Modelling Police Community Support Officer Management by Agent-Based Simulation

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Abstract

Complexity theory within public management is becoming a recognised field, but currently without consensus about the contribution it could make to theory and practice. This paper suggests a promising route to engage with management practitioners, in this case within policing by the use of agent-based simulation of a policing team subject to policy changes. Policing has fractal self-similar management structures at all levels.

A general methodology is presented to explore the motivational consequences of policies at all levels in these complex multilevel systems as an alternative to 'point-in-time' staff surveys. It is illustrated by the motivation of Police Community Support Officers (PCSOs) at the front line of the police management hierarchy. The computational model is based on qualitative team dynamics data collected using Grounded Theory. This produced 'behavioural codes' for aspects of PCSO work, the most prevalent six being taken forward for simulation design: ***P****urpose (feedback on role)*; ***A****vailability of supervision and support*; ***T****hreat and risk of harm*; ***R****elevance to role*; ***O****rientation in relation to geographic responsibility*; and ***L****one working (patrolling)*. The first letter of each phenomena (a vertex) gives the acronym PATROL (a simplex). This greatly facilitated the design and implementation of the simulation and subsequent communication with practitioners. These simplices are highly non-linear in their impact on motivation. We created an interactive computer simulation of the PCSO task execution system, where each task is a combination of simplices called a *hypersimplex* (a 'system of systems').

To model motivation and demotivation PATROL simplices are mapped to an ordinal *emoticon scale*. Combinations of emoticons are mapped into a sequence of pair-wise connected local *attractors* in order of increasing motivation. PCSO motivation tends to stay in these 'basins of attraction' by forces driving it away from adjacent attractors. The boundaries between attractors are characterised by *tipping points*. Generally, the PCSOs' motivation stays in the central attractor or above for normal empirically validated settings, based on published job satisfaction survey results. However abnormal situations, such as the sustained absence of sergeant supervision can drive motivation over the tipping points into lower states. Such low motivation has implications for performance, sick leave and retention, and may influence other PCSOs. Modelling PCSO motivation dynamics and computer simulation provide a step towards improved management procedures that avoid unnecessary demotivation. The simulation allows the possible outcome of policies to be explored *before* they are implemented.

Keywords: complexity theory; agent-based simulation; policing; change management; policy

1. introduction

Management involves designing and implementing polices to give desired outcomes. But how can the mangers of complex multilevel organisations know that an intervention will have the desired outcome and not undesirable unexpected consequences?

One approach to this question coming from the science of complex systems is *agent-based computer simulation*. This paper seeks to offer an example of this promising route to engage with management practitioners by the use of agent-based simulation of a policing team subject to policy changes. We focus on the motivation of Police Community Support Officers (PCSOs) at the front line of the police management hierarchy. Policing has fractal self-similar management structure meaning that the approach can be applied at all levels in the organisation.

The computational model developed is based on qualitative team dynamics data collected using Grounded Theory. This produced 'behavioural codes' for aspects of PCSO work, the most prevalent six being taken forward for our simulation: *__P__urpose (feedback on role)*; *__A__vailability of supervision and support*; *__T__hreat and risk of harm*; *__R__elevance to role*; *__O__rientation in relation to geographic responsibility*; and *__L__one working (patrolling)* The first letter of each of these gives the acronym PATROL. This acronym greatly facilitated the design and implementation of the simulation and subsequent communication with practitioners.

An innovative feature of this research is the explicit recognition that the *combination* of these PATROL features in a task has implications for motivation beyond the individual features – *the whole task is more than the sum of its parts*.

We model this using the mathematical concept of *simplices* in *hypernetworks*. These are very simple building blocks in social systems and are just a generalisation of nodes and links in networks. For example, a task involving the demotivating `this is not my role' feature < R > is even more demotivating when combined with the demotivating 'outside my patch' feature < O > as 'this is not my role *and* it's taken me away from my patch', < R, L >.

The individual features <P>, <A>, <T>, <R>, <O> and <L> are called *vertices.* Combinations of vertices such as <T R O L > are called *simplices*. The <T R O L> simplex combines a potentially dangerous task <T> that the PCSO thinks they should not be doing <R> taking them away from their usual patrol area <O> undertaken alone <L>. Demotivation is an *emergent feature* of the combination of *all* the vertices. The whole simplex is experienced as a whole or a Gestalt. These simplices are highly non-linear in their impact on motivation.

To model motivation and demotivation PATROL simplices are mapped to an ordinal *emoticon scale*, ☹̲ < ☹ < 😐 < ☺ < ☺̲. We use emoticons rather than numbers such as -2, -1, 0, 1, 2 because we think motivation cannot be quantified in this way. For example, methods that use numerical scales often use arithmetic operations such as (-2) + (+ 2) = 0. In contrast the combination of ☹̲ with ☺̲ is not equivalent to 😐. We use the emoticons to rate the PATROL tasks. Tasks with few negative features tend to be rated ☺ or ☺̲ while those with many negative features ten to be rated ☹ or ☹̲. The PATROL simplices used in this study were rated on the emoticon scale by the PCSOs we interviewed. This shows that the approach is operational.

Another innovation in this study is the definition of a motivation scale as five *attractors* denoted by the symbols Ω < ψ < M < B < A (Omega, Phi, Mu, Beta, Alpha). Each of the attractors has a set of ten internal states. A PCSO's motivation varies between these states within an attractor depending on the positive or negative rating of the tasks they do. However, it is unusual for a PCSO's motivation to jump into an adjacent attractor. This reflects a hypothesis that motivation may be subject to minor fluctuations but tends to stay in these 'basins of attraction'. Occasionally tipping points are passed as a major change in motivation from one attractor to another.

Generally, a PCSO's motivation stays in the central Mu attractor for empirically validated normal settings. However abnormal situations, such as the sustained absence of sergeant supervision can drive motivation over the tipping points into lower states. Such low motivation has implications for performance, sick leave and retention, and may infect other PCSOs.

Modelling PCSO motivation dynamics and computer simulation provides a step towards improved management procedures that avoid unnecessary demotivation. Simulations allows the possible outcome of policies to be explored *before* they are implemented. The simulation presented here is in early stage of development. It gives interesting and promising results but these have to treated with caution and the paper ends with a critical discussion and open questions for further research. The objective of our research is the creation of an operational methodology for the management of social systems that can be realised as practical tools that managers find useful.

2. The Police Community Support Officer System

Community-focussed work can be very time consuming for highly trained police officers and in 2002 the then Home Secretary, David Blunkett, introduced the role of *Police Community Support Officer*, PCSO, as part of the Government's new Neighbourhood Policing Programme.

The main role of PCSOs is to help the police tackle low-level crime, anti-social behaviour and nuisance and to reassure the public by providing a visible police presence. Uniformed officers patrol the community on foot, engage with and get to know the community, provide an accessible point of contact between the public and the police, and help local people feel more secure. Greater Manchester Police invested heavily in PCSOs and they now form an integral part of local policing, as replicated in all 43 forces in England and Wales (Davies, 2018).

The community-based structure of PCSOs has been selected for this research due to the abundance of replicated teams across the sample organisation, Greater Manchester Police, and the topical policy debate on their role. Policy makers at all levels are considering major revisions to PCSO job duties and responsibilities, particularly during the response and recovery from the Covid-19 pandemic. An opportunity therefore presented itself to test the hypotheses within this environment and the Rochdale District command team volunteered to support this collaboration with the Open University Centre for Police Research & Learning.

