Using Feedback to Conduct Crowd Control

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Abstract

Crowd Control is a function generally associated with the police more than the military. However, the Canadian Forces are occasionally asked to intervene in riot situations either in Canada, in support to Federal, Provincial and Municipal Governments, or overseas, during Coalition operations. Thus, there is a need to understand crowd behaviour and to determine optimal intervention strategies for crowd control. Arguably the most famous recent event involving the Canadian Forces was the Oka Crisis in 1990 in which Mohawk Warriors carried out a 76 day standoff and the Quebec Provincial Police were unable to handle the situation. Another example of situations concerning governments around the world are unruly protests during visits of foreign dignitaries, such as the Vancouver APEC Protest, in 1997. Although, the Canadian Forces have not been employed in these events, they have skills and resources that might be called upon if a situation gets out of control and must be prepared to deploy on short notice. A model has been developed that can be used to understand these events in the time dimension both inside the event and from event to event. The model has been developed theoretically and "face validated" using data from two case studies. The model is required to evaluate appropriate tactics such as the employment of non-lethal weapons, and as a training simulator for strategic and tactical commanders.

1 Introduction

There is a need to take a long-term view of civil disobedience. The apparently successful police and military actions to control unruly crowds during one event may have detrimental effects for future events. Therefore, the Canadian Forces need to have methods and skills which apply force in the right measure to defuse an event today while maintaining a balance that will not create new problems tomorrow. One of the more controversial tools at hand are non-lethal weapons [4, 6]. The effective use of non-lethal weapons as force multipliers is the subject of much study in the Defence Research and Development Canada, and in particular in the Centre for Operational Research and Analysis. As part of this work, the Operational Research Team in Valcartier, Quebec has initiated a three-year project that aims at studying crowd dynamics by means of numerical simulation. Two modelling paradigms have been selected for this study - System Dynamics and Agent-Based Modelling - with the intention of comparing their respective advantages and disadvantages when used to simulate crowd dynamics in confrontation situations. In the first year of this study, the focus has been on data collection and literature review. As expected, a great deal of recent research is going on with Agent-Based Modelling applied to crowd behaviour (e.g. [11]). However, there is a dearth of System Dynamics literature in this area [10].

The System Dynamics model described in this paper is adapted from a game-theoretic approach [1] that was originally developed to explain bank runs and currency attacks [7] using the theory of rational choice [3]. The philosophy behind this model is that individuals in a crowd make independent decisions to riot if the potential payoff from rioting exceeds the potential penalties that might be imposed by the controlling forces. This is implemented in the model through imperfect signaling between the individuals in the crowd and between the controlling forces and the crowd. These signals are compared to decision thresholds that employ subjective judgements about potential payoffs and penalties [5]. One of the features of this approach is that these thresholds can be solved analytically to obtain a unique equilibrium using Bayes Nash Theory (see [3]). However, more practically, a feedback technique can be applied using a System Dynamics model which employs a 'tit-for-tat' strategy [2] to obtain a stable equilibrium. This equilibrium is significant because it demonstrates a balance between the rights of the individuals for freedom of expression while appropriate force is applied to maintain control.

Two case studies are described that are of great interest to the Canadian Forces: the Oka Crisis [12] and the Asian-Pacific Economic Conference (APEC) protest [9]. The details of these events are provided in Appendix A. The first is based on an aboriginal standoff in 1990 in which the Quebec Provincial Police were ineffective and the Canadian Forces were called in to resolve the situation. These standoffs have occurred relatively frequently over the past twenty years [8] and the Canadian Forces may be involved in the future. The second is based on a protest against visiting dignitaries during economic talks in Vancouver in 1997. In this case, the situation was handled by the Royal Canadian Mounted Police although they came under a great deal of criticism for their "so-called" indiscriminate use of pepper spray [9]. The Canadian Forces were not involved in the APEC protest. However, as seen during the World Trade Organization protest in Seattle in 1999 when the US National Guard had to be called in to quell the riots, the Canadian Forces need to have contingency plans for handling these types of protests to ensure that they do not get out of control. We will see that the Oka case appears to be similar to the common phenomenon of "overshoot and collapse". The APEC case appears to show a more "stable oscillation". However, the possibility of "expanding oscillation" if the event had gone on longer cannot be ruled out. The novel aspect of the model that will be developed is that both of these case studies can be analyzed using the same model. Furthermore, the feedback approach has the ability to extend the time line to take in more than one event of the same type separated in time and space.

