Exploring the Effects of Subversive Agents on Consensus-Seeking Processes Using a Multi-Agent Simulator

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Abstract: In this paper we explore the effects of subversive agents on the effectiveness of consensus-seeking processes. A subversive agent can try and commit industrial espionage, or, could be a disgruntled employee. The ability of an organisation to effectively execute projects, especially projects within large and complex organisation such as those found in large corporates, governments and military institutions, depend on team members reaching consensus on everything from the project vision through various design phases and eventually project implementation and realisation. What could the effect be of agents trying to subvert such a process in a way that does not raise suspicions? Such an agent cannot openly sabotage the project, but rather tries to influence others in a way that increases the time it takes to reach consensus, thus delaying projects in subtle ways. Here we explore the effect such agents could have on the time and effort to reach consensus though the use of a stochastic Multi-Agent-Simulation (MAS).

1 INTRODUCTION

Project complexity, the ability of project team members to reach consensus on the relevant topics or moving to next phases before reaching consensus have repeatedly been quoted as reasons for project delays and failure (Al-Ahmad et al., 2009; Whitney and Daniels, 2013; Kian et al., 2016; Waheeb and Andersen, 2022).

In this paper we investigate the effect that subversive agents (SAs) could have on project timelines and work effort. Our approach uses Multi-Agent-Simulation (MAS) wherein we model agent behaviour and in particular the behaviour of SAs. In the text below we use the terms *team members* or *members* to refer to the conventional members of the team and the term *agents* refer to the subversive members of the team that has as goal to delay project delivery by sowing discord within the team.

We regard the delivery of a project as a series of consensus seeking processes wherein team members have views that are debated and discussed in meetings. A particular phase of a project, say the requirements gathering phase, can only conclude if all participating parties agree on particular topics. Members of the project team reach this consensus through repeated discussions where opinions are shared and discussed.

SAs have two goals; firstly, to promote views and opinions that would create more debate, thus delaying the project; and secondly, to not have such radical views that they are regarded as outliers and thus ignored.

We investigate, though simulation, the effect that a small number of SAs could have on project timelines. First, we define and discuss our approach to modelling this interesting problem. Then we simulate the behaviour of team members during consensus-seeking discussions. We investigate the ranges of views (using statistics) that promote faster consensus and which ranges delay consensus, first theoretically and then through simulation. Next, we investigate the effect of the level of subversion, from mild to severe. Finally, we investigate the effects of a very small number (one to four) of SAs on project delivery if they are coordinated in their efforts.

The delivery of a project can be seen as a series of consensus-seeking processes. For example, the project vision is discussed, reviewed, debated and eventually agreed upon. This is a process where the

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stakeholders gravitate towards a shared single vision, consisting of many topics, for the project.

Next, perhaps, follows an architectural design phase. This phase will follow a similar pattern where initial stakeholders may have widely different views of how the design should look to fulfil the project vision. This phase of the project concludes when all members agree on what the architecture should look like.

That may be followed by systems and sub-systems design phases, again, starting with disagreements and various opinions that, though a process of lots of meetings, eventually settling on a position of consensus between the various stakeholders.

The use of MAS and in particular the achievement of consensus and synchronization in these systems have seen extensive research in the past decade, as is evidenced by the depth of research, see Bao et al. (2022) and Yang et al. (2022) for overviews of cooperative control and distributed coordination of MAS. That line of research focus on high-speed consensus algorithms for use in UAV and autonomous vehicles under variations of network topology, error-rates, and cyberattacks.

Consensus in MAS is a challenging problem which in the literature has mostly been social sciences research, economical model simulations, or MAS consensus algorithms. Social Sciences research focussing on crowd and voter behaviour which as a three decade deep research history starting with Dunbar (1998)'s 'social brain', Stocker et al. (2001)'s social information exchange, and the formation of consensus groups discussed by Leishman et al. (2008) also see Gilbert and Gilbert (2010). On the other hand, MAS consensus algorithmic solutions focus almost exclusively on high-speed applications already mentioned, see Amirkhani and Barshooi (2022).

This work is perhaps closest to MAS in Computational Economics discussed for example in Tesfatsion and Judd (2006) at least in terms of project synchronization as an impact factor for project economics.

Chang and Harrington (2004) described a scheme for modelling organisations using multi-agent systems (MAS) with specific focus to answer economic questions. Later Will et al. (2019) investigated the role of organisational structure in innovation project selection wherein they point out the effect of organisational structure as an enabler (or blocker) of decision-making. In particular, they describe three organisational forms (polyarchy, hierarchical and hybrids of the two). In a polyarchy members of the team are fully connected and allowed to talk to each other across hierarchical boundaries. We use fully connected polyarchies in all the simulations discussed in this paper. For a more detailed discussion of the three hierarchies in terms of this simulator and simulations, see Vorster and Leenen (2023).

The study of subversive agent behaviour and impact has focused on many domains ranging from psychological (McDowell, 2002), business (Manky and Dolores, 2022), political (Barnes and Prior, 2009), and obviously espionage (Evans and Romerstein, 2012).

The study of the impact that SAs could have on project delivery seems, to the best of our knowledge to not have been studied before. Furthermore, our approach to study this effect through the use of models for consensus also seems to be novel.

In our previous paper (Vorster and Leenen, 2023) the model and simulation implementation using MAS for the investigation of consensus-seeking processes such as project delivery within various organisational architectures and project delivery methodologies has already been reported. This paper describes the effects that a subversive agent, or a group of such agents could have on the time and effort to reach consensus if they try and delay the achievement of consensus by promoting views that cause more debate and thus longer times to reach consensus.