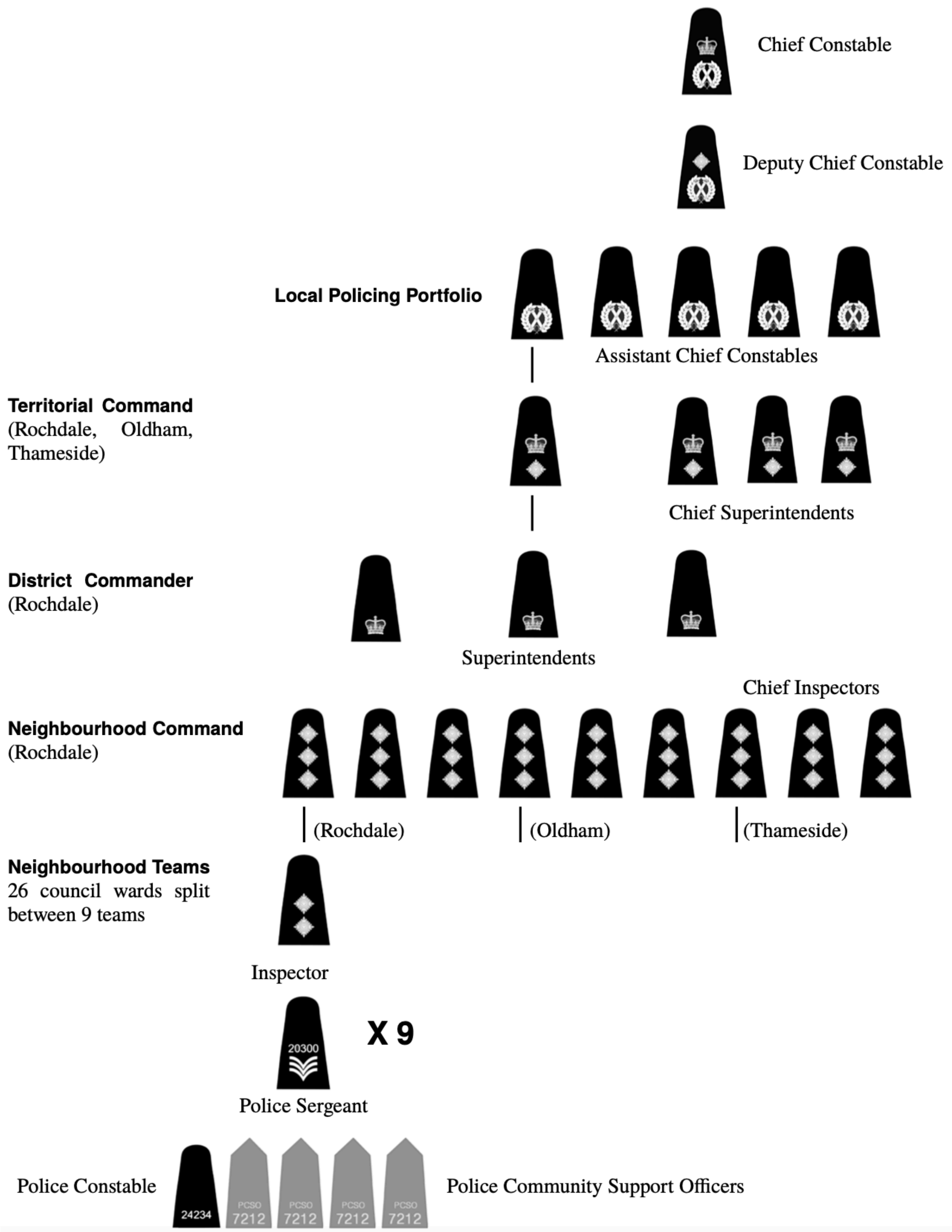

Fig. 1 Rank Structure Fractal for Rochdale District in GMP (Davies 2020)

The policing system could be described as 'fractal' because it has self-similar structures at higher and lower levels of aggregation. For example, at the policing 'front line' level PCSOs form teams with their supervising sergeants, who in turn report to Inspectors. At a District Command level teams of Inspectors form management teams with Chief Inspectors and Superintendents. At the executive level District and Branch Heads (Chief Superintendents or police staff equivalent) are part of the Force Leadership Team supporting the Chief Officers as shown in Figure 1. This fractal structure suggests that our approach could be applied at all levels of management with the police.

3. Complexity Science and Management of Change in Public Organisations

There is no widely accepted definition of 'complex' but some easily recognised features can make systems complex. These include: many heterogeneous parts; unexpected or unpredictable emergence; sensitive dependence on initial conditions; path-dependent dynamics; network connectivity; dynamics emerge from interactions of autonomous agents; self-organisation into new structures and patterns of behavior; non-equilibrium and far-from equilibrium dynamics; adaptation to changing environments; co-evolving subsystems; ill-defined boundaries; and multilevel dynamics (Johnson, 2010).

All social systems are sensitive to initial conditions and it is impossible to predict that they will be in a particular state at a particular time. However, it is possible to identify states they may have at future times, and computational modelling may be able to identify those future states that are more or less likely.

Agent-based simulation is a computational method that enables researchers and policy makers to create, analyse, and experiment with models composed of agents that interact within an environment (Gilbert and Troitzsch, 2011). At its simplest, the agents (usually people) and other parts of the system are represented by a description of their *state* at time t. *Transformation rules* are used to compute the change of these states between time t and the next 'tick of the clock', $t + 1$.

New system states *emerge* during computer simulation and sometimes this is the only way to investigate future behaviour since there is no set of equations that can be solved to predict the behaviour of the system. There is little literature on agent-based simulation directly related to policing (Davies, 2020) and examples that do exist rely on data gathered from technology carried by officers (e.g. radios) rather than their human experiences of patrolling (Melo et al., 2005), (Wu and Lou, 2010), (Zhang and Brown, 2013). The study reported here is one of the first to investigate the application of agent-based modelling to UK policing.

4. Motivation Dynamics and Complexity Theory

Work motivation is widely covered in both managerial and psychological disciplines. A common goal is exploring 'why people do what they do' in order to use management theories to improve performance in the workplace. (Grant and Shin, 2012) define work motivation as 'the psychological processes that direct, energise, and maintain action towards a job, task, role or project'.

Motivation is a human emotional response to internal and external stimuli. It is dynamic, non-linear, heterogeneous, sensitive to conditions, and is influenced by complex social interaction which some would describe as 'emotional contagion' (Hatfield et al., 1994).

A context sensitive model able to identify employee mood before a 'tipping point' such as a demotivated employee resigning is reached would be useful for policy makers. The stressors and de-motivators of a member of police staff will have a different context to those of a health worker or teacher for example.

Identifying motivators and de-motivators is an important step in understanding their impact on employee outcomes (Lepine et al., 2005). Challenge stressors create opportunities for employees' work-related accomplishment and personal development; hindrance stressors constrain or interfere with an individual's work accomplishments (Cavanaugh et al., 2000).