Section 2 of this paper will provide two behaviour over time graphs that can be envisioned to understand the dynamics of crowd control situations in the "stable oscillation" case like the APEC Conference and the "overshoot and collapse" case such as the Oka Crisis. Section 3 will provide a description of the game-theoretic model developed by Atkeson [1] which will be the framework for the System Dynamics model. The analytical version of the Atkeson model will be described in Section 3.3 with a numerical example which demonstrates the common problem with the static approach if the thresholds are not measured exactly. Section 3.5 provides a System Dynamics version of the Atkeson framework which includes feedback to solve for the equilibrium numerically. This feedback based approach resolves the problems we found with the static approach. In the concluding section, future work for this three-year project will be discussed such as how we plan to introduce non-lethal weapons into the model and how this model might be used as a simulation training game.

2 Behaviour Over Time

It will help us in the hypothesis process to examine the behaviour over time graphs for the two case studies mentioned. The behaviour will be examined from the crowd's point of view and plot the cumulative payoffs awarded and penalties inflicted over time in these two cases. The case studies are described in some detail in Appendix A.

2.1 The Oka Crisis

In Figure 1, we have plotted the cumulative gains of the Mohawk warriors over the 17 major incidents that occurred during the 76 day period of the Oka Crisis in 1990. It was arbitrarily assumed that an effective tactic by the Mohawk warriors gave them a payoff of +1 while an effective tactic by either the police or the military gave the Mohawk warriors a penalty of −1. One can see that the warriors made steady gains over the first few incidents of the crisis. At the peak, a gun battle between the Mohawk warriors and the Quebec Provincial Police took place and a policeman was killed. The police then retreated and the provincial government called in the Canadian Forces. The Canadian Forces applied overwhelming force and the warriors took continuous losses until at the end of the time line the warriors surrendered. This appears to be similar to the classic behaviour mode in System Dynamics of “overshoot and collapse”. This was not an ideal situation for the warriors or the police although the Canadian Forces were able to successfully defuse this situation which goes to show the classic axiom of System Dynamics that growth cannot last forever.

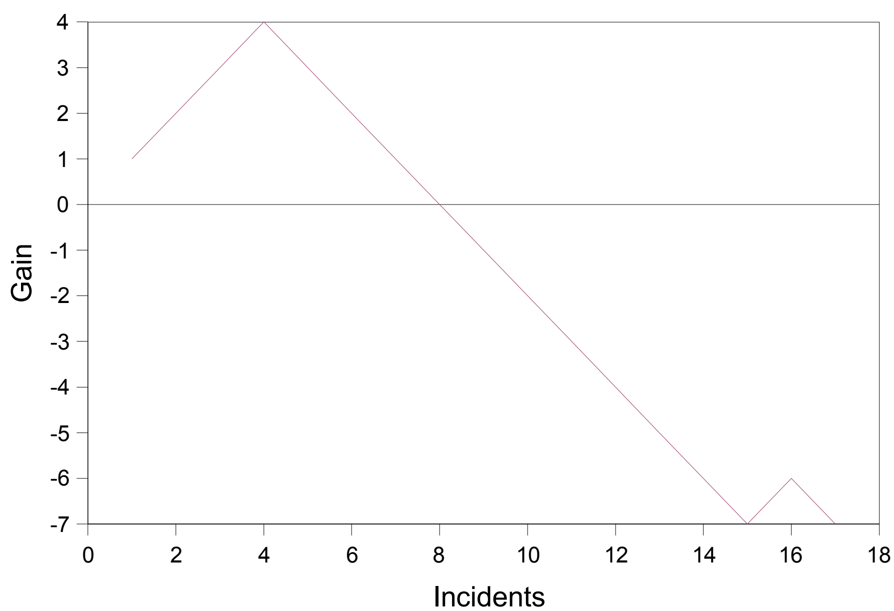

Figure 1: Behaviour Over Time Graph for the Oka Crisis

2.2 The APEC Protest

Figure 2 shows the cumulative payoffs/penalties for the 11 significant events analyzed in Appendix A concerning the APEC protest in Vancouver in 1997. Again, we have arbitrarily assumed that the payoffs for an effective protester tactic is $+1$ and the penalty for an effective police tactic is -1. We can see that there does not appear to be a clear winner or loser in this case. In fact, this might be close to the situation we wish to achieve from the point of view of the controlling forces. Also it is not necessarily negative from the point of view of the protesters because they got some opportunity to give voice to their dissent.