The approach is to simulate the consensus process by way of team members setting up meetings with other members on topics they do not have agreement on and through the meeting try to resolve their differences in one of three ways. Let us say members m and n meet. Then for every topic (k) discussed, one of three outcomes are possible: (a) m and n reach a consensus, a middle-ground between their two views, (b) m convinces n or (c) m is convinced by n.

Through such a process of repeated meetings, each issue gets resolved for all members of the team so that at the end of the process all members agree on all topics. Only when this state of agreement has been reached can it be said that consensus has been reached and can that part of the project conclude.

The SAs in these simulations have two goals (a) to increase discord within the group thus increasing the time it takes to reach consensus, and (b) to not be identified as subversive, which can happen if the SAs promote radical views or consistently promote extreme views.

Team members initially have stochastically (statistical) chosen views and through iterative meetings resolve differences in views while the SAs will promote the views of other team members or their own views where those views are further away from the mean views of the group, yet, not so far away from the current consensus view that it creates suspicions.

The document has the following section layout:

- *Modelling Consensus*, §2, introduces the concept of consensus as a measurable quantity as well as how topics and each member's view on a topic is modelled;
- *Subversive Agent Behaviour*, §2.1, gives an introduction to subversive agent behaviour within the group;
- *Evolution of Views*, §2.2, reports on the initial results of how SAs influence the consensus process in terms of the consensus measures and the distribution of views;
- *Yes-agents*, §2.3, discusses the effects of agents that constantly promote the group view and the effect they have on the time to reach consensus;
- *Subversive Agent's Impact on Project Delivery*, §3, reports on the effectiveness of SAs to delay projects;
- *Coordinated Agents*, §3.1, discusses the ways in which SAs can cooperate to delay projects within this narrow application;
- *Level of Control*, §3.2, investigates the conditions under which SAs have such control that they can dictate the outcome of decisions;
- *Group delay & control*, §3.3, discusses the overall effect of SAs in larger groups and the critical number of SAs to control both outcomes and delays; and
- *Discussion*, §4, wherein a brief overall discussion of the results and consequences from the data presented in the various sections are discussed.

Some remarks are needed on subversive agents versus conventional disagreement on topics between peers trying to find satisfactory solutions. In many projects the issues are complex and people have justifiable reasons for arguing positions that others may consider unimportant. This is normal and part of finding good solutions, the fact that there are debates imply that topics are not simple. These debated indeed do lead to longer times to reach consensus, but the balance of that is that better decisions are reached, more options are considered, and more variables are investigated and brought into the discussion. However, we are using the term subversive agent to mean someone that is pro-actively trying to find arguments, trying to convince others of potions that they themselves do not believe. In short, they may be disgruntled employees or any other range of possibilities.

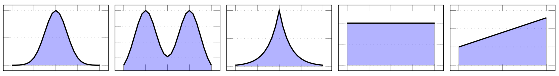
(a) Normal (a) Double Normal (b) Exponential (c) Uniform (d) Skew

Figure 1: Distributions of views on a topic can take many forms.

2 MODELLING CONSENSUS

In our model a number of members, N, try to reach consensus through a process of repeated meetings wherein a number of topics are discussed. Consider a given problem under discussion, say the project vision, or the requirements specification, or any other aspect of the project. This problem consists of a number of topics and members of the project team will discuss these topics in a series of meetings. Each member has a view (opinion/belief) about each topic and as members meet, they discuss these topics and are swayed by the presented arguments.

Let us denote two members by i and j, the specific topic they want to discuss is denoted k. Member i has her own view of topic k, denoted by b_i^k. Similarly member j may have a different view on the same topic, denoted b_j^k. The mean view of all the members on topic k are denoted $\hat{b}^k$.

The two members may differ in opinion on topic k, and that can abstractly be denoted by $u_{ij}^k = |b_i^k - b_j^k|$. When considering these differences in views for many members, the expected value (or mean value) for the difference in views on topic k can be denoted $\hat{u}^k$.

Through meetings, members will consider each other's views on every topic discussed. For a discussed topic there can be one of three outcomes, (a) they reach some agreement somewhere in the middle of the two initial views; or (b) i is convinced by j, $b_i^k \leftarrow b_j^k$; or (c) i convinces j, $b_i^k \rightarrow b_j^k$. After the meeting, no matter which one of these options occurred, $u_{ij}^k = 0$, meaning they resolve their differences and agree on what they believe to be the correct answer.

Throughout the process members meet each other to discuss topics and this continues until all topics are resolved. The total time it takes for all members to reach consensus on all topics are denoted $t^{\max}$.[1]

The distribution of real-life views could have many forms depending on the topic and people involved and has been found to have Normal, Uniform, Skew (Den Boon and Van Meurs, 1991), and even Exponential (Lang et al., 2018) distributions, see Figure 1. In our simulation members are initiated

[1] A detailed mathematical description of this process can be found in Vorster and Leenen (2023).

