Design Structure Matrix and Discrete Event Simulation methods produce similar estimates of coordination load

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Abstract: tools have been developed for organizational simulation and optimization that have found uses among both scholars and practitioners. Yet external validation remains a challenge. The tools always represent a simplification of reality and may produce results that are difficult to test and verify. However, one viable method for validation is docking, i.e., the use of an already established tool to validate a new tool that makes use of alternative data or methods. In this article, we follow such an approach, examining a tool that is used for organization re-design—Reconfig, which is based on the Design Structure Matrix (DSM) and uses a genetic algorithm. We compare the coordination load estimates produced by Reconfig with the results from SimVision, an established Discrete Event Simulation (DES) tool. The results are close and consistent as long as the organization has sufficient capacity to handle the expected coordination, but when the amount of coordination exceeds the capacity of the organization, DSM underpredicts the required volume of work required to handle it since it does not have a model for coordination capacity.

Keywords: DSM, departments, clustering, coordination, consolidation

1. Introduction

Computer simulations have been used in organization science for more than 50 years (Fioretti, 2012). They can be used to demonstrate various phenomena, discover unexpected interactions between variables, and explain the processes that produce certain system behaviors (Harrison et al., 2007). Simulations developed by scholars are sometimes also commercialized into tools that practitioners can use to predict outcomes and thereby support decision making (Carroll et al., 2006). In this article, we consider two such tools: Reconfig, an organization design tool (Worren et al., 2020) and SimVision, a project management tool (Levitt, 2012).

Although computer simulations are useful, they are artificial in the sense that they are based on a model that is supposed to represent either a real-world organization or some proposed, non-existent organization. Another complication is that they are rarely transparent: It is often difficult to track the sequence of events that produced a certain result, which may be the emergent result of multiple, interdependent processes (Fioretti, 2012; Harrison et al., 2007). Validation of new tools is therefore a key challenge. However, one viable strategy is *docking*, which means cross-checking the results produced by a new tool with the results from one that is more established and has already been validated (Burton, 2003).

Reconfig and SimVision are two software tools that are built for different purposes and utilize different methods. Yet they have similar notions of coordination load, a key indicator of the effectiveness of any organization design choice (Worren et al., 2020). This means that we can first use the Design Structure Matrix (DSM) in Reconfig to re-organize the teams in an organization and then cross-check the predicted decrease in coordination load with the predictions from Discrete Event Simulation (DES) in SimVision. Because SimVision is a well-established tool that has been validated multiple times (Levitt, 2012), corresponding results will give credence to the results from Reconfig, which is a new tool. Reconfig is also a much simpler tool that is less time-consuming to use than SimVision. The results will therefore indicate whether (or when) quicker and less costly methods are likely to produce trustworthy results.

Because we compare DES with DSM methods, our results are relevant for research into application and validation of DSM as a tool for analysis and improvement of complex systems (Eppinger & Browning, 2012; Sharman & Yassine, 2004). Secondly, by demonstrating how organizations can be quantified and compared in terms of their coordination load, we contribute to the literature that uses a coordination approach to evaluate alternative organizational models and develop practical tools for decision makers (Carroll et al., 2006; Worren et al., 2020).

2. Comparison of variables in Reconfig versus SimVision

Reconfig is based on the established Design Structure Matrix (DSM) methodology (Eppinger et al., 2012). It is mainly intended as an organization re-design tool: It maps the interdependencies between individuals or teams, which is compared with the formal structure—the grouping of roles into teams or departments (Worren et al., 2020). Reconfig visualizes the current organization but also makes use of a genetic clustering algorithm (Goldberg, 1989) to identify a more optimal grouping of roles.

SimVision is mainly a project planning and management tool: It uses a information about teams and task structures, dependencies, and the probability of coordination events to predict resource utilization and project completion times (Levitt, 2012).

Reconfig provides an estimate of Coordination Load (CL) based on the number of dependencies within and across units (or groups/clusters). In contrast, SimVision predicts the additional volume of Coordination Work (CW) caused by exceptions for actors that are responsible for tasks that have dependencies. These indicators are different and cannot be directly compared.