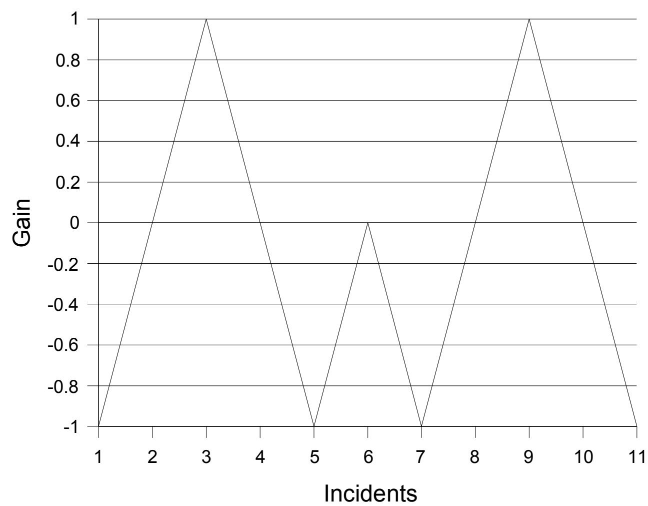

Figure 2: Behaviour Over Time Graph for the APEC Protest

3 Atkeson's Game-Theoretic Model

3.1 Parameter Definition

Let us define the following parameters of the model.

- x will be the signal that is received by an individual in the crowd about the strength of the police. This will be a normally distributed random variable.
- θ will be the strength of the police which will be a Bayesian updated value based on a strength prior for the police and the signals sent to the crowd.

W will be the positive payoff that is received by individuals that riot if they are successful. This could be the result of a symbolic gesture or a physical gesture.

L will be the negative penalty inflicted on individuals that riot if they are controlled. This would most likely be a physical punishment such as the use of a non-lethal weapon.

$a(\theta)$ will be a function representing the fraction of the crowd that can be controlled by the police with strength θ. We will assume that this function is linear with $a(0) = 0$ and $a(100) = 1$.

3.2 The Coordination Problem

When θ is such that $a(\theta)$ is between 0 and 1, the police cannot control the crowd if they all riot. If the crowd could perfectly coordinate their behaviour, then their optimal strategy would be to riot, overwhelm the police, and reap to the payoff. However, we assume that each individual makes an independent decision about whether to riot or not based on the signals they receive from the police, and based on their impressions of how the rest of the individuals in the crowd will react to the signals they receive.

Let's say for instance that $\theta = 20$. In our linear model, $a(\theta) = 0.2$. That is, if more than 20% of the crowd riots, they will overwhelm the police and receive a payoff. If less than 20% of the crowd riots, they will be controlled by the police and receive a penalty. The rational individual in the crowd will wait to see what the others in the crowd do. The individual will not take the initiative to act first because he or she cannot guarantee that enough of the crowd will follow to make the 20% threshold. This is the heart of the rational crowd's coordination problem.

3.3 The Threshold Concept for Finding the Equilibrium

The threshold concept that Atkeson proposes works as follows. The crowd applies a signal threshold x^* to the actual signal that they receive from the police about the police's strength. This is a trigger such that if an individual sees a signal of $x < x*$ then he or she will riot. The police have a strength threshold θ^* which they use as a trigger strategy as well. If the strength they wish to apply to the incident is $\theta > \theta^*$, then they will punish the crowd. Thus, $Prob(x < x^*|\theta^*)$ = the probability of the individual rioting and $Prob(\theta \geq \theta^*|x^*)$ = the probability of the rioters being controlled and therefore punished by the police.

To find the equilibrium, we wish to find x^* and θ^* such that

$$Prob(x < x^*|\theta^*) = a(\theta^*)$$

and

$$WProb(\theta < \theta^*|x^*) + LProb(\theta \geq \theta^*|x^*) = 0$$

3.4 An Implementation

The simulation shown in Figure 3 and documented in Appendix B utilizes a Bayesian updating of the strength by employing a normally distributed random variable with mean

$$\frac{\left(\frac{m_\theta}{s_\theta^2} + \frac{x^*}{s_x^2}\right)}{\left(\frac{1}{\frac{1}{s_\theta^2} + \frac{1}{s_x^2}}\right)}$$

and standard deviation

$$\sqrt{\frac{1}{\left(\frac{1}{s_\theta^2} + \frac{1}{s_x^2}\right)}}$$

with x^* and θ^* solved outside the model using a trial and error approach.