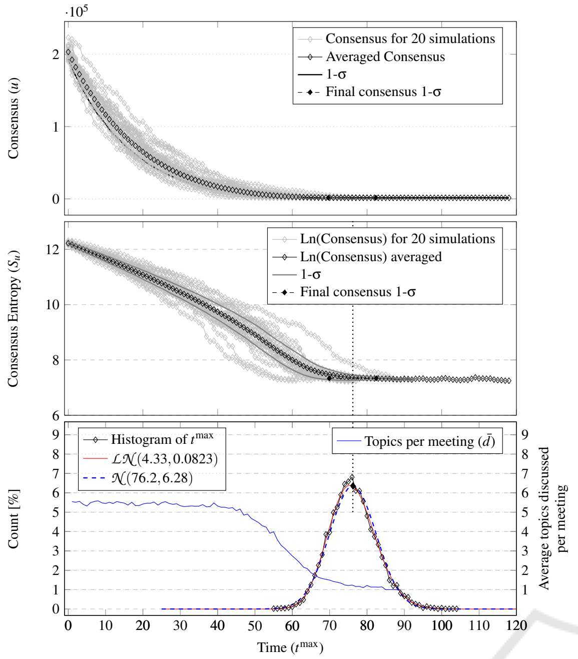

Figure 2: (Top) Various simulations of the 10-group showing the consensus measure over time. (Middle) The same data as in top graph, but now using $\log_e$(consensus). (Bottom) Histogram of the time it takes to reach consensus over many such runs ($\mu = 76.2$, $\sigma = 6.28$, n=10000) and Normal and Lognormal fits to the histogram data.

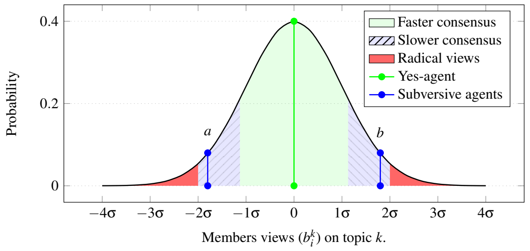

Figure 3: Distribution of views, $b_i^k \sim \mathcal{N}(\sigma)$. The opinion of a Yes-agent (always at $b_y^k = 0$) and a subversive agent in this case with views $|b_s^k| = 1.8\sigma$. Agents with view in the 🟩 region, $|b_i^k| < \frac{2}{\sqrt{\pi}}\sigma$, reduces the time to reach consensus, otherwise it leads to longer time to reach consensus.

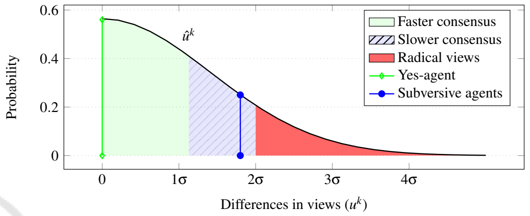

Figure 4: Distribution of differences in views, $u^k = |b_i^k - b_j^k|$, with average $\hat{u}^k = \frac{2}{\sqrt{\pi}}\sigma$. The opinion of a Yes-agent (always at $b^k = 0$ and a subversive agent in this case with views $|b^k| = 1.8\sigma$ are shown in green and red respectively.

with random views from a Normal distribution, that is $b_i^k \sim \mathcal{N}(\sigma)$.

At any time during the simulation, the overall level of consensus can be measured by summing over the differences in view between all members on all topics. If there are $k^{\max}$ topics we can define

$$u_t = \sum_{i=1}^{N} \sum_{j=1}^{N} \sum_{k=1}^{k^{\max}} u_{ij}^k \tag{1}$$

As example, consider Figure 2 that shows the measurement of consensus over time for many simulations of a group of a ten member group. Consensus measure, as defined by (1), decreases exponentially (top diagram in Figure). The same data is presented using a log scale (middle), and the final time to reach consensus is plotted in histogram form for many such runs (bottom).

The average time to reach consensus was $\hat{t}^{max} = 76.2$ ($\sigma = 6.28$, $n = 10000$). This is an abstract number representing the real time it would take to resolve the topics and could present any time measure (hours, days) depending on the complexity of the topics. We are not interested in the absolute times but rather in the relative differences in times. For example, we will shortly compare the time it takes to reach consensus when a subversive agent is present with the time when such an agent is not present.

Each member has a view (opinion, belief) on a specific topic, which we model as a numeric value. The views of team members have a Normal distribution, $d^k \sim \mathcal{N}(\sigma)$, see Figure 3. The figure also shows the view of an agent that always aligns its view to that of the majority, we call such an agent a yes-agent, always saying yes, and always agreeing with the majority. Also shown are the average positions of SAs (at $-1.8 \cdot \sigma$ and $1.8 \cdot \sigma$).

The difference in views between members (i, j) on a topic k is given by $u_{ij}^k = |b_i^k - b_j^k|$ and has a Folded Normal ($\mathcal{FN}$) distribution, where $\mathcal{N}(\sigma_{i-j} = \sqrt{2} \cdot \sigma)$. Then the *expected value*, denoted with a hat, of the difference in views is $\hat{u}^k = \sqrt{\frac{2}{\pi}} \cdot \sqrt{2} \cdot \sigma = \frac{2}{\sqrt{\pi}}\sigma$ as per the statistics of an $\mathcal{FN}$ distribution, see Figure 4.

An interesting aspect, key to the results discussed later, is that if an agent, i, maintains a view b_i^k on topic k in the range $|b_i^k| < \hat{u}^k$ then the result is shorter time to reach consensus for the project. On the other hand, if an agent maintains a view $|b_i^k| > \hat{u}^k$ the result is longer time to reach consensus for the project. These theoretical results are verified by simulation later in section §3.

2.1 Subversive Agent Behaviour

We are interested in SAs and how they affect the process of the group to reach consensus. SAs do not actively sabotage projects, they are more subtle and rather opt for creating project delays by promoting views that will cause the group to take longer to reach consensus. However, SAs also do not want to take such radical positions that they are discovered.

The $u^k = \hat{u}^k$ boundary line in Figure 4 is such that half the view differences (u^k) are to the left (🟩, with $u^k < \hat{u}^k$) and half to the right (▨ + 🟥, with $u^k > \hat{u}^k$). That means that an member, i, with view $|b_i^k| < \hat{u}^k$ (🟩 in Figure 3) will, through interactions with other members, improve the overall consensus, and thus lead to faster times to reach consensus.