In Reconfig, coordination requirements are represented as dependencies between actors. Coordination capacity (the ability to handle coordination) is only implicitly represented. A clustering algorithm seeks to maximize the number of intra-unit dependencies and minimize the number of inter-unit dependencies. SimVision represents coordination requirements by explicit dependencies between activities (and not actors, as in Reconfig) and coordination capacity by the skill, experience and number of actors. But our SimVision model mirrors the key assumption regarding grouping in Reconfig in that the amount of coordination required in an activity to handle an exception in another activity is smaller if the two activities are handled by actors in the same unit and larger if the two activities are handled by actors in different units. A comparison of the key variables in Reconfig versus SimVision is provided in Table 1.

Table 1. Comparison between Reconfig and SimVision with regards to key variables

Variable	**Reconfig**	**SimVision**
Assumed driver of coordination	Interdependency between actors (individuals or units)	Interdependency between activities (by actors)
Interaction types	Sending and receiving information between actors	Rework, informal requests and scheduled meetings
Organizational coordination capacity	Only implicit; but re-grouping of Actors (clustering) assumed to reduce coordination load	Explicitly represented by actor ability (number of actors, with defined skills and experience)
Indicator used for "goodness" of solution	Reduction in coordination load (CL) due to re-grouping /clustering	Reduction in coordination work (CW) due to better handling of exceptions

3. Methodology

Because the Reconfig and SimVision models are quite different, their indicators for coordination load cannot be directly compared. But we can compare their predictions about relative improvement resulting from consistent changes in the data for both tools. More specifically, we can model an ungrouped organization in Reconfig and SimVision using the same number of dependencies between actors (in Reconfig) and activities (in SimVision) and then change the grouping and observe the change in coordination load predicted by each tool. If the tools predict the same (amount of) change in performance over a range of organizational situations, we can claim that they are comparable.

Our data set (drawn from Fyall, 2002) represents a small organization with eleven actors and eleven activities with zero to four dependencies between each activity, We model the same organization in Reconfig with zero to four dependencies between each actor. We first run both Reconfig and SimVision with an ungrouped organization. We then optimize the grouping of actors in Reconfig (using the clustering algorithm) to find an optimized grouping and run the simulation with the optimized grouping in SimVision. Finally, we compare the change in coordination load (CL) and coordination work (CW) between the ungrouped and optimized organizations in Reconfig and SimVision to see if and how the predictions are comparable (or differ in consistent manner) across a test-space of coordination requirements—quantified by the number of dependencies (DR) between activities (in SimVision) or actors (in Reconfig).

Figure 1 shows the Reconfig model of a Team leader, two Subteam leads and eight Subteam members, as an 11-by-11 DSM. The interactions between actors (marked by "X" in the cells) occur because they need to send and receive information in order to handle dependencies between the activities that they perform. Initially, the actors are ungrouped (they are not grouped into teams) and with three dependencies (each actor is dependent on information from three other actors—the three "Xs" in each row of the matrix).

The corresponding SimVision model is shown in Figure 2. It consists of the same 11 actors (one Team leader with two Subteam leads, and eight Subteam members)[1], with 11 activities (also referred to as tasks in the SimVision model) that run in parallel, and three failure dependencies between each activity. These dependencies, which are represented by the red broken links between activities, are directional and run from the activity causing the failure to the activity affected by the failure. So, there will be three dependencies[2] from, and three activities to each of the tasks in Figure 2. Each actor is responsible for one task that lasts from start to finish, and thus the model could represent any (project or permanent) organization with actors carrying out parallel activities with dependencies that create coordination.

Figure 3 shows the corresponding SimVision model in Figure 2 represented as a DSM model (as used in Reconfig) with dependencies between each activity. Note that this is the same matrix as the DSM model in Figure 1, but with the actors replaced by activities (*tasks*) carried out by the various actors in SimVision. Instead of the work-process interdependencies in the DSM, the marks here represent failure dependencies between the activities.

Actor		1	2	3	4	5	6	7	8	9	10	11
Team leader	1		**X**	**X**				**X**				
Subteam lead 1	2	**X**		**X**				**X**				
Member 1	3				**X**		**X**			**X**		
Member 2	4			**X**		**X**					**X**	
Member 3	5				**X**		**X**					**X**
Member 4	6			**X**		**X**			**X**			
Subteam lead 2	7	**X**	**X**						**X**			
Member 5	8				**X**					**X**		**X**
Member 6	9					**X**			**X**		**X**	
Member 7	10						**X**			**X**		**X**
Member 8	11			**X**					**X**		**X**	

Figure 1. The ungrouped Reconfig model where each actor is dependent on three other actors.