For our study the theoretical framework of (Herzberg, 1968) was aligned to the practicalities of finding a reliable data source for a simulation. Herzberg's findings (Mullins, 2002) suggested that the factors involved in producing job satisfaction and motivation (growth factors of achievement, recognition and advancement) were separate and distinct from the factors that lead to job dissatisfaction (hygiene factors of company policy, supervision, working conditions). This provided a series of behavioural themes for forming the questions to be asked of participants in our study.

(Howard, 2006) describes negative and positive emotional attractors triggering a situational response, referencing *Intentional Change Theory*. The positive helps recover from negative emotional experiences and crises and 'keeps us grounded'. The negative calls attention to behaviours and events that compromise effectiveness and 'threaten our safety'. Co-occurring positive and negative emotional appraisals helps us to understand and respond to environmental complexity and can provide leverage for emotional regulation.

Waninge in (Dörnyei et al., 2014) states that a key characteristics of motivation as a dynamic system is that it displays ongoing change on the one hand, while it is also characterised by occasional states of stability on the other.

Motivation has been demonstrated to fluctuate over time (MacIntyre & Serroul, same volume) yet it also tends to self-organise and settle into relative stable attractor states (Hiver, same volume).

(Boyatzis, 2006) applies complexity theory to conceptualise individual change, in particular non-linear and discontinuous dynamical systems including tipping points; self-organising into patterns of equilibrium or disequilibrium through the pull of specific attractors; and fractals or 'multileveledness'.

Changes in an individual's behaviour, thoughts, feelings or perceptions are non-linear and discontinuous. Although a person's psychological state and performance may appear unrelated, once a specific point is reached, a discontinuity can occur. Then the effect of a small incremental increase in the person's behaviour can produce a dramatic increase in effectiveness.

This literature supports the way we define our ordinal motivation scale in Section 8.

5. Gathering appropriate data on motivation for the simulation

There was no existing data suitable for our proposed computer model. The only available data relevant to study was the GMP annual staff survey which asked 3 sets of questions to provide an overall aggregate scoring for 'Public Service Motivation', Job Satisfaction' and 'Hindrance Stressors', (Fig. 2). Although interesting, these ‘static snapshot’ data are not useful for simulating motivation dynamics, asking participant ‘how they feel on a scale of 1-7’ at a point in time. In the absence of useful data, we investigated possible quantitative and qualitative sources.

Measure	COM	Salford	Tameside	Stockport	Bolton	Wigan	Trafford	Bury	Rochdale	Oldham
Public Service Motivation	5.51	5.47	5.56	5.56	5.43	5.44	5.44	5.54	5.51	5.46
Job satisfaction	4.95	5.04	5.04	5.04	4.26	4.63	4.67	4.87	4.93	4.96
Hindrance Stressors	3.13	3.00	3.04	3.26	3.17	3.10	3.04	3.27	3.08	3.00

Figure 2: Summary extract of GMP Staff Survey 2019

Motivational variables can be abstracted from self-reporting in surveys on occupational preferences. Whilst popular due to the ease of construction, scoring, and reliability, such methods are far from perfect predictors of choice with many investigations showing negligible relationships between the attitudes of persons, based on self-reports, and overt behaviour (Vroom, 1964).

System dynamics is interested in the collection and analysis of qualitative data for modelling purposes. (Luna-Reyes and Andersen, 2003) identify that although system dynamic models are mathematical representations of problems and policy alternatives, most of the information available is not numerical in nature. (Coyle, 2000) observes quantification may create model outputs that are misleading.

For our study, Classic Grounded Theory (CGT), as devised by Glaser & Strauss (1967) cited in (Birks and Mills, 2015) was used to gather the data. Grounded Theory is an inductive methodology suited to researching new areas, aimed at identifying participants' main concerns and developing a theory that explains their behaviour.

Whilst the aim of this project is not to provide a theoretical explanation of officer behaviour, it does require a method of categorising such behaviour in a manner that allows translation into a valid simulation, and it this can be successfully completed using Grounded Theory. In addition, the end product of Grounded Theory provides a conceptual narrative to the identified categories that is abstract of specific people and places, allowing for future simulations beyond the initial parameters encapsulating more the complex system in scope. Grounded Theory is contested (Bryant and Charmaz, 2007) but (Adams, 2018) highlights a number of strengths of Grounded Theory in dealing with complex phenomena.

For our study semi-structured interviews of 10 PCSOs in Rochdale District in Greater Manchester were undertaken in the summer of 2018. This represented a 16% sample of all the PCSOs in this district. The questions were based on topic areas from Herzberg developed as a conceptual framework for the study.

1. Tell me about your role and your main responsibilities in the team

2. How is it decided what you do on a day-to-day basis?

3. Who reports to you, and who do you report to?

4. Describe other connections in your role that are not direct reporting lines.

5. Amongst your day-to-day activities, what do you like the most?

    (a) What do these activities have that make you like them?

6. Amongst your day-to-day activities, what do you dislike the most?

    (a) What do these activities have that make you dislike them?

7. What are the things that help you do your job?

    (a) Why are they important to you?

(b) Are there any policies or rules that support this?

8. What are the things that hinder you doing your job?

(a) Why do they impact you?

(b) Are there any policies or rules that compound this?

9. What works well in your team?

(a) Are there any personal dynamics that support this?

(b) Is there are particular interaction you have that you like?

10. What doesn't work well in your team?

(a) Are there any personal dynamics that compound this?

(b) Is there are particular interaction you have that you don't like?

11. When you are asked to change how you work, how do you feel?

(a) What makes you feel better about change?

(b) What makes you feel worse about change?

12. Does job satisfaction play an important part in how you feel about work?

13. Does job security play an important part in how you feel about work?

14. Are you comfortable with your level of responsibility?

(a) Do you want more?

(b) Do you want less?

15. If you were paid less, would it impact how you work?

16. If you were paid more, would it impact how you work?

17. Are you recognised for the work you do?

6. Fieldwork Results and Analysis

All the interviews lasted about 45 minutes, and were recorded, transcribed and analysed by hand. The interviewer, Davies (a police Chief Superintendent), selected staff members with no prior working relationship to him and undertook the interviews in civilian clothing. Davies had previous experience of working within a neighbourhood team and having strategic responsibility for PCSO resources in a neighbouring District to support recognition of colloquial terms.

The coding procedure involved different stages, in line with the classic grounded theory method. Firstly, the interviews were open coded (summarised with key phrases) to explore in detail the empirical material. This resulted in a long list of 1,319 codes. Secondly, axial coding was completed to assess overlapping responses and to identify differences in the data, allowing loose grouping to form. This created a collation of concepts of the experiences of the PCSOs.

Finally, the axial coding was grouped into categories under selective coding. Example of this are given in Figure 3 describing the concept of geographic alignment. This illustrates these codes for the high-level construct of *geographical alignment.*

Typical behavioural codes	Typical axial codes	Typical selective codes
Area (beat) assignment Requests for community visits Rules on allocating area broken Sticking to own never happens Patrolling allocated beat Going where the problems are Proactive seeking of problems Attraction to hotspot areas Finding work (for us) Unfamiliar beats unwelcome Beat ownership builds contacts, relationships, and knowledge Required to deliver on the role Investment in our beats Random patrolling lowers morale Pride in beat knowledge Role needs eat knowledge Public reassurance is nice Visits seen as important Visits make people comfortable Our area is not patrolled Covering another's area is a chore Approaches by public welcomed Frustrated when outside my area	Geographic ownership and control appear to be important, and frustration is expressed when tasks take the PCSO away from their area of responsibility. Local knowledge is clearly valued and boasted about and seen as vital to deliver core services. Being assigned duties in areas where knowledge is poor is seen as inefficient use of their time. Identifiable core tasks are often linked to physical locations and contacts on the beat, and there is a strong focus on being visible to the public. Crime and anti-social behaviour hotspots are a focus for PCSOs and they will actively target them on their area.	*Geographic Alignment* An agent's motivation to work in the system is influenced by presence or tasking on their allocated area of responsibility, which builds over time.