Importantly, members that express views such that $u^k > \hat{u}^k$ (▨ + 🟥) will, through their actions, lead to longer time to reach consensus. These are ideal positions for SAs to promote.

However, such SAs do not want to constantly take up controversial or fringe positions since that could lead to their detection or labelling as subversive. We select 2σ as the cut-off point (🟥 in Figure 4) and SAs will avoid expressing opinions on topics in that range ($u^k > 2\sigma$), even though other team members are likely to have such opinions from time-to-time.

This leaves the blue hatched area in Figure 3 and Figure 4 as the ideal ideas for SAs to promote.

The SAs change the view they project to other members based on the overall group view. That is, as the group as a whole moves towards consensus, so does the SAs. They maintain their views such that they stay in the hatched blue region, $\hat{u}^k < b^k < 2$, but obviously the distribution of views contracts as the meetings and negotiations continue.

2.2 Evolution of Views

The initial distribution of view $b_i^k \sim \mathcal{N}(\sigma)$, as discussed in §2 and shown in Figure 4. In this subsection we discuss the evolution of this distribution as the consensus process continue.

To illustrate the evolution of member views we show the distribution of u^k over time in Figure 5 for a scenario with no SAs (blue) and when two SAs are present (red, with $b^k = 1.8\sigma$, -⊖-) in a group of twenty members trying to reach consensus on twenty topics.

The top graph shows the initial distribution at $t = 0$, as well as the mean values, blue solid diamond (-■-) for the mean without SAs and red solid diamond (-◆-) when SAs are present. The graph is directly comparable to Figure 4. The graph second from top is the same data (at $t = 0$) but using a log-y scale. The remainder of the graphs show the distribution of u^k as time progresses ($t = 0$, 25, 50, 75, 100, and 125) on a log-y scale.

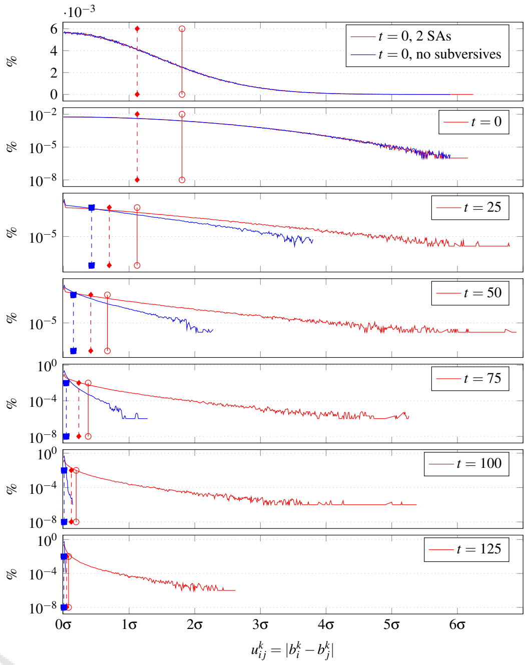

Figure 5: As the consensus process continues, the distribution of differences in opinions, $u_{ij}^k = |b_i^k - b_j^k|$, changes. The blue graph represent the u^k values of a 20-group with no SAs, and the red graph represent the u^k values for a 20-group with two SAs. The dashed vertical lines show the mean values $\hat{u}^k$ for the two distributions, and the solid vertical line shows the positions that the SAs took, at $b^k = 1.8\sigma$, where σ is the standard deviation for the group at that time.

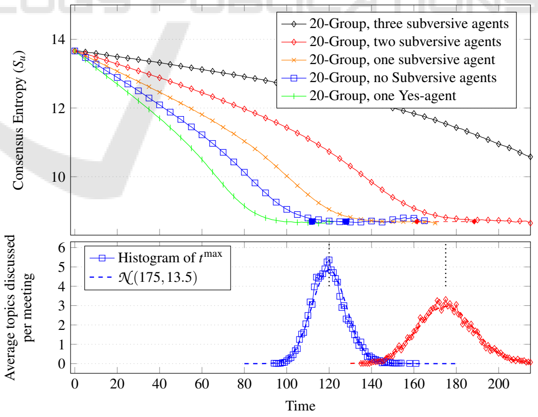

Figure 6: Consensus measures over time (top) for various numbers of subversive agents with a fixed group size (20). (Bottom) two histograms for zero subversive agents ($\mu = 120, \sigma = 8.22$) and two subversive agents ($\mu = 175, \sigma = 13.5$) of time to reach consensus for $n = 10000$ simulations each.

The difference in views, u^k contracts until, towards later time-steps, the members reach consensus (blue graph). Here the influence of the SAs is obvious, in that the distribution of views when there are SAs present (red graphs) significantly lag in their evolution towards consensus as can be seen by visual inspection of the graph.

Each graph in Figure 5 is related to the data points in Figure 6 for the same time step. Over time the views on a topic will converge as members start to agree on the correct position on a topic. Figure 6 shows how the sum of opinions (u) changes over time and eventually converges. The slope of the graphs in Figure 6 is interesting and a comparison of the graph for a normal group with no SAs with a that of a group with two SAs show that towards the end of the consensus process the SAs have little effect (the graphs have the same slopes). That is because the distribution of opinions is small, and thus the ability of SAs to influence the process is also limited. In this specific example, the dramatic difference in slope only lasts to about $t = 120$ after which the slopes become similar.