[1] The SimVision model requires a formal hierarchy of a Team Leader, Subteam leads and Subteams in order to run the simulation. Decision-making about coordination is handled by message-passing in this hierarchy and will add to Coordination Work (CW). But this addition is the same for both the original and optimized SimVision models and will not affect the comparison of improvement between the two tools.

[2] Although SimVision includes different types of exceptions (failures, communication and meetings), for simplicity of the current model we have only used failure dependencies as a source of Coordination Work. Including informal communication and formal meetings would have the same effect as a source of Coordination Work. The details of exception handling and participation would differ, but those details have no impact on the overall behavior of the simulation.

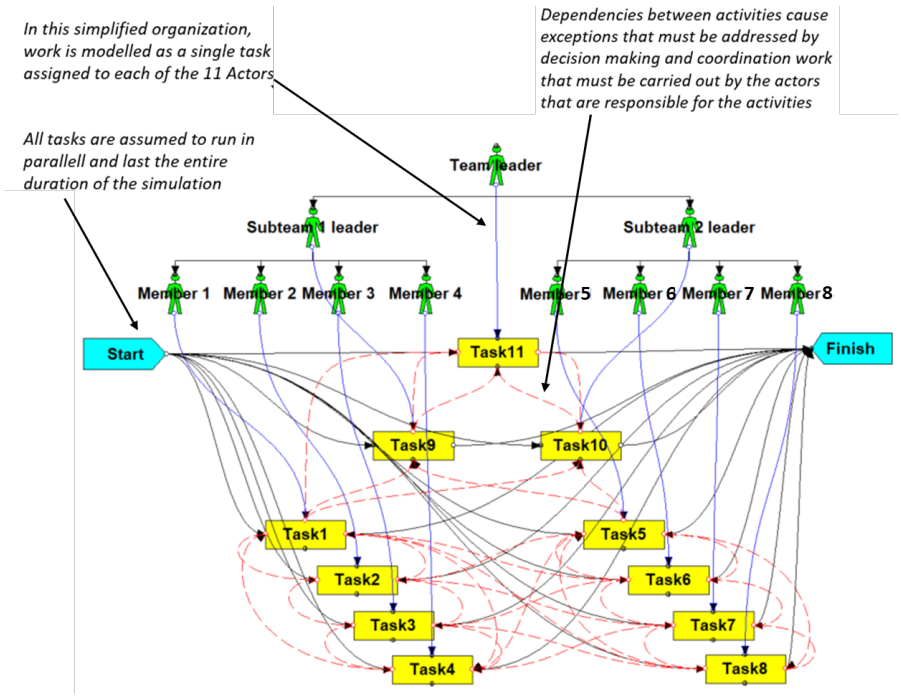

Figure 2. The base SimVision model with three dependencies per activity (called tasks in the figure).

Actor	***Task***		1	2	3	4	5	6	7	8	9	10	11
Team leader	Task 11	1		X	X				X				
Subteam lead 1	Task 9	2	X		X				X				
Member 1	Task 1	3				X		X			X		
Member 2	Task 2	4			X		X					X	
Member 3	Task 3	5				X		X					X
Member 4	Task 4	6			X		X			X			
Subteam lead 2	Task 10	7	X	X						X			
Member 5	Task 5	8				X					X		X
Member 6	Task 6	9					X			X		X	
Member 7	Task 7	10						X			X		X
Member 8	Task 8	11			X					X		X	

Figure 3. The base SimVision model (from Figure 2) represented as a DSM matrix

In SimVision, it is assumed that exceptions occur with a certain probability, which depends on the difficulty of the work that the actors carry out. Easy tasks have lower exception probability than standard tasks, which in turn have lower probability than difficult tasks. The exception probability will determine the rate at which exceptions occur and must be dealt with – which will determine how much they add to Coordination Work (CW). In addition to causing coordination work for the actor that is responsible for itself, an exception originating in a task can have an effect on another task which has a responsible actor that may or may not be in the same organization unit (group) – corresponding to intra-group versus inter-group dependencies in Reconfig.