3.5 Results with Atkeson's Model

A typical behaviour over time graph for this simulation is shown in Figure 4 for the hypothethical parameters: $W = 10, L = 100, m_\theta = 20, s_\theta = 10, s_x = 1$.

In this case, it is assumed that the payoff is relatively small while the penalty is relatively severe. Thus, if the police wish to achieve balance, they must be judicious in utilizing force. In this case, the crowd would be allowed to receive a payoff in approximately 90% of the incidents and the police would impose a penalty in approximately 10% of the incidents. To implement this, the Atkeson threshold values are $x^* = 5.590$ and $\theta^* = 7.061$.

The behaviour over time graph shows the cumulative gain for the rioters for the period of 100 incidents (to model discrete incidents, we use a 'work-around' that there is one incident every model day). The gain in this case looks fairly well-balanced.

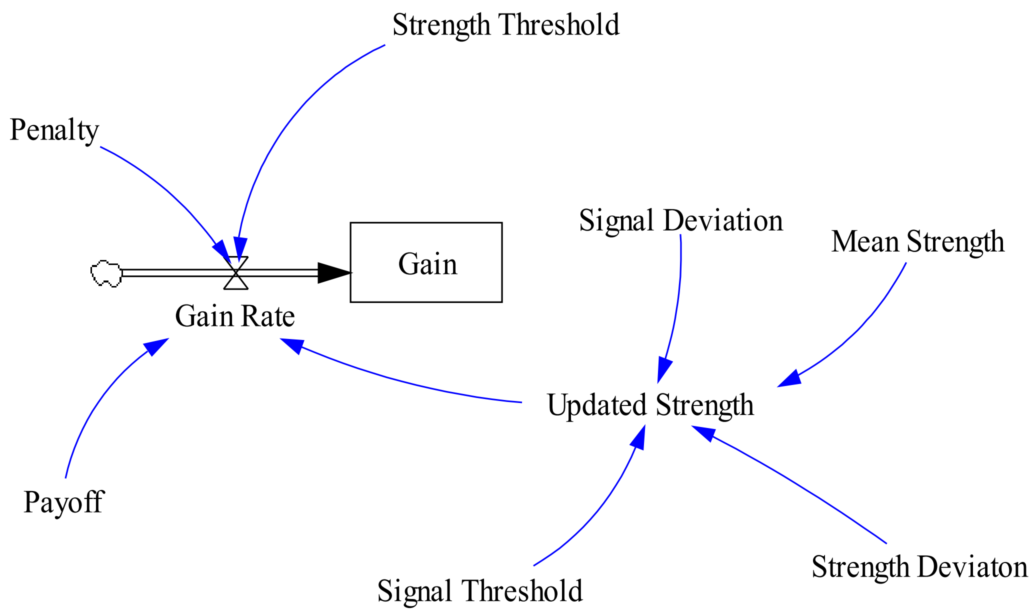

Figure 3: Simulation Model for the Atkeson Framework

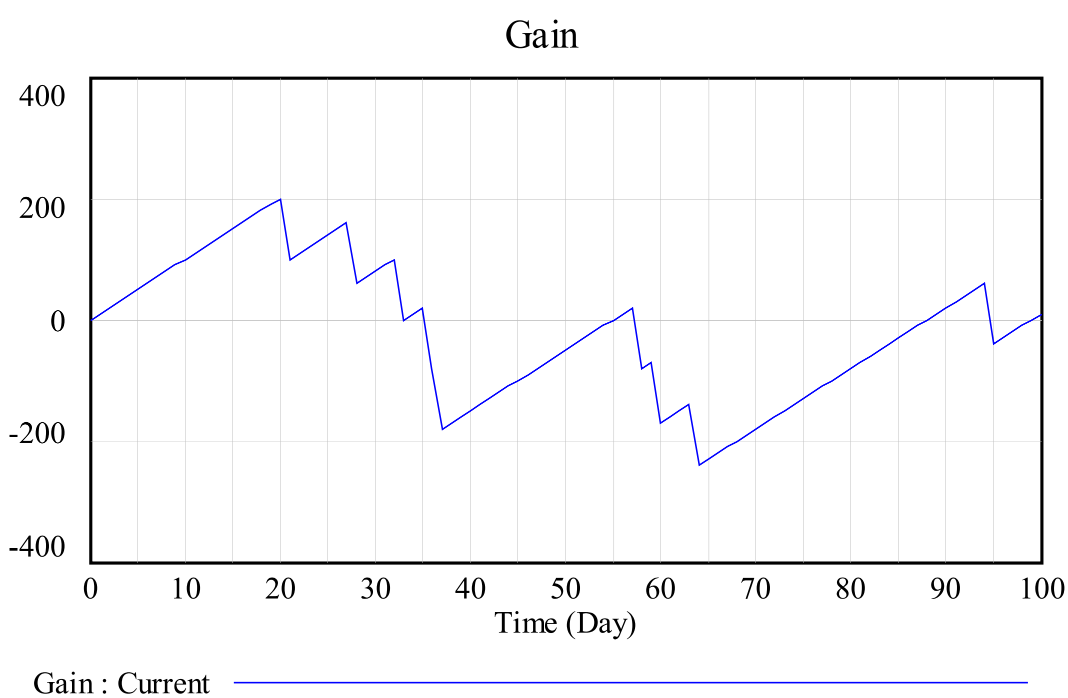

Figure 4: Behaviour Over Time Graph for the Atkeson Model

3.6 Instability in the Long-Term

This short-term result is misleading as we can see from Figure 5 when we extend the period to 500 incidents. The gain diverges quite considerably from a stable result because of the well-known problem of imprecise specification of the initial conditions (i.e because the threshold values were specified to only 4 digit accuracy). This puts into question the value of the analytical approach to solving the Atkeson model in practice.