Figure 3: Extract from grounded theory data coding (Davies 2018)

This process created 18 phenomena, as presented in Figure 4. Each category provided a simulation requirement. The top six most prevalent categories were taken forward to the simulation design phase on the basis of providing meaningful multi-dimensional complexity without over-complicating the experiment to a point where verification and validation of the prototype model became unachievable.

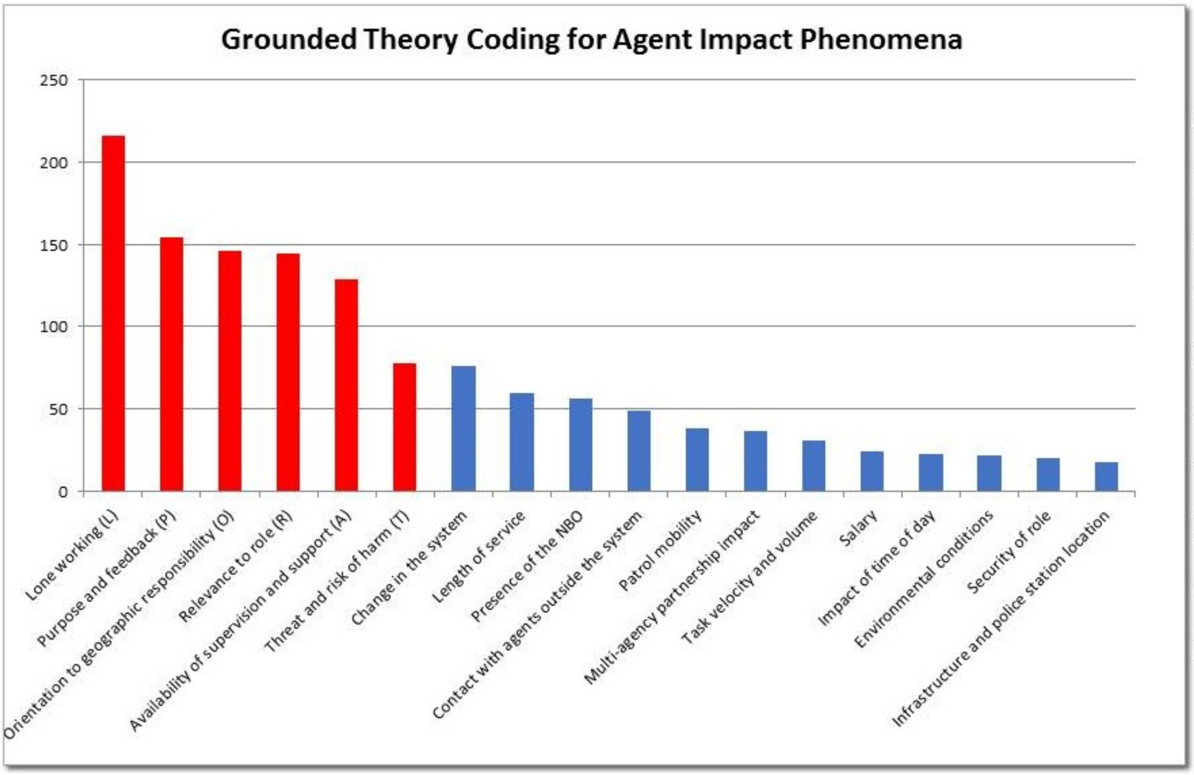

Figure 4: Summary of Categories from selective coding process (Davies 2020)

The first six of these categories were taken forward to investigate the motivation dynamics of the PCSOs as listed below on the left followed by their identifying letter in parentheses. The categories can be reordered so that their codes create the acronym PATROL:

P urpose and feedback

A vailability of supervision

T hreat and risk of harm

R elevance to role

O rientation to geography

L one working

Davies explains the PATROL variables as follows:

P = Purpose (feedback on role)

This category was originally called 'visibility of impact' but later called 'purpose' in the simulation design. It established a concept for PCSOs that feedback is needed to maintain motivation to work. This comes from task completion and interactions with the public through presence on their beat. This category was created from four axial coding concepts at the next level down in detail;

(i) pride in role

(ii) satisfaction from results

(iii) community perception impacting difficulty of role

(iv) feedback from supervisors

A = Availability of supervision and support

This category referred to the importance of the Sergeant on the team. In most neighbourhood teams in GMP a group of Police Constables and PCSOs are led by a uniformed police sergeant with responsibility for a geographic area. Interview subjects made direct references to the presence and absence, or effectiveness and ineffectiveness of the Sergeant having a bearing on their motivation and their effectiveness, even if the presence is via telecommunications instead of physical presence. Four axial coding concepts make up this category;

(i) absence of a supervisor regarded as a negative factor on work;

(ii) identification of effective Sergeants as proactive, supportive and protective

(iii) colloquial behaviour of Sergeants benefits their own team but not others

T = Threat and risk of harm

This category involved perception of risk whilst on patrol. Subjects demonstrated less motivation to patrol high crime areas without a colleague, or communities where the relationship with police is tense. Time of day and distance from the safety of the police station compound this. This proposition was developed from four axial coding concepts;

(i) personal safety when set solo tasks

(ii) geographic areas where greater confrontation occurs

(iii) time of day

(iv) distance from the police station or other staff for support and back-up

R = Relevance to role

This category relates to the official core role of a PCSO as defined in the GMP job description. The subjects' responses to questions clearly identified a collective view of a PCSO's role and how it is changing. If a PCSO is set a task clearly in the remit of a Police Constable or another agency, resentment will cause a reduction in motivation. This was observed to increase over time as the PCSO ages and becomes more experienced based on the responses from different demographics. This category was developed from three axial coding concepts, made up of 108 codes;

(i) clear role definition and allocation of Constable tasks;

(ii) acknowledgement system demands are changing their work;

(iii) disgruntlement at no rank progression in the PCSO role.

O = Orientation in relation to geographic responsibility

This category was a frequent reference to the importance of geographic ownership; '*e.g.* my patch, my beat, our community'. The PCSO's motivation to work in the system is influenced by presence or tasking on their allocated area of responsibility, which builds over time. Three axial coding concepts made up this category;

(i) the importance of ownership and it being taken away

(ii) the value of local knowledge

(iii) Core tasks and visibility at identifiable landmarks and locations

L = Lone working

This category involved the proximity of a colleague and how their actions and motivation impacted on the interviewee. A PCSO in close proximity to another PCSO demonstrating positive motivation will have a secondary effect of motivation on them. Conversely negative motivational effects also apply. This proposition was developed from four axial coding concepts;

(i) team dynamics;

(ii) influential team members;

(iii) impact of negative behaviour

(iv) isolation reduces motivation to complete tasks.