The strength of a dependency determines how strongly the dependent (target) activity influences the (origin) activity that causes the exception, and thus how much work is needed in the target activity to rework the effect.

In the ungrouped model, we assume that exceptions are communicated less frequently and less accurately and thus have a larger effect on the target activity. We have therefore set the work that must be done each time there is an exception (the link strength) for all activities to 10 % of the work volume of the activity that triggered the exception.

In the optimized model we assume that intra-group exceptions are discovered earlier because interactions are now placed within the same group. We therefore reduced the “strength” (amount of coordination associated with each exception) for these activities to 5 %.

We ran the ungrouped models in each of the tools to get measures of coordination load (CL) and coordination work (CW). We then used the clustering algorithm in Reconfig to identify an optimized grouping of actors and calculate the percentage decrease in coordination load (CL) between the ungrouped and optimized models. Finally, we changed the SimVision model to match the optimized Reconfig model, reran the simulation to compare the percentage reduction in coordination work (CW). Figure 4 shows the optimized grouping represented as a DSM matrix.

Actor	***Task***		1	2	7	3	4	5	6	8	9	10	11
Team leader	Task 11	1		X	X	X							
Subteam lead 1	Task 9	2	X		X	X							
Subteam lead 2	Task 10	7	X	X						X			
Member 1	Task 1	3					X		X		X		
Member 2	Task 2	4				X		X				X	
Member 3	Task 3	5					X		X				X
Member 4	Task 4	6				X		X		X			
Member 5	Task 5	8					X				X		X
Member 6	Task 6	9						X		X		X	
Member 7	Task 7	10							X		X		X
Member 8	Task 8	11				X				X		X	

Figure 4. The optimized model created by Reconfig represented as a DSM matrix.

The coordination load (CL) estimates from Reconfig for the ungrouped organization and the optimized organization with three dependencies (DR) are 10.68 and 5.75, respectively – which represents an improvement (i.e., reduction) of 46 percent[3] (Table 2).

The simulated predictions from SimVision for the reduction in coordination work (CW) for the corresponding ungrouped and optimized models are 239 and 131 – which represents an improvement of 45 percent. These results show that the predictions from the tools are largely consistent—and that we calibrated the models such that the magnitude of the change is nearly equal for the chosen set of model parameters.

Given the agreement between DSM and DES with three dependencies (DR), we repeated the analyses with a DR equal to zero, one, two and four dependencies between actors/activities, and compared the predicted improvement to see if changes in DR would affect the consistency of results. Table 2 shows the coordination load predictions and the difference between the predicted improvement from the two tools.

From the table, we can see that the improvement due to grouping increases significantly for both CL and CW (from 16% to 51%) as DR changes from 1 to 2. This is because the optimized organization from Reconfig changes from six to three groups. The improvement then decreases slightly as DR is increased to 3 and 4, probably because of the dependencies between the three suggested groups. But we also note that the difference between the predicted improvement from Reconfig and SimVision increases only slightly across the whole range of DR values (from 0% to 1,2%), showing that the behavior of the DSM model in Reconfig is largely consistent with the DES model in SimVision across the range of number of dependencies (values of DR).

[3] The CL of both the ungrouped and optimized organizations are relative to an initial "current organization" with a grouping that gives a CL corresponding to 100%. But in this study we are only concerned with the difference between the ungrouped and optimized grouping, and the "current organization" is not used.

Table 2. Comparison between the predictions from the two tools with regards to coordination load (CL) and coordination work (CW) with varying number of dependencies (DR) and low difficulty (easy tasks)

	DSM (Reconfig)			**DES (SimVision)**			***DSM-DES***
DR	**CL ungrouped**	**CL optimized**	**CL improvement**	**CW ungrouped**	**CW optimized**	**CW improvement**	**Difference**
0	2.08	2.08	0 %	25	25	0 %	0.0%
1	4.94	4.15	16 %	83	70	16 %	0.3%
2	7.81	3.80	51 %	170	84	51 %	0.8%
3	10.68	5.75	46 %	239	131	45 %	1.0%
4	13.55	7.71	43 %	320	186	42 %	1.2%

The results in Table 2 hold for routine work with easy tasks over a range of number of dependencies (DR). This raises the question of whether similar results would be observed with more difficult tasks. This can be modelled in SimVision by increasing the probability that work causes exceptions, which leads to decision making about how to handle the exceptions. It cannot be modelled in Reconfig, which has no representation of task content, but we can compare with the results we obtained earlier to see if the difficulty of work affects the consistency between the two data sets.

