	x			x
AB	39946			none		x		
AB	44792	x		none		x		
AB	51298	x	x	5000	x		x	x
AB	59937	x	x	8000	x		x	x

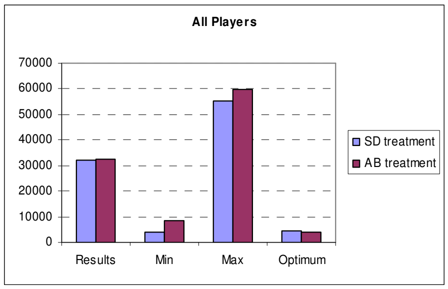
Table 3: General Results of the experiment.

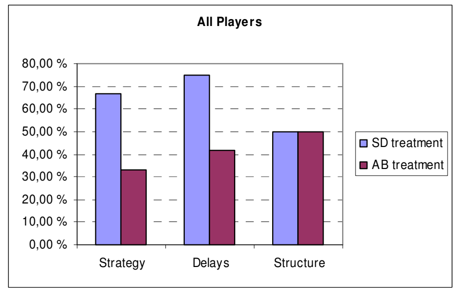
Structural Analysis

For the analysis of the data, we first grouped data by treatments, which showed no significance. The second approach to group, according to academic background, showed more interesting results as displayed below.

ALL RESULTS

	Results	Min	Max	Optimum	Strategy	Delays	Structure
SD treatment	32231	4010	55392	4288	66,67 %	75,00 %	50,00 %
AB treatment	32657	8589	59937	3955	33,33 %	41,67 %	50,00 %

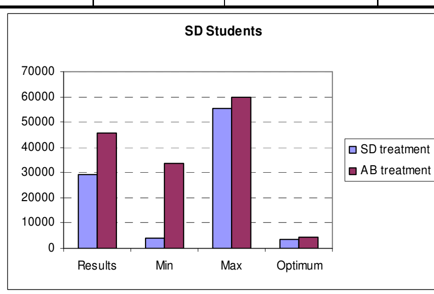


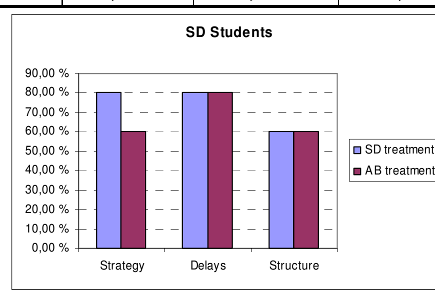


The only significant difference that can be observed between the two treatments here is a discrepancy in the understanding of the delays and the strategy formulation.

SD STUDENTS

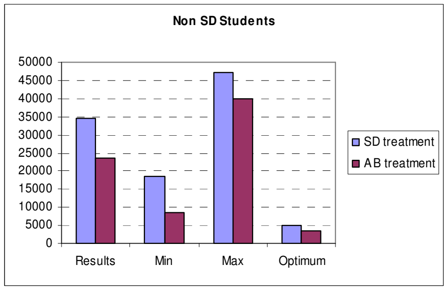
	Results	Min	Max	Optimum	Strategy	Delays	Structure
SD treatment	29116	4010	55392	3400	80,00 %	80,00 %	60,00 %
AB treatment	45498	33525	59937	4500	60,00 %	80,00 %	60,00 %

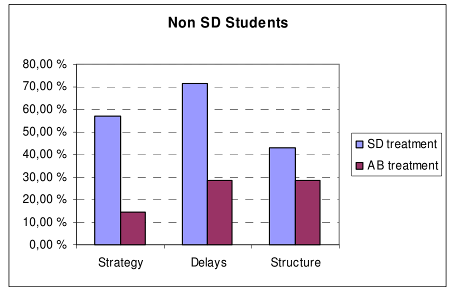




The graph on the left-hand side shows a difference in the average results of more than 15.000 tourists as also seen in the table above. The statistical analysis of this divergence can be found below.

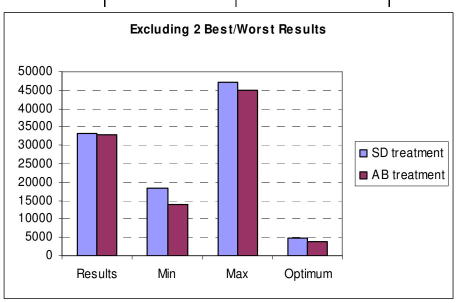
NON SD STUDENTS	Results	Min	Max	Optimum	Strategy	Delays	Structure
SD treatment	34457	18423	47088	5000	57,14 %	71,43 %	42,86 %
AB treatment	23486	8589	39946	3520	14,29 %	28,57 %	28,57 %

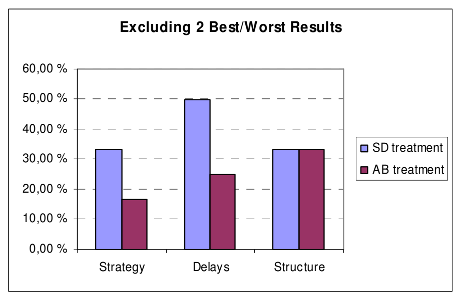




The graph on the left-hand side shows the opposite result for the non-SD students. Here the average result of the SD treatment is approximately 11.000 tourists higher.