The overall time to reach consensus with two SAs has mean $t = 177$, so that one can postulate that SAs do most of their damage in the first 60% of the project, after which group views have contracted sufficiently so that the agents cannot continue being subversive without risking being revealed.

2.3 Yes-Agents

An interesting category of non-normal agents are those that tend towards agreeing with the majority view on all topics, all the time. The extreme *Yes-agents*[2], who only take up positions that are non-controversial, in the middle of the distribution of the views of other members, see Figure 4, has the most significant impact on the time to reach consensus.

To investigate this phenomenon we simulate a group consisting of twenty members working on a problem with twenty topics. We vary two parameters, firstly the number of Yes-agents in the group, and, for every such Yes-agent configuration we vary the position, b^k, that those Yes-agents take within the distribution of views (the x-axis of Figure 3). We measure the time it takes for the group to reach consensus ($t^{\max}$).

The results are depicted graphically in Figure 7, where the zero-SAs are used as reference and scaled to 100. The Yes-agents has a positive impact on time to reach consensus; the more Yes-agents the greater the impact; and the more extreme their centerredness the bigger the impact of improving $t^{\max}$.

A single (1 of 20) extreme Yes-agent ($b^k = 0$, the green line in Figure 3) improves the overall project delivery from 100 time-units to 92 time-units, point (0,92) —+— in the Figure. That is, an 8% improvement. However, this obviously comes at the risk of making the wrong decision. If that agent's views was not needed, the agent should not have been in the group in the first place, some may argue. Consider the graph (—+—) of a single Yes-agent as a function of the subversiveness of its views b^k. At $b^k = \hat{u}^k$ this agent's impact is the same as if it were a conventional cooperative agent with its own independent views.

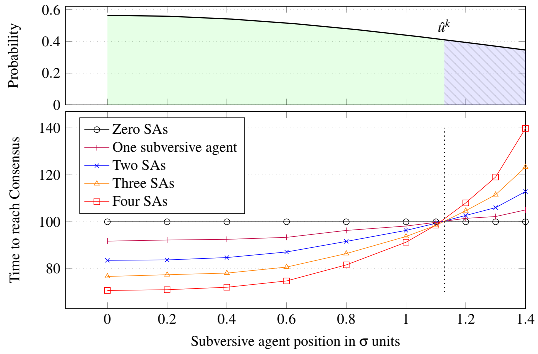

Figure 7: Simulation of various subversion factors ranging from 0 (no subversion) up to 1.4σ. The graph shows the effect that zero to four SAs have on the time to reach consensus.

For $b^k > \hat{u}^k$ the impact of the SAs causes the time to reach consensus to increase dramatically, as can be seen from the data, shown in the Figure. The remainder of this paper focuses on the impact of SAs with views in the range $\hat{u}^k < b^k < 2$ (▨). In particular, the extension of Figure 7 to that region is discussed in §3 and shown in Figure 8.

3 SUBVERSIVE AGENT'S IMPACT ON PROJECT DELIVERY

We now turn to the impact of SAs on the time to reach consensus when the agents take up subversive views on topics in the range $\hat{u}^k < b^k < 2$, (▨ in Figure 3) on purpose. It may be that they do not even believe such a position is correct, they may be promoting other group-member's views, or they try to be controversial, or, even that they are pro-actively trying to find ways to sow disarray.

Whatever the reasoning for their actions, here we explore the potential impact that such agents could have on the time to reach consensus, and thus on the time to delivery that phase of the project.

Figure 8 extends the positions taken by the SAs from that shown in Figure 7. The results from the

[2] A sycophant in late Latin or a 'Jabroer' in Afrikaans

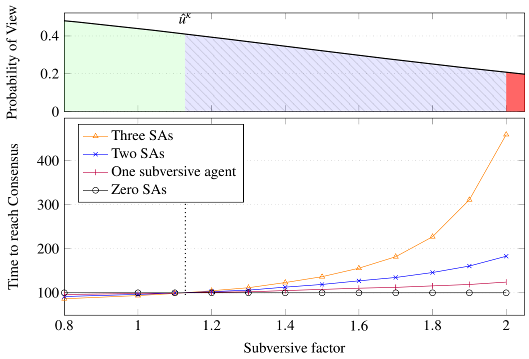

Figure 8: Simulation of various subversion factors ranging from 0.8σ up to 2σ. The graph shows the effect that zero to three SAs have on the time to reach consensus.

simulations show that SAs can create significant increases in project times by delaying the consensus process. The values in Figure 8 have been normalized so that the consensus-time for processes with zero SAs are scaled to 100 time-units. Recall that an agent taking a position at $\hat{u}^k$ has the same effect as a normal agent.

If SAs take up positions at $\hat{u}^k + \frac{1}{2}\sigma \approx 1.6\sigma$ then the simulations show that a single agent in a 20-group can delay a project by 10.5%, two SAs can delay the project by 27.2%, and three agents can cause 55.9% delays, see Table 1.

If the SAs take up position at 2σ, which is only 0.9σ bigger than $\hat{u}^k$, then the impact on project delays are even more significant and for one, two and three SAs the delays are 24.3%, 83.1%, and 359.5% respectively, see Table 1. The missing number in Table 1 for a 4/20 ratio and $b^k = 2\sigma$ (🟥) is because for that configuration the SAs have the ability to delay the consensus process indefinitely. The ability of agents to control the outcome of decisions is briefly discussed in the next section.

Table 1: The data for the *delay* in time to reach consensus for different ratios of SAs to total members and different relative positions of SAs. The '$R > b^k$' row indicates for each subversive position (b^k) what percentage of the total members have an even more radical view (statistically). All numbers are percentages. The red bar indicate that 4 SAs at $b^k = 2\sigma$ can indefinitely delay consensus.