Hence, we repeated the above simulations with different levels of task difficulty in SimVision – by varying a parameter named the project error probability (the chance that exceptions occur in one activity, which may require coordination in the activities that are dependent on that activity). We increased the error probability from 5 percent (corresponding to easy tasks) to 10 percent (corresponding to standard tasks) and to a critical level (corresponding to difficult tasks). For the latter we used the values found by Fyall (2002) to cause a "phase transition" from orderly to chaotic behaviour in exception handling, corresponding to Carroll & Burton (2000) described as "the edge of chaos".

Table 3 shows the predictions from Reconfig and SimVision for tasks with different degrees of difficulty. We see that for easy tasks, the predicted improvements are nearly equal for the two tools (the difference is close to zero). But for standard tasks the prediction from DSM is larger (the difference increases as the number of dependencies increases). For difficult tasks, the over-prediction from DSM increases even faster with the number of dependencies. Note that the difference is equal for a DR of 4, since the critical exception probability found by Fyall (2002) for a SimVision model with four dependencies between its tasks is 10% and even standard tasks will cause break-down in orderly processing if the number of dependencies (DR) increases to 4.

Table 3. Comparison between the predictions from the two tools with regards to coordination load (CL) and coordination work (CW) with tasks that vary in difficulty (i.e., error probability).

	Easy tasks (low error probability)			**Normal tasks (medium error probability)**		**Difficult tasks (high error probability)**	
DR	DSM CL reduction	DES CW reduction	Difference DSM-DES	DES CW reduction	Difference DSM-DES	DES CW reduction	Difference DSM-DES
0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1	16.0%	16.0%	0.3%	15.0%	1.0%	14.0%	1.9%
2	51.0%	51.0%	0.8%	48.0%	3.4%	46.0%	5.4%
3	46.0%	45.0%	1.0%	41.0%	4.8%	39.0%	6.8%
4	43.0%	42.0%	1.2%	35.0%	8.2%	35.0%	8.2%

Figure 5 shows the difference in predicted improvement as a function of the number of dependencies (DR). We interpret the results as follows: When an organization is performing easy tasks, the coordination capacity of the organization is sufficient to meet the coordination requirements of the task environment. Reconfig has no notion of capacity and can therefore only predict the potential for improvement given that there is capacity available. Consequently, the DSM model—which only implicitly represents coordination requirements (and assumes that there is sufficient coordination capacity)—is accurate for easy tasks. As tasks become more difficult, however, the requirements exhaust the capacity, and regrouping of resources to increase capacity is no longer sufficient to meet the requirements. Therefore, the potential reduction in coordination load from optimizing the grouping of actors is now reduced by an increasing amount of coordination required to handle the additional number of exceptions from difficult tasks.

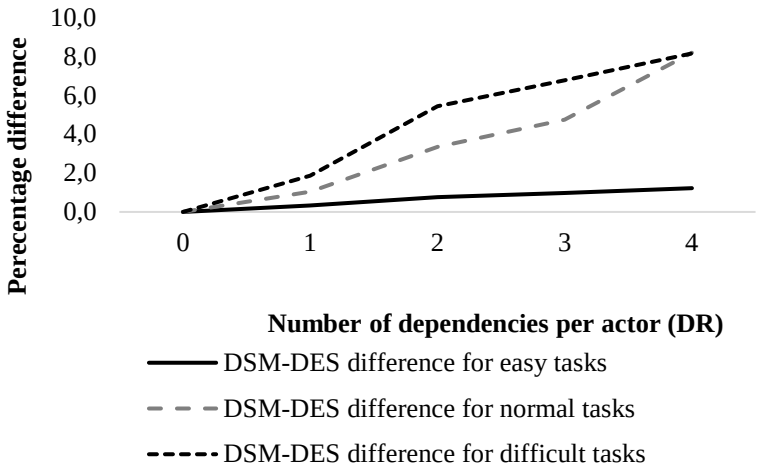

Figure 5. Comparison between Reconfig and SimVision predictions for tasks with varying degrees of difficulty and with different dependency rates.