EXCLUDING 2 BEST/WORST RESULTS	Results	Min	Max	Optimum	Strategy	Delays	Structure
SD treatment	33359	18423	47088	4833	33,33 %	50,00 %	33,33 %
AB treatment	32897	13994	44792	3800	16,67 %	25,00 %	33,33 %





The exclusion of the two worst and the two best results does not change the observations made in the first analysis.

Table 4: Results of the experiment by grouping subjects.

The calculation of the statistical significance delivered for the comparison of the two treatments, with SD and non SD students as a covariate, a t-ratio of 0,06 and a p-value of 0,95. Even if the two best and the two worst results are excluded no significance is achieved. In the analysis of the SD students, the AB approach seems to have an advantage. The t-ratio for this hypothesis is 1,15 and the p-value is 0,29. Even more interesting are the results for the covariate (male and female) which got a t-ratio of 2,16 and a p-value of 0,067. Nevertheless due to the small number of subjects conclusions seem fraught with risk. For the non-SD students on the other hand, SD seems to better suited. Here a t-ratio of -1,5 and a p-value of 0,16 is calculated.

Behavioural analysis

Treatment	SD Student	Hotels Ordered																					Total Hotels Ordered	Overshooting	Learning	Initial Orders
		0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*				
SD		1	50	15	15	20	21	160	150	**103**	103	35	45	90	12	2	25	0	0	0	0	0	847	x		x
AB	x	10	10	5	5	8	10	15	5	10	20	20	25	30	35	**40**	40	35	30	50	20	20	443	x		
AB		1	1	10	10	15	15	15	20	25	25	35	35	**35**	5	0	10	10	20	10	5	5	307	x		
SD		4	6	8	6	4	6	10	4	20	5	10	10	20	20	10	15	**20**	15	0	5	5	203	x		
SD		50	50	30	30	40	0	**15**	25	35	0	0	0	-25	-25	-10	-10	-10	-15	0	5	5	190	x		x
AB	x	5	5	10	0	0	0	10	0	15	0	0	0	30	0	0	0	10	100	300	**0**	0	485	x	x	
AB		15	13	25	15	20	17	40	40	45	**10**	1	0	0	0	0	0	0	0	0	0	0	241	x	x	
SD	x	10	10	10	0	0	25	25	0	0	25	8	0	0	0	0	20	20	**20**	0	0	0	173	x	x	
AB	x	50	50	50	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	150	x	x	x
SD		2	60	0	0	0	0	0	0	10	1	0	0	4	4	2	0	2	25	25	250	250	635			x
O		97	0,2	0,4	0,7	0,9	1,1	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	3,3	150			x
AB		2	2	6	6	10	0	0	0	1	1	6	10	5	5	20	20	20	0	10	10	10	144			
SD	x	1	3	10	15	15	15	10	7	0	0	15	15	10	10	0	0	0	0	0	0	0	126			
SD		10	20	20	0	0	0	0	0	5	10	10	10	10	0	0	10	0	0	0	5	5	115			
AB	x	20	0	0	0	10	5	6	4	5	6	4	6	8	10	10	5	3	3	3	3	3	114			
SD	x	3	3	0	0	0	0	7	5	0	5	0	37	0	0	0	50	0	0	0	0	0	110			
SD		1	2	4	8	0	0	0	0	0	10	10	20	40	10	0	0	0	0	0	0	0	105			
AB		4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	84			
SD		5	3	1	1	3	5	5	3	3	1	1	1	4	1	2	2	10	5	5	10	10	81			
AB		3	2	1	1	1	2	3	2	1	1	2	10	2	2	5	2	2	5	8	13	13	81			
AB	x	20	20	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80			x
AB		3	5	2	1	0	1	2	0	0	0	0	0	1	1	0	0	0	0	0	0	0	16			
SD	x	5	5	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	14			
AB		6	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13			
SD	x	2	1	0	0	0	1	0	2	0	0	0	0	2	0	0	2	0	0	0	0	0	10			

Table 5: Results of the behaviour analysis.