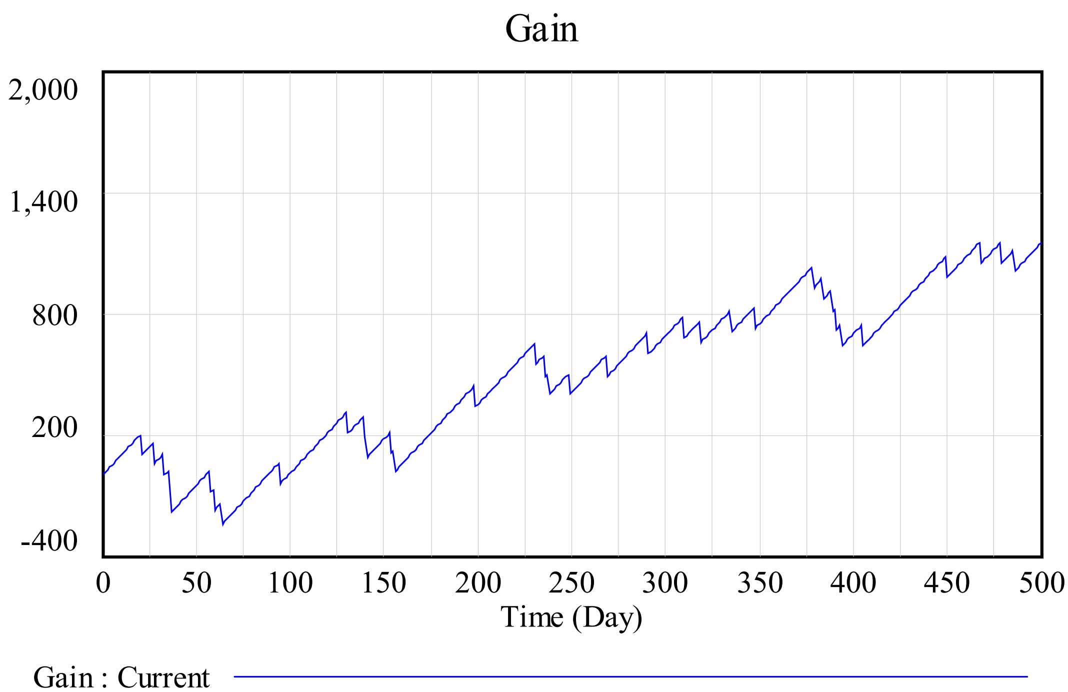

Figure 5: Behaviour Over Time Graph for the Atkeson Model in the Long-Term

3.7 A Feedback Implementation

Figure 6 shows a model and Appendix B provides the documentation of a version of Atkeson's framework which employs feedback to dynamically determine the strength threshold based on any given parameter set. The strength threshold applied by the police is adjusted downward by a value of $\frac{W}{W-L}$ if the rioters are successful in an event. Recall that if the updated strength (θ) is greater than the strength threshold (θ^*), the police will use their strength to control the crowd. Thus by adjusting the threshold downward, the police will be more likely to inflict a penalty on the crowd and therefore more likely to balance the crowd's cumulative gain. Conversely, the strength threshold is adjusted upward by a value of $\dfrac{-L}{W-L}$ if the rioters are controlled.

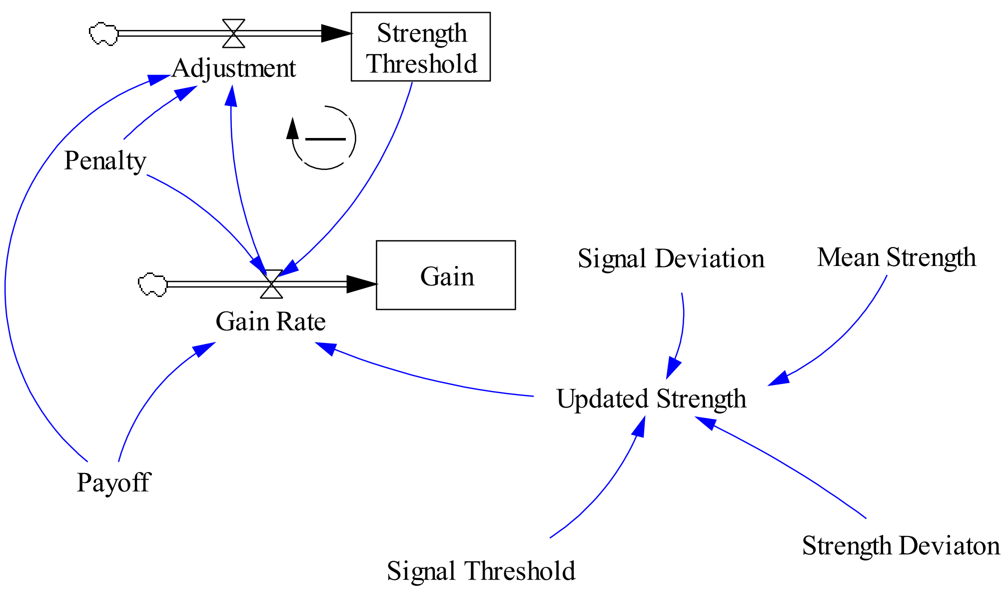

Figure 6: Simulation Model with Feedback

Figure 7 shows the behaviour over time graph in the long-term for this model. One can see that there is a sense of stability in this case.

Another useful feature of the feedback approach is that the behaviour stabilizes without any prior calculation of the strength threshold. That is, after a short 'burn in' period the strength threshold stabilizes at the appropriate level for any given signal threshold. Figure 8 shows the strength threshold in equilibrium when the model begins with the strength threshold of zero at the start of the simulation.

Thus, the feedback approach produces a stable solution for the Atkeson model without complex Bayesian calculations and independent of the initial threshold settings. This is a very satisfying result created through the use of feedback in the Atkeson framework.

4 Concluding Material

The first year of a three-year study of crowd control modelling using Agent Based Modelling and System Dynamics has been completed. Although there is a great deal