These terms correlate to Herzberg's growth and hygiene factors although the interpretation of levels of importance is specific to the sample group, as Herzberg would place all growth factors (**P**, **R**, **O**) above hygiene (**A**, **T**, **L**) in his model, whilst the respondents clearly articulated factors linked to the policing environment.

7. The PATROL hypersimplices

Let the elements P, A, T, R, O and L form a set of *vertices* to describe a task allocated to a PCSO. A task with all these vertices is a six-vertex *hypersimplex*, as shown in Figure 5. Each of the vertices is potentially demotivating, but the combination of them all gives the *ultimate demotivational PATROL hypersimplex*.

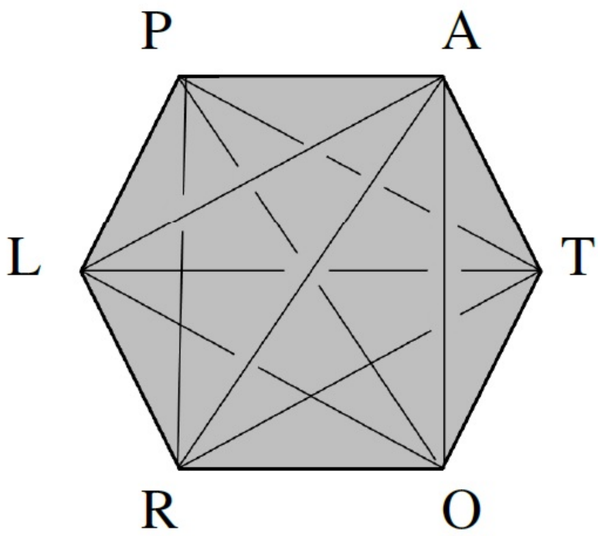

Figure 5: The ultimate demotivational PATROL hypersimplex

The hypersimplex represents the basic unit of a task within the system impacting the PCSO, or agent. There are 64 hypersimplex combinations available. At its simplest a *team* of five PCSOs is supervised by a single sergeant in this simulation. The sergeant allocates a set of eight *tasks* to the individual PCSOs for their daily eight-hour *shift* and debriefs them at the end of the day. Tasks are randomly generated from the vertices of the 64 hypersimplices.

Each task involves a combination of the PATROL vertices as a hypersimplex, *e.g.* < T, O, L >. This means the task carries a threat of danger (T), the task is outside the PCSO's area of geographical responsibility (O), and the PCSO is patrolling on their own (L). All 64 hypersimplices were provided with a contextual narrative to support communication with practitioners and policy makers. Each one was validated by a Neighbourhood Sergeant who was previously a PCSO, and the PCSO union representative who is a serving PCSO in Rochdale.

Davies gives the following example of a task with the hypersimplex < P, A, T, R, O, L > which resonated strongly with the practitioner validators:

There is currently no sergeant for our team (A) following a personnel move, and this has reduced the focus of the team on good community work, and we have become more and more responsive to the radio dispatcher who has been sending us to all manner of jobs just to reduce the calls for the service demand queue. I do not feel I am spending enough time on my beat on longer-term problem-solving initiatives. Today I was sent to a dispute between two neighbours quarrelling over a boundary issue on someone else's beat (O). When I arrived, they were in a heated argument and it became physical. I was in fear for my safety (T) as I was on my own (L) but managed to separate them and get them inside each of their houses, where I spoke to them individually. Both were abusive and did not respect my authority (P). One called me a 'plastic copper'. I felt like I was wasting my time (R).

8. The Ordinal Emoticon Motivation Measurement Scale

The five-point ordinal *emoticon scale* used to rate the PATROL hypersimplices is shown below

☹ ☹ 😐 ☺ ☺

Fig. 6 The five-point ordinal emoticon motivation scale

The emoticon scale is used to rate PCSO tasks according to their levels of demotivation and motivation. ☹ means a particularly demotivating task while ☹ means a less demotivating task. **A** *positive task* is ranked as ☺ and the emoticon ☺ signifies the most positive tasks.

Based on the PCSO interview data each of the sixty four PATROL hypersimplices was mapped to the five-point emoticon scale, as shown in Table 1.

☺ < >	☺ <O>	☺ <L>	😐 <OL>
☺ <P>	😐 <PO>	😐 <PL>	☹ <POL>
☹ <A>	☺ <AO>	☺ <AL>	😐 <AOL>
☹ <PA>	☹ <PAO>	☹ <PAL>	☹ <PAOL>
☺ <T>	☹ <TO>	☺ <TL>	😐 <TOL>
😐 <PT>	😐 <PTO>	☹ <PTL>	☹ <PTOL>
😐 <AT>	😐 <ATO>	☹ <ATL>	☹ <ATOL>
☹ <PAT>	☹ <PATO>	☹ <PATL>	☹ <PATOL>
☺ <R>	😐 <RO>	😐 <RL>	☹ <ROL>
☹ <PR>	☹ <PRO>	☹ <PRL>	☹ <PROL>
☹ <AR>	😐 <ARO>	😐 <ARL>	☹ <AROL>
☹ <PAR>	☹ PARO>	☹ <PARL>	☹ <PAROL>
☺ <TR>	☹ <TRO>	☹ <TRL>	☹ <TROL>
☹ <PTR>	☹ <PTRO>	☹ <PTRL>	☹ <PTROL>
☹ <ATR>	☹ <ATRO>	☹ <ATRL>	☹ <ATROL>
☹ <PATR>	☹ <PATRO>	☹ <PATRL>	☹ <PATROL>

Table 1. The PATROL simplices and their emoticon ratings

Most of the time PCSOs undertake motivating tasks, with demotivating tasks occurring less often. This positive-negative split underlies the *status quo* that most PCSOs take pride in their work, are satisfied, and are well motivated, as indicated by the GMP staff survey.

9. The simulation program

The human agents in our model are groups of five *PCSO*s supervised by a *Sergeant*. The Sergeant allocates eight policing *tasks* to each PCSO each working day.

As explained previously there are six PATROL variables. Each patrol variable has default frequency:

P	A	T	R	O	L
30%	20%	20%	30%	20%	40%

so that 30% of tasks lack **P**urpose (feedback on role), 20% lack **A**vailability and Support, 20% involve a **T**hreat and risk of harm, 30% lack **R**elevance to the role, 20% have inappropriate geographical **O**rientation taking a PCSO away from their ‘patch’, and 40% involve **L**one working.

Although we usually do not make it explicit, the *absence* of a PATROL vertex can have a significant impact on motivation. For example, PCSOs like very much to patrol with a colleague and ‘not L’ is very motivating. The symbol ~L is used to represent this. Then, for example, <~~P ~A ~T ~R ~O ~L > is a task with no negative features and could be called the *perfect task*. In contrast < ~P ~A T R O L > is a demotivating task but the combination of negative vertices is mitigated by good feedback <~~P> and good supervision and support from the sergeant <~~A>. For this reason the PCSOs rating the simplices gave <T R O L> (or more explicitly < ~P ~A T R O L >) a ☹ rating rather than the ‘double-frowny’ rating ☹̲.

The ratings { ☹̲, ☹, 😐, ☺, ☺̲ } form a five-point ordinal scale with ☹̲ < ☹ < 😐 < ☺ < ☺̲. This is very different to 5-point numerical scale such as { 0, 1, 2, 3, 4 }.