Ratio	$b^k = 0$	$b^k = 1.6\sigma$	$b^k = 1.8\sigma$	$b^k = 2\sigma$
1/20	-8.3	10.5	15.7	24.3
2/20	-16.4	27.2	46.1	83.1
3/20	-23.3	55.9	127.3	359.5
4/20	-29.3	119.9	385.3	🟥
1/10	-10.8	18.2	26.8	41.6
2/20	-16.4	27.2	46.1	83.1
3/30	-18.8	30.3	58.2	115.4
4/40	-20.1	32.2	67.3	144.6
$R > b^k$	100	10.1	7.2	4.6

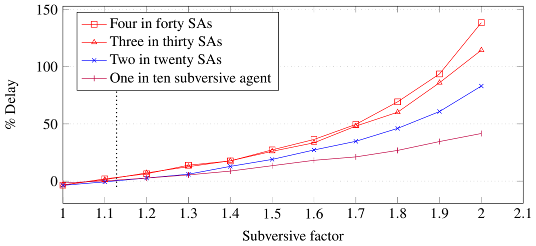

Figure 9: Each simulation line keeps the ratio of SAs to total members constant at 10%. The results show increase in project delivery time as measured relative to groups with zero SAs.

The argument can be made that the reason for these increases in delays are because a greater percentage of the overall number of agent are subversive. That is, one, two, and three SAs make up 1/20, 2/20 and 3/20 of the total number of project team members, and so, perhaps this increase percentage SAs are creating the delays, rather than the actions that these agents take to delay the project. To address this criticism a series of simulations was conduction where that ratio of SAs to normal members are kept static at 10%. That is, simulations were generated with one subversive agent in a 10-group, two in a 20-group, three in a 30-group, and four in a 40-group.

The results are shown in Figure 9 and Table 1. One, two, three, and four SAs at $\hat{u}^k + \frac{1}{2}\sigma \approx 1.6\sigma$ caused delays of 18.2%, 27.2%, 30.3%, and 32.2% respectively and at 2σ they can create project delays of 41.6%, 83.1%, 115.4%, and 144.6% respectively.

3.1 Coordinated Agents

A single agent is a lone wolf, however, two or more SAs can form a pack and launch coordinated attacks, or, in this case, coordinate in the disruption of the project, increasing delays.

In this section we investigate the patterns of cooperation and coordination of multiple SAs. We consider the following modus operandi; they can act uncoordinated, they can push the same side of an issue, and they can take up opposite sides of an issue thus trying to split the other members into two groups.

There can be other ways to coordinate, for example targeting specific members of the team trying to influence them rather than trying to influence all members. These and other such strategies are not investigated and left as future research.

Consider again Figure 3 and the two marked positions of a SAs, labelled (a) and (b) in the figure. The three patterns of cooperation we investigate are then firstly that each agent selects a position either (a)

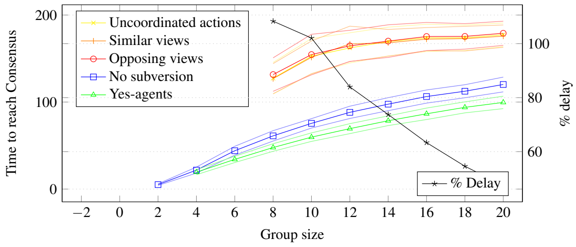

Figure 10: The graphs show the impact on time to reach consensus for three types of cooperation between two SAs, uncoordinated, promotion of similar views, and promotion of opposing views. This is plotted for various group sizes. The bands indicate a $1-\sigma$ spread (n=200 pp).

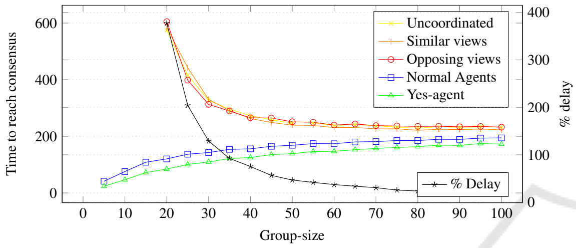

Figure 11: Time to reach consensus for different group sizes and cooperation types (n=100 pp).

or (b) independent of other SAs. This pattern is the safest in that there are no correlation between the positions that SAs take, and thus no way to link them based on their views. The second approach, calls for all SAs to take up the same position, either left or right of an issue, but they are coordinated in that decision. This is less desirable from an attempt to stay hidden. The third method of coordination is that the SAs form two groups, one group promoting views close to (a) on the left of an issue and the other group promoting position (b) on the right of an issue.

To investigate the impact of the type of cooperation between SAs could have on the consensus processes we ask the question; are some types of cooperation more destructive than others, if measured by time and effort to reach consensus? To answer this question simulations were constructed to investigate the type of cooperation and its impact on the consensus processes as a function of the group size, fixing the number of subversive agent and their position $(r\sigma, r = 1.8)$.

For each configuration point (group-size and number of SAs), simulations were run, $n = 100$ per configuration, to achieve statistical significance. Figure 10 shows the results for the simulations when two SAs are present. Figure 11 shows results with four SAs. For the graphs where two SAs are present, the smallest group size shown is eight; this is because for smaller groups, the SAs assert enough control that

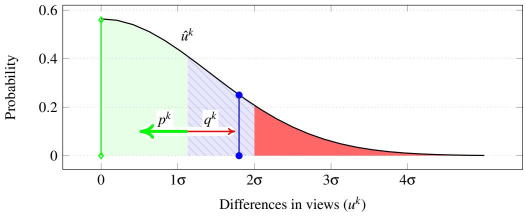

Figure 12: Conventional consensus processes (meetings and discussions) acts like a force (p^k) that narrows the consensus distribution. SAs within that process acts like a force (q^k) trying to widen the consensus distribution. If $p^k < q^k$ then SAs control the process.

they can delay consensus indefinitely. The same limit exists for when four SAs are present but for even larger groups.