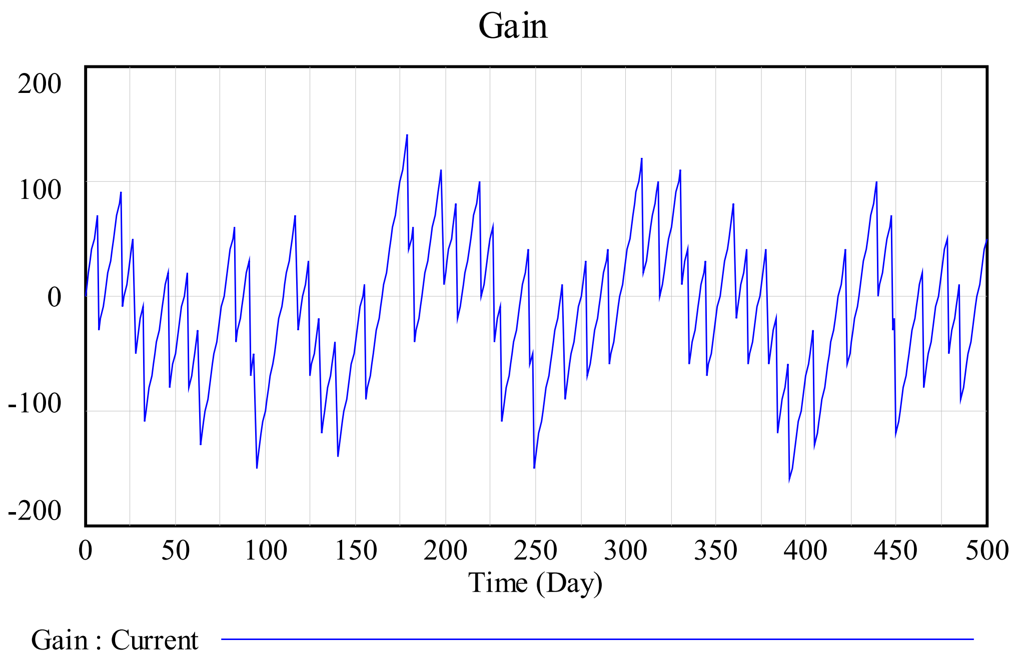

Figure 7: Behaviour Over Time Graph for Feedback Model

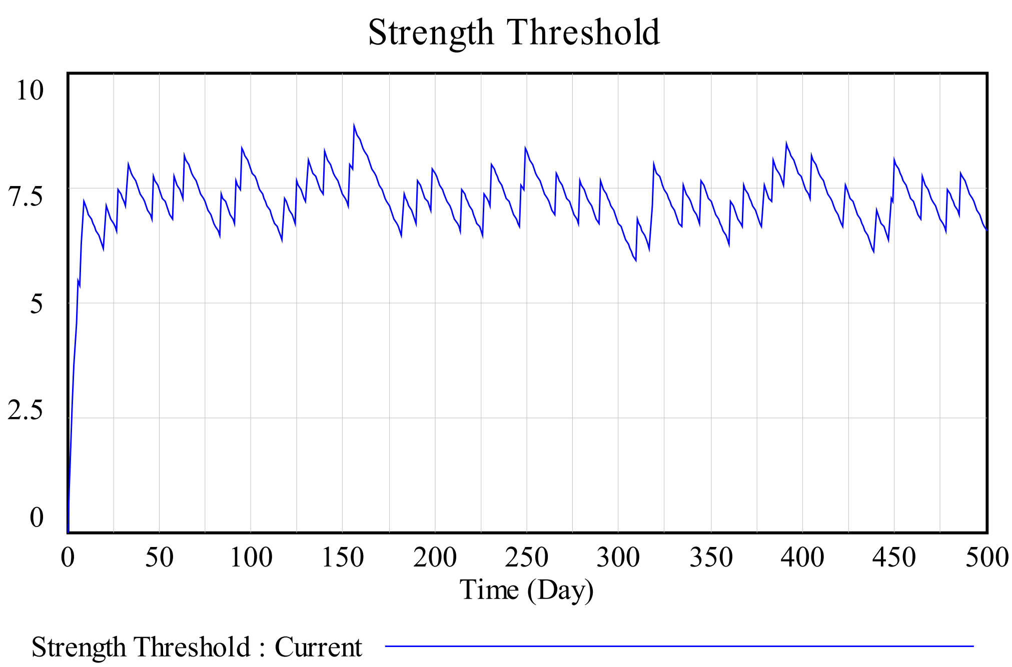

Figure 8: Solving for the Strength Threshold

of work being done around the world on Agent-Based Modelling, there is very little relevant work being done in this area using System Dynamics. One promising approach that was discovered during our literature search was a game-theoretic model which uses rational choice theory [1]. This threshold-based framework involves a complex analytic solution technique called Bayes Nash Equilibrium [3]. It was implemented in this study using a simulation model. However, there were problems with the long-term behaviour of the framework that may have been caused by the inability to exactly define the solution thresholds numerically.