The SimVision prediction of reduction in coordination work is a result of a simulation that accounts for both the coordination required to carry out scheduled work tasks and the capacity of the organization to carry out the needed coordination, while the Reconfig estimate of coordination load is solely based on coordination requirements (the number of interactions that are needed to carry out work). Thus, as long as the organization has capacity to meet the coordination requirements, the predicted improvement from regrouping should be equal for the two tools. When work gets more difficult the potential for improved performance because of the regrouping reduced because of the delay and confusion caused by insufficient Coordination Capacity. This is not considered in Reconfig, but included in the SimVision simulation, manifested by overloaded in-trays and waiting time for decisions about exception handling from over-burdened actors. This results in increasing divergence between the predictions from DSM and DES as coordination increases and work is no longer routine (easy), but becomes non-routine (normal) and then critically demanding (difficult).

4. Conclusion

Comparing Reconfig and SimVision, we find that when task difficulty is low, the predictions are nearly equal. This holds true in situations with low or high levels of interdependency between actors or activities. But when task difficulty increases, the predictions start to deviate as the level of dependencies increases. In these situations, the total amount of coordination exceeds the capacity of the organization. But even for the highest level of dependency and difficulty (the highest coordination requirements) the Reconfig prediction only exceeds the SimVision prediction by eight percent.

In other words, this docking exercise with simplified data sets suggests that – at least for our example – it is meaningful to compare predictions from Design Structure Matrices (DSM) and discrete event simulation (DES). We intend to continue and extend our work to include comparison with larger data sets from real world organizations and work processes.

As long as the work environment is characterized by tasks of moderate complexity, Reconfig appears to give reasonable and realistic estimates and can thus be used to predict organizational improvement for a range of dependencies between actors and activities. The broader implication is that one may be able to replace complex and time-consuming DES models that require detailed information about actors and the work processes with simplified

DSM models that only require a list of participants and their interactions. This makes it quicker and cheaper to model organizations and predict their performance. However, the limitation is that the predictions from the DSM need correction when the work environment becomes more complex.

Further work could be undertaken to compensate for this limitation. More specifically, one could consider whether task difficulty could be added as a parameter in Reconfig. Even if the tool does not explicitly model coordination capacity, the predicted improvement in coordination cost as a result of regrouping elements (roles/units) could then be adjusted somewhat downwards when task difficulty is moderate to high, based on results from simulation results from similar organizations.

References

Burton, R. M. (2003). Computational laboratories for organization science: Questions, validity and docking. *Computational & Mathematical Organization Theory 2003 9:2*, *9*(2), 91–108.

Carroll, T., & Burton, R. M. (2000). Organizations and complexity: Searching for the edge of chaos. *Computational & Mathematical Organization Theory*, *6*(4), 319–337.

Carroll, T. N., Gormley, T. J., Bilardo, V. J., Burton, R. M., & Woodman, K. L. (2006). Designing a new organization at NASA: An organization design process using simulation. *Organization Science*, *17*(2), 202–214.

Eppinger, S. D., & Browning, T. R. (2012). *Design structure matrix methods and applications*. MIT Press.

Fioretti, G. (2012). Agent-based simulation models in organization science. *Organizational Research Methods*, *16*(2), 227–242.

Fyall, M. (2002). When information flow becomes turbulent: Toward an organizational Reynolds number. In *CIFE Technical Report #138, Stanford University*.

Goldberg, D. E. (1989). *Genetic algorithms in search, optimization and machine learning*. Addison-Wesley.

Harrison, J. R., Lin, Z., Carroll, G. R., & Carley, K. M. (2007). Simulation modeling in organizational and management research. *Academy of Management Review*, *32*(4), 1229–1245.

Levitt, R. E. (2012). The virtual design team: Designing project organizations as engineers design bridges. *Journal of Organization Design*, *1*(2), 14–41.

Sharman, D. M., & Yassine, A. A. (2004). Characterizing complex product architectures. *Systems Engineering*, *7*(1), 35–60.

Worren, N., Christiansen, T., & Soldal, K. (2020). Using an algorithmic approach for grouping roles and sub-units. *Journal of Organization Design*, *9*(8), 1–19.

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