In the current version of our model a PCSO’s motivation is adjusted each day depending on the tasks done. Suppose the eight tasks each had the emoticon rating (☺̲, 😐, ☹, ☹̲, ☺, 😐, ☹̲, ☺̲). What is the score for the whole day? If the day had been rated with numbers, (4, 2, 1, 0, 3, 2, 0, 4) it could be assigned the score (4 + 2 + 1 + 0 + 3 + 2 + 1)/8 = 2. The score of 2 is equivalent to 😐, and this suggests an ‘average day’. However, this day has involved 2 very bad tasks rated ☹̲ and one bad task rated ☹. It also involved 2 very good tasks rated ☺̲ and a good task rated ☺. This has not been an uneventful average day – it has been a day of mixed highs and lows. No single number can represent this. However, the emoticons can be counted to give 2☹ + 1☹ + 2😐 + 1☺ + 2☺ as the score for the day. This is much richer than the number 2.

The literature on motivation generally allows that a person can be more motivated or less motivated at any particular time. So, if motivation can be measured at all, it can be measured on an ordinal scale. The literature gives little guidance on how the concept of motivation can be represented and processed in computers. So, our starting point is the assumption that motivation can be measured on an ordinal scale

$$\{ \Omega, \psi, M, B, A \}$$

where Omega (Ω) < Psi (ψ) < Mu (M) < Beta (B) < Alpha (A), and each scale elements has a discrete number of sub-states. For example, Mu has the sub-states $M_1 < M_2 < \ldots < M_{10}$.

We hypothesise that motivation does not readily change between the states and that Ω, ψ, M, B, and A are *attractors* and transition between the attractors involves the motivation going beyond *tipping points* (Figs 6 and 7).

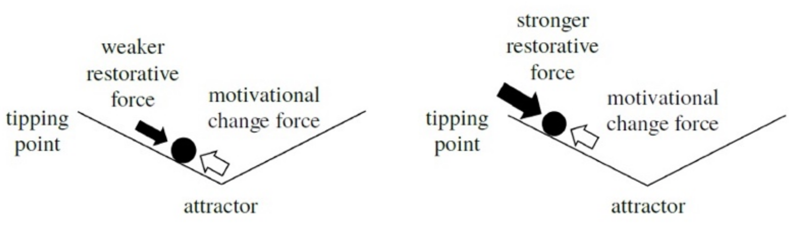

Figure 6. The motivational state tends to remain in its current attractor

E.g., if a PCSO's motivation state at time *t* is M_{10} in attractor MU, the motivation state at time $t+1$ is more likely to be M_9 than B_1 in attractor B. However, if it does go beyond the M_{10} tipping point into B_1 it is then more likely to stay in the attractor Beta than go back into attractor Mu (Fig. 7).

To aid understanding and provide visual feedback that the program is working properly we have a developed a graphical display of the motivation dynamics in Figure 7.

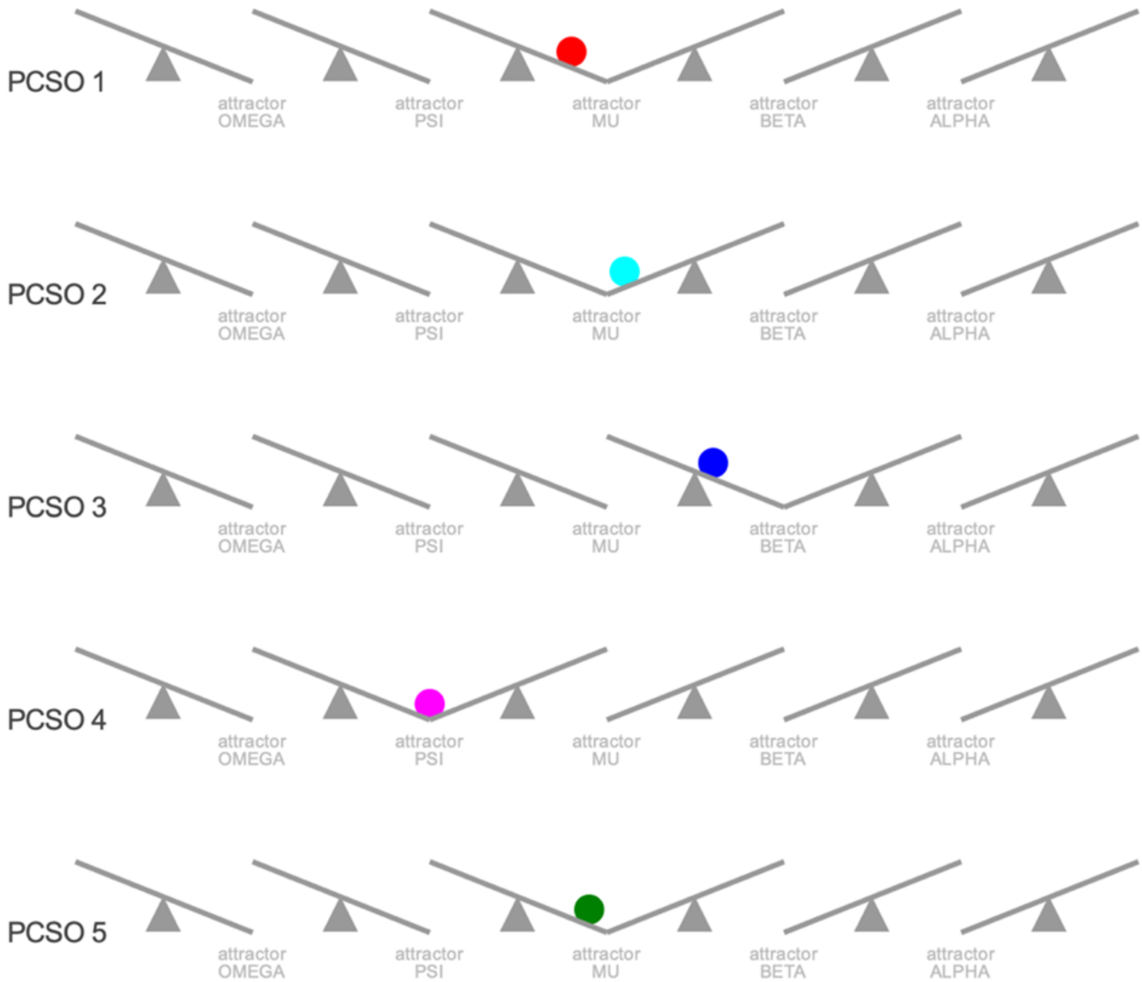

Figure 7

Our simulation counts the emoticons for each day to give the numbers [$n_{\underline{☹}}$, $n_{☹}$, $n_{😐}$, $n_{☺}$, $n_{\underline{☺}}$] with each of numbers in the range of 0 (no tasks in this day) to 8 (all tasks in this day). At its simplest our simulation uses the rule

if ($n_{\underline{☹}} + n_{☹}$) >= 4 there will be a jump to a lower motivation state

if ($n_{☺} + n_{\underline{☺}}$) >= 4 there will be a jump to a higher motivation state

However, the model does not assume a deterministic relationship between a day’s tasks and the change to a PCSO’s motivation. Sometimes a bad day will reduce motivation but sometimes it won’t. Similarly, sometimes a good day will improve motivation and sometimes it won’t.