As an alternative, a System Dynamics implementation of the framework was developed that allows for feedback to adjust the strength threshold based on the evolving situation. This approach has two appealing features. First, the results were stable over the long-term. And second, the feedback approach adjusts the thresholds dynamically avoiding the need for the complex Bayesian updating process.

Two case studies were examined from recent Canadian history: the Oka Crisis in 1990 and the APEC Conference protest in 1997. The examination of the behaviour over time graphs from the point of view of the crowd lent "face validity" to the simulation model of the threshold framework. It would be highly desirable to conduct more case studies and attempt to validate the framework by estimating the parameters of the model based on the data collection. Then apply these parameters in the model to attempt to replicate the behaviour over time graphs of the case studies.

The examination of the model for various parameter settings to determine the sensitivity of the cumulative gain to various combinations of input parameters will need to be conducted. The goal here would be to determine the set of robust tactics that lead to stable and desirable behaviours.

In the current model, the payoffs and penalties are assumed to be constant values. Penalties are the primary approach to the use of force in the model. There is a need to look at various options in applying force and in this case, the penalties would need to be variable to consider the employment of different types of non-lethal weapons in isolation and in combination. Similarly, the payoffs should vary depending on the effectiveness of the crowd's tactics. It would be beneficial to have a number of independent evaluators examine the case study materials and rate the payoffs and penalties on a floating scale.

The potential use of this model as the basis of a training simulator will be investigated in the fullness of time. Tactical commanders would benefit from experimentation with the model to develop knowledge about how to use feedback to apply levels of force appropriate to the evolving situation so that the event does not get out of control and in particular ensuring that their use of force does not make matters worse in the short-term. Strategic commanders might learn about the systematic longer-term relationship between events and how the application of force in one event effects future events.

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A Case Studies

Table 1: The Time Line for the Oka Crisis

Date and Description of Main Incident	Payoff
11 Mar 90: Kanesatake Mohawks set up a blockade in an effort to stop the town of Oka from expanding a golf course on land the Mohawks claimed contained a cemetery.	Blockade (effective for Mohawks).
11 Jul 90: The Sortie du Quebec (SQ) police are called in. Just before dawn the SQ arrived in rental cars and vans. The SQ fires tear gas after asking to speak to a Mohawk spokesperson and are not satisfied when a woman says she is the spokesperson. There are more than 100 officers and Mohawks fear more are to come so they build a wall of tires and set them on fire to prevent other SQ officers from arriving. The SQ officers begin to move forward using tear gas and concussion grenades. A gun battle starts. Hundreds of rounds are shot but the battle lasts no more than a few seconds. SQ Marcel Lemay is killed. Raphals recounts, The SQ officers launched an ill-planned attack on the Mohawk barricade at Kanesatake. Their own tear gas blew back in their faces, one police officer was shot and killed-perhaps by his own side- and they were forced to retreat. In the aftermath the Mohawks fortified their barricade with crushed SQ cruisers, topping it off with a sign reading, "They came, they saw, they ran". The SQ had retreated, leaving most of their vehicles near the barricade. The Mohawks destroyed police cars and took control of a bulldozer to reinforce their barricade. The SQ watched the Mohawks for the rest of the day from a helicopter. Mohawk Warriors at the Kahnawake reserve 29 km southwest of Montreal set up a blockade at the Mercier bridge in the morning in support of the Kanesatake Mohawks. The bridge is used by up to 60,000 commuters every day from South Shore communities to Montreal.	Tear gas (not effective for SQ). Gun battle (effective for Mohawks). Destroying police cars and seizing a bulldozer (effective for Mohawks). Mercier Bridge blocked (effective for Mohawks).

Table 1: The Time Line for the Oka Crisis (Continued)

Date and Description of Main Incident	Payoff
July 90: The Mohawk Warriors join the Kanesatake Mohawks at the barricades. The Quebec government orders the SQ to erect its own barricades on the roads leading to the municipality of Oka and the Kanesatake reserve. The police set up roadblocks 5 km outside of Oka. Both sides try intimidation tactics during the night. They send men into the woods. Sometimes officers or Mohawks go in silence to spy and other times they create noise to let the other side know they are watching. The police have greater resources and always have fresh crews to watch the barricade. The