What is surprising and interesting about the results, shown in Figure 10 and repeated in Figure 11, is how similar, in fact indistinguishable, the three cooperative models are from each other in terms of time to reach consensus.

This warrants some reflection. The conclusion we reached, was that in order to affect the time to reach consensus SAs must widen the distribution of views. It does not matter what view they put forward (left or right of an issue); what matters is that the overall distribution of views widen. That is, the actual position that is taken (left or right) does not matter in terms of the time to reach consensus, since both these views will widen the overall distribution of views. If the agents are coordinated to the extent that they take position on the same side of a topic (say right) then they will widen the distribution of views *and* shift the consensus view, see Figure 12.

3.2 Level of Control

In this subsection we investigate the ability of SAs to control the outcome of a decision. We define a goal, one that is sufficiently far away from the starting conditions that achieving it is a clear indication of control over the group by the SAs. We are interested in what the boundary conditions are for allowing such control and to what extent the SAs can achieve these goals.

We define a target for each topic, k, that is 6σ away from the initial group mean view on that topic. SAs still have to stay within the boundaries of $\hat{u}^k < b^k < 2$ to prevent detection. We vary the number of agents and the relative subversive positions they take.

This is a theoretical exercise to test control (hence pushing decisions in only one direction). Such a situation is not realistic in the real world, however, in the real world SAs can use their influence to not only delay decisions but also strive to achieve a specific

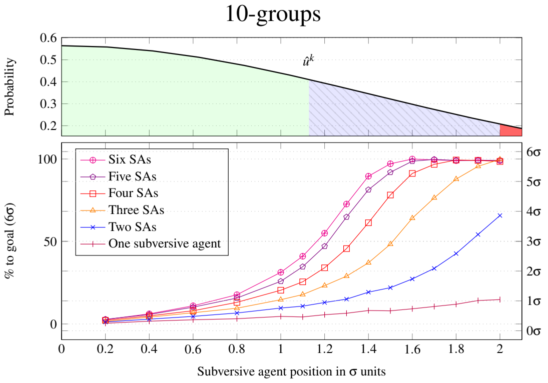

Figure 13: Graphs of the % that SAs can move the outcome of a consensus process relative to a goal of 6σ. The group size is ten members.

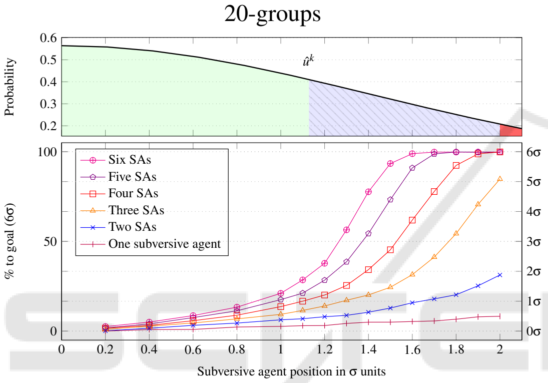

Figure 14: Graphs of the % that SAs can move the outcome of a consensus process relative to a goal of 6σ. The group size is twenty members.

outcome.

The main point is that SAs will often strive for a specific outcome, and if that outcome is reasonably within the scope of the original set of views, then it will be easy for them to achieve while still delaying the project.

The first set of simulations that was constructed focused on the effects that SAs can have when working together in controlling the outcome of the consensus process when they operate within the $b_s^k < \hat{h}^k$ range (🟩 in Figure 3, 4, 12, and of interest here 13 and 14).

For these simulations, the delays in reaching consensus are not of interest.

We believe there is a definite theoretical boundary where the SAs can fully control the consensus process, which means they can both control the time to reach consensus, stretching it out as long as they want and control the final outcome of the process.

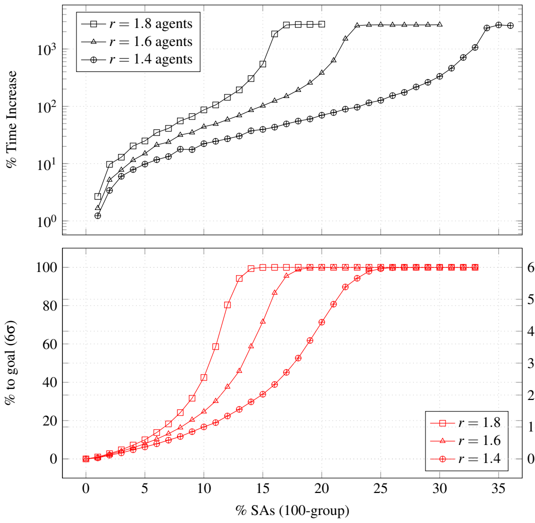

Figure 15: Subversive agents as percentage of total team members. The top graphs show how much they can delay the consensus process and bottom graphs show how much they can influence the outcome.

In a conventional consensus process through meetings and discussion, the distribution of views contract over time and this contraction can be seen as a force closing the distribution of views, p^k in Figure 12. Similarly the SAs, during the same process, acts like a force pushing the distribution wider, q^k in the Figure. Therefore, as long as the p^k, the closing force from all the conventional team members is greater than q^k, the force from the SAs, the process will reach consensus, though taking longer than without SAs. In a scenario where $p^k < q^k$ the SAs have great control over the outcome, both in terms of time to reach consensus and also the overall outcome.