The default settings for the frequency of the PATROL vertices means that some combinations are more likely to occur than others, *e.g.* the probability of the perfect task <~P ~A ~T ~R ~O ~L > is

$$(1.0 - 0.3) \times (1.0 - 0.2) \times (1.0 - 0.2) \times (1.0 - 0.3) \times (1.0 - 0.2) \times (1.0 - 0.4) = 0.15$$

so that about 15% or about one in six tasks has entirely positive vertices. In contrast completely negative task, < P A T R O L > has probability $0.3 \times 0.2 \times 0.2 \times 0.3 \times 0.2 \times 0.4 = 0.0003$ and occurs about three times in ten thousand tasks.

Figure 8 shows the flow of the simulation program. It starts by giving each PCSO an initial state. A *task generator* creates eight daily tasks for each PCSO according to the frequencies of the PATROL vertices. The task emoticon scores are calculated for each PCSO and used to calculate the changes to the motivation score which are then updated. The results are saved and displayed, and clock advances by one ‘tick’. Then the simulation begins for the next day with the creation of a new set of tasks.

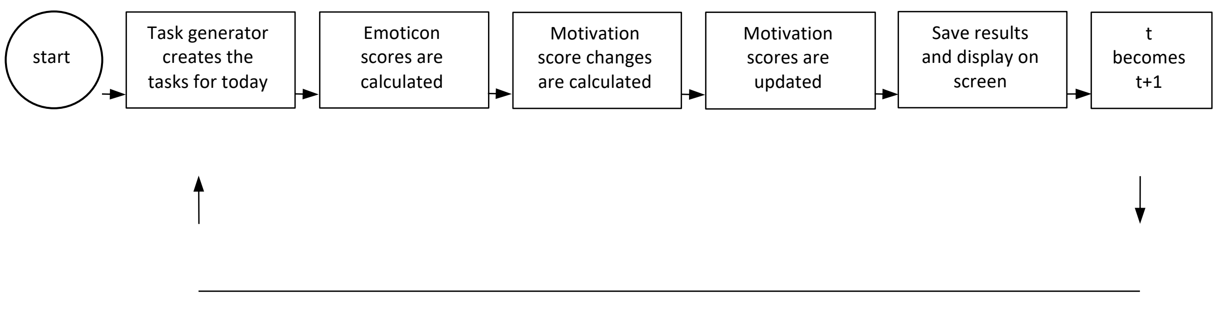

Figure 8 The simulation program flow

10. Results

To test our simulation, we devised two scenarios.

Scenario 1:

A policy has been set to widen spans of control for frontline supervisors and support a new force-wide initiative on public protection. Since no additional funding has been identified this will require a reduction in local policing to resource the new function. The result is that neighbourhood teams will not have a dedicated Sergeant per geographic area. Consequently, access to a supervisor is halved, and more interactions are managed remotely through telephony or video conferencing. There will be a negative impact to A and P since there will be less sergeant interaction (A), and subsequently less support to public service improvement resulting in worse feedback (P).

Scenario 2:

Following a critical report, a policy has been set to improve interactions with local people in terms of legitimacy and community cohesion. Consequently, PCSO geographic responsibilities and deployments are ring-fenced activities unless a critical incident requires support. PCSO are posted for three years to an identified ward to develop community relationships. The result is a significant improvement in ownership of geographic policing. This impacts positively on O and R because of increased exposure to the PCSO's dedicated 'patch' (O) and a greater alignment to PCSO perspective on their role (R).

For each of these scenarios the simulation was run ten times with PATROL percentages shown at the top of Table 2. For example, in Scenario 1 the default percentages were changed from 30% to 20% for P and from 20% to 10% for A.

The results of the runs are tabulated after the parameter listing. So, for example, the first run with the default parameters has the outcome that PCSOs 1, 3 and 5 ended the 250 day simulation in central attractor Mu, while PCSOs 2 and 4 finished in attractor Beta. For the second run PCSOs 1 and 3 finished in attractor Phi (ψ), PCSOs 2 and 5 finished in attractor Mu, and PCSO finishing in Beta.

Default	Scenario 1	Scenario 2	Scenario 2′
P 30%	P 20%	P 30%	P 30%
A 20%	A 10%	A 20%	A 20%
T 20%	T 20%	T 20%	T 20%
R 30%	R 30%	R 20%	R 10%
O 20%	O 20%	O 10%	O 5%
L 40%	L 40%	L 40%	L 40%

PCSO	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Run 1	M B M B M	Ω Ω Ω Ω ψ	B ψ M M B	M M B B M
Run 2	ψ M ψ B M	Ω Ω Ω 0 ψ	B ψ B B M	ψ M M ψ B
Run 3	Ω A M M ψ	Ω Ω Ω Ω Ω	M M M ψ M	M B M ψ M
Run 4	M M ψ B M	Ω Ω ψ Ω ψ	ψ B ψ M M	M B A M M
Run 5	ψ M M B M	ψ Ω Ω Ω Ω	B ψ M M ψ	M B M A M
Run 6	ψ M B M M	Ω Ω Ω Ω ψ	ψ M B ψ B	A B ψ B B
Run 7	Ω M M B Ω	Ω Ω Ω Ω Ω	B M B ψ B	M B A B M
Run 8	A ψ M M B	Ω Ω Ω Ω ψ	M M B A B	A B A B M
Run 9	M B ψ M M	Ω Ω Ω Ω ψ	M M A B M	B B B B M
Run 10	M B M M B	Ω Ω Ω Ω Ω	A ψ M M B	M M B M B

Table 2. Results of the simulations

As a first measure of the outcome of the scenarios the numbers of end states were counted. These are shown in Table 3.

For each scenario, ten runs for five PCSOs gives fifty outcomes. These are distributed across the attractors. *E.g.* for the default 26 of the outcomes were in attractor Mu. 8 were in attractor Phi and

11 were in attractor Beta. Just 3 were in attractor Omega (Ω) and just 2 were in attractor Alpha. Thus most outcomes for the default or control parameters were in the centre of the motivation range.

Increasing the parameters for P and A in Scenario 1 has a dramatically negative impact. All the runs resulted in negative motivational states with 42 in Ω and 8 in ψ. Thus the simulation suggests that the proposed Scenario 1 policy could have a very bad outcome.

For scenario 2 the frequency of R was changed from 30% to 20% and for O it was changed from 20% to 10%. This show a modest improvement in PCSO motivation with six PCSOs moving from attractor Mu to attractors Beta and Alpha. Since this result was less definitive the scenario was run again with R changed to 10% and O changed 5% as Scenario 2'.

The outcome for Scenario 2' is a distinct improvement in motivation across all attractors. Now more than half the PCSO finish in the motivated or very motivated attractors Beta and Alpha with just four PCSOs in negative attractors.

	Ω	ψ	Mu	Beta	Alpha	Total
Default	3	8	26	11	2	50
Scenario 1	42	8	0	0	0	50
Scenario 2	2	9	20	16	3	50
Scenario 2'	1	3	20	20	6	50

Table 3. The relative performance of the scenarios given by the numbers of simulation end states.

11. Validity and verification: ‘can you trust it’ ?

Creating a computer simulation to make predictions for policy purposes is easy. But can you trust it? There are two major reasons for a computer simulation to give unreliable forecasts. The first is that the underlying model is not a *valid* representation of the system. The second is that, even if the model were perfect, the implementation may be flawed. For example, how can it be *verified* that the program does not have errors and the data used is not poor or incorrect.