A data which is marked bold signifies that the subject overshoots the sustainable hotel capacity at that point in time, which causes the attractiveness of the place to decrease. The column "overshooting" gets a flag if the subject has overshot, while the column "learning" receives a flag if the subject has stopped ordering after overshooting. "Initial orders" get a flag if the subject has ordered 2/3 of the initial orders of the optimal run (60 hotels) within the first three time periods[16]. The row O states the optimal run, the graph "Analysis" below shows it. One interesting result of the upper table is the learning effect, whereas in total nine people overshot (4 SD students, 5 non SD students), only four of them adjusted orders afterwards and, out of these four, three are

[16] The three time period has been chosen for the analysis in order to calculate how many subjects understood, at the beginning of the experiment, that the maximum sustainable number of tourists was 5000. After the year three, the number of interested tourist stay constant at a value of 5000 until overshoot happens. This would make the understanding of the sustainable number of tourists easier for the players.

studying SD (and are therefore used to the problems caused by overshooting). Below the graph for the optimum is shown.

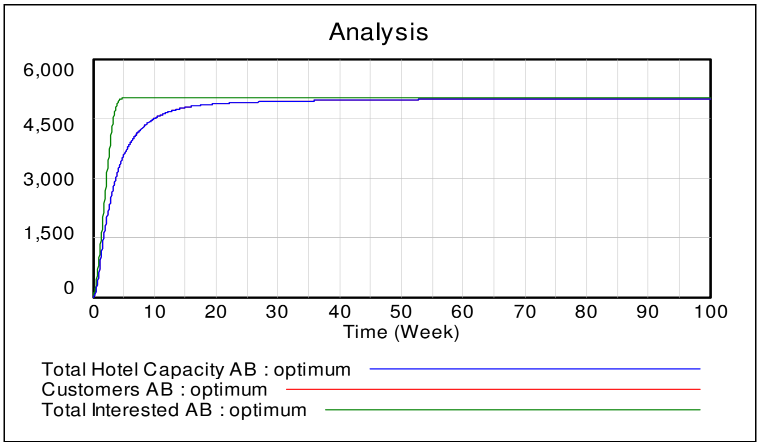


Figure 4: Optimum run

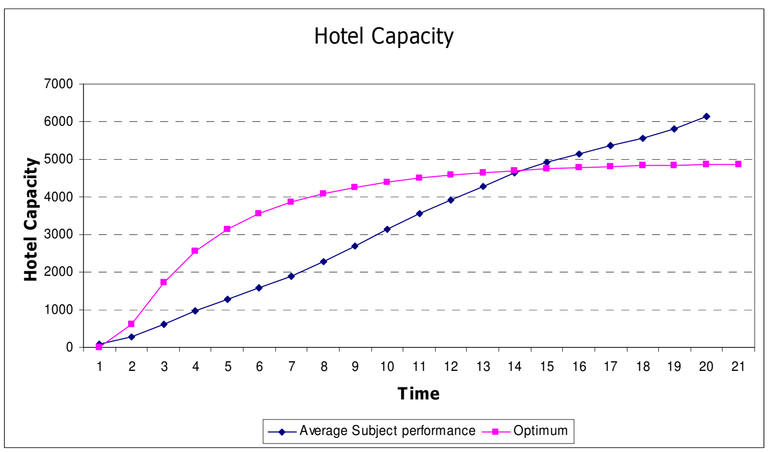


Figure 5: Optimum run and average run.

Figure 5 displays the average hotel capacity of all subjects, which seems to follow a rather linear trend. It seems as if the sustainable number, as well as the nonlinear relationships, in the model hasn't been considered so much as to find their way into the strategy formulation. Nevertheless due to the fact, that the sustainable number of tourists was unknown, caution with the number of hotels orders seems reasonable.

DISCUSSION AND CONCLUSION

It can finally be concluded that there does not seem to be too much difference between the AB approach and the SD approach towards the understanding of dynamic complexity. One hypothesis and question for further research would be, as there was a difference between the two groups, if experienced modellers seem to have an advantage with the more detailed AB methodology, whereas SD is more suitable for explaining complex problems to people with less of a modelling background. Nevertheless, the small number of subjects with which the experiment has been run, as well as our general impression of non-comprehension of task as well as structure of the simulator put some question marks over the results.

Apart from trying to discriminate the methodologies, several attempts have been made to integrate the two methodologies; two main ways can be imagined. On the one hand agents can interact in an SD environment or agents, which consist of SD - structures can interact without a predefined SD-environment.

In addition a list of criteria for when to use which approach would be desired. Bonabeau (2000)[17] proposes a list of characteristics for when to use ABM, which can unfortunately not be discussed further here:

a) when the interactions between the agents are complex, nonlinear, discontinuous or discrete;
b) when space is crucial and the agents positions are not fixed;
c) when the population is heterogeneous, when each individual is (potentially) different;
d) when the topology of the interactions is heterogeneous and complex;
e) when the agents exhibit complex behaviour, including learning and adaptation.

To broaden the discussion again, the rivalry with AB modelling seems for us, out of a SD perspective, as a fruitful competition. Assumptions are re-questioned and can be thrown overboard where unnecessary. In addition new problem contexts might be accessible to be modelled in future which could not yet be modelled adequately. Most importantly, mental models are challenged further, which is increasing the scientific value and challenges further what Phelan[18] considers unscientific resemblance thinking.

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