3.3 Group Control and Delays

In this sub-section the ability of SAs to delay the process but also control the outcome is investigated. Here we will are interested in the effects as a function of the % of SAs in the group.

Since it should be clear by now that if there are sufficient SAs present then they can delay the consensus process indefinitely. To constrain the simulation we curtail the SAs to stop their antics once a project had been delayed by 2500%, that is, by a factor of more than 20.

The group-size is kept at 100, and the number of SAs are increased from 0. Also, the positions that the SAs occupy are varied ($r = 1.4, 1.6, 1.8$).

The questions we then want to answer here are how much control does the SAs have, as a function of the group make-up, over the (a) outcomes and (b) total project times.

The results from these experiments are shown in Figure 15. The top graphs show that for $r = 1.8$ the SAs gain full time-control when there are more than

16% SAs. For $r = 1.6$ and 1.4 full control is gained at 23% and 34% respectively.

This should however be seen in context since these measures are for a more than 20 times delay. If the benchmark is a more reasonable 100% delay in time to reach consensus, then for $r = 1.8, 1.6, \text{and} 1.4$ the resulting number of SAs needed are 10%, 15%, and 23% respectively.

The bottom graphs in Figure 15 shows the level of control that the SAs can exert on the final outcome, similar to the measurements from the previous section. Again, shifts in position are capped at 6σ. SAs can reach this benchmark when 14% SAs are present for $r = 1.8$. This changes to 17% and 25% for $r = 1.6$ and 1.4, respectively.

4 DISCUSSION

We started off with the simple assumption that the delivery of a project is fundamentally a series of consensus-seeking processes. We assumed all team members are cooperative and work under assumptions of good-faith on the part of other members.

However, the introduction of a subversive agent that pro-actively tries to influence other members towards views that are plausible yet create more debate has a significant impact on the time and effort to reach consensus. This was surprising.

The initial distribution of views has the effect that SAs have a much wider range of views to promote and thus we see that the influence of SAs are strong initially but as the consensus distributions contracts the SAs also loose their ability to influence. The influence of SAs are stronger in the earlier parts of the consensus process, Figure 6.

Yes-agents can significantly improve consensus times, however, since they are actively lobbying for the group mean view (or any other specific view), they can also cause the group to abandon valid views thus increasing the probability that the wrong decisions are reached. This is obviously not a new discovery; yes-agents have been used to sway decisions for all of recorded history (Browning, 2010).

However, when SAs operate to increase the range of options or act to polarize the group then the impact on the time to reach consensus can be significant, Figures 8 and 9.

An interesting result from this study was that the level of cooperation and synchronization between SAs do not have a significant impact on the time to reach consensus. That is, SAs acting as a group, or acting in isolation have the same effect as measured by consensus time. However, SAs acting in a coordinated way can significantly influence the outcome of a decisions, even if the SAs form a small minority in the group, Figures 14 and 15.

Under the right conditions a small minority of SAs (say 10%) can have a significant impact on the time to reach consensus, extending it by as much as 100% (doubling the time it would have taken), Figure 15 (top). Surprisingly, a small number of SAs (20%) can indefinitely stall the consensus process. A slightly bigger SAs group of 20% of the group membership can have effects ranging from a doubling of the time to reach consensus ($r = 1.4$) to indefinitely delaying consensus ($r = 1.8$).

5 LIMITATIONS

We would like to point out some limitations to this approach and results. Firstly, this is a theoretical model showing what is possible with consistently operating subversive agents. Reality may be vastly different and more complex. Secondly, we see a specific topic, say k, as a single atomic topic with a single outcome. In reality this topic may consist of many sub-topics, and the actual complexity of a project is much greater than what we model. The sub-topics issue is less of a problem since that strengthen the Gaussian distribution assumptions we made. We do not think the results will differ if the problem size is increased, as we have demonstrated in an earlier paper (Vorster and Leenen, 2023), however, other researchers should verify this.

Lastly and perhaps the most important limitation is that it will be difficult to verify these results in real-world projects, since subversive agents are by definition hidden. Any team member may act as a subversive agent due to being disgruntled or a host of other reasons. One way to verify these results would be to insert such an agent into 'play' projects, an interesting topic for Social Psychology research.

6 CONCLUSION AND FUTURE WORK

In this paper we investigated the effects that subversive agents may have on consensus processes and in particular the speed of project delivery if a project is seen as a series of consensus-seeking processes.

The important results are that even small numbers of SAs can have a significant effect on the time it take a group to reach consensus. The delay effects of SAs are most significant during the earlier parts of the consensus process. SAs need not coordinate to achieve significant delays but, if they do coordinate, they can both delay the process significantly and also have a significant influence on the decision outcomes (controlling which decisions are finally made).

A small number of SAs, as little as 10% can, under the right conditions, double the time to reach consensus (and thus also doubling the cost, as a measure of effort).

A group of well coordinated SAs that make up more than 20% of the group can cause delays ranging from about doubling the time for project completion to completely stall projects.

As future work we propose Social Psychology research experiments to covertly observe the behaviour of a planted agent within a mock project and the effect this could have. For one, can such an agent stay hidden, what would be good strategies for subverting team members, and, when to give up being subversive, since our research suggest most of the damage had been done about halfway through the project, and thus that seems to be a good point in time to stop being subversive, or at least reduce risk of detection by being more cooperative.

From a computational intelligence perspective, extending a multi-agent system with AI-based subversive behaviour could yield more complex strategies; and, ways to address such behaviour, both form a detection as well as a mitigation perspective.

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