The challenge to create a ‘realistic’ model for a computer simulation is complicated by the argument that there is no single objective reality of human society – we all see what appears to be the same thing differently. There is a large literature on the *construction* of social reality, *e.g.* (Searle, 1995) writes that “there are portions of the real world, objective facts in the world, that are only facts by human agreement”. In this context the best that can be hoped for is that observers and stakeholders will agree that the model underlying a simulation is realistic from their own perspectives.

Programming is notoriously subject to error. *Debugging* programs that don’t behave as expected is a fundamental skill for the professional programmer. Although *tests* are devised to see if the program gives the expected output for a given input, it is usually impossible to test for all possible inputs, and the life cycle of software involves periodic updates to fix the bugs that emerged since the last update. The generality of software engineering is that ‘there is always another bug’.

Increasingly, the validation and verification of computer simulations involves making the code and data publicly available so that other can reimplement, *e.g.* the influential simulations of coronavirus infection in the UK done at Imperial College were verified by other scientists (Singh Chawla, 2020).

12. Critique, discussion and next steps

Our simulation is still at the prototype stage and these first results must be considered tentative. With this in mind it is nonetheless interesting that the simulation showed Scenario 1 to have such a poor outcome. It can be asked whether this is a genuine result or is it an artifact of the model. For example, all the vertices except A (absence of sergeant supervision and support) are distributed at random across the tasks. The A vertices are deliberately clustered to adjacent days to represent the possibility of a sergeant being on leave for one or two weeks, or being seconded to another role. Thus while the sergeant is away there may be an abnormal number of consecutive negative days and this may facilitate pushing the motivation over the tipping points.

The Scenario 2 and 2' simulations show that reducing the percentage of O (outside geographics area) and R (not core role) vertices has positive impact on motivation. But is this a self-fulfilling prophesy? The model is designed so that reducing the percentage of negative vertices will tend to have an improvement in PCSO motivation. So, are these results predictable without computer simulation? The management team already know that reducing anything the PCSOs see as onerous will probably improve motivation – but do they know what the level of tolerance is? This critique is similar to asking whether the model gives qualitive results (*e.g.* this policy will improve motivation) versus quantitative results (*e.g.* this policy will improve motivation to a high or low degree). The former is considerably less useful than the latter.

The response of the simulation to any proposed policy change depends on the calibration of the program. Currently the program is calibrated by adjusting the impact of the negative and positive emoticon counts so that in the default steady state condition most of the PCSOs stay with the central attractors. This has a quantitative impact on the simulations both in terms of how many of the PCSOs reach extreme negative and positive states, and how quickly.

The simulations reported here began with all the PCSOs in the same state and ran for 250 days. They are based on a clock tick of one day, but changes in motivation are likely to be determined by longer periods of time such as week, a month, or more.

This simulation is based on the PATROL simplices, but it is likely that the individual vertices are also relevant to changes in motivation. For example, it is possible that over time a PCSO would be assigned disproportionately many tasks outside their role <R> resulting in accumulating resentment and lowering motivation.

Currently this research does not include the social dynamics of the PCSOs. For example, when the PCSOs meet in the canteen the low or high motivation of one or more PCSO could be contagious and impact on the others. Also, some PCSOs may have more positive outlooks than others.

All these things are topics for the next stage of the research as the model evolves. The next steps in this research and development will investigate the simulation behaviour

- for clock ticks of a week, and month, a quarter, etc.
- for PCSOs with different initial states and over longer timespans
- for different patterns of emoticon counts
- for different distributions related to sergeant absence
- with emoticon counts projected onto each PATROL vertex
- for PCSOs with positive and negative outlooks
- for PCSO interaction and positive or negative contagion

References

Adams, A., 2018. Grounded Theory Analysis.
Birks, M., Mills, J., 2015. Grounded Theory: A Practical Guide, 4th ed. SAGE Publications, Ltd.
Boyatzis, R.E., 2006. An overview of intentional change from a complexity perspective. J. Manag. Dev. 25, 607–623. https://doi.org/10.1108/02621710610678445
Bryant, A., Charmaz, K., 2007. The Sage Handbook of Grounded Theory. Sage Publishing.
Cavanaugh, M.A., Boswell, W.R., Roehling, M.V., Boudreau, J.W., 2000. An Empirical Examination of Self-Reported Work Stress Among U.S. Managers 10.
Coyle, G., 2000. Qualitative and quantitative modelling in system dynamics: some research questions. Syst. Dyn. Rev. J. Syst. Dyn. Soc. 16, 225–244.
Davies, P., 2020. Investigating motivation in policing systems by computer simulation.
Davies, P., 2018. Pursuing Validity in Agent-Based Simulations of a UK Metropolitan Police Service.
Dörnyei, Z., MacIntyre, P., Henry, A., 2014. Motivational dynamics in language learning, 1st ed. ed. Clevedon: Channel View Publications.
Gilbert, N., Troitzsch, K., 2011. Simulation for the Social Scientist, 2nd ed. Open University Press.
Hatfield, E., Cacioppo, J., Rapson, R., 1994. Emotional Contagion: Studies in Emotion & Social Interaction. Cambridge University Press.
Herzberg, F., 1968. One More Time: How Do You Motivate Employees? Harv. Bus. Rev. 46, 53–62.
Howard, A., 2006. Positive and negative emotional attractors and intentional change. J. Manag. Dev. 25, 657–670. https://doi.org/10.1108/02621710610678472
Johnson, J., 2010. The future of the social sciences and humanities in the science of complex systems. Innov. Eur. J. Soc. Sci. Res. 23, 115–134. https://doi.org/10.1080/13511610.2010.518422
Lepine, J.A., Podsakoff, N.P., Lepine, M.A., 2005. A Meta-Analytic Test of the Challenge Stressor–Hindrance Stressor Framework: An Explanation for Inconsistent Relationships Among Stressors and Performance. Acad. Manage. J. 48, 764–775. https://doi.org/10.5465/amj.2005.18803921
Luna-Reyes, L.F., Andersen, D.L., 2003. Collecting and analyzing qualitative data for system dynamics: methods and models. Syst. Dyn. Rev. 19, 271–296. https://doi.org/10.1002/sdr.280
Melo, A., Belchior, M., Furtado, V., 2005. Analyzing police patrol routes by simulating the physical reorganization of agents, in: International Workshop on Multi-Agent Systems and Agent-Based Simulation. Springer, pp. 99–114.
Mullins, L., 2002. Management and Organisational Behaviour, 6th ed. FT Prentice Hall.
Searle, J., 1995. The Construction of Social Reality. Penguin Books.
Singh Chawla, D., 2020. Influential pandemic simulation verified by code checkers. Nature 582.
Vroom, V., 1964. Work and Motivation. Jossey-Bass Publishers.
Wu, J.-S., Lou, T.-C., 2010. Evaluating freeway police patrol performance by simulation, in: Information Networking and Automation (ICINA), 2010 International Conference On. IEEE Publishing, pp. V1-104-V1-109. https://doi.org/10.1109/ICINA.2010.5636424
Zhang, Y., Brown, D., 2013. Police patrol districting method and simulation evaluation using agent-based model & GIS. Secur. Inform. 2, 1–13. https://doi.org/10.1186/2190-8532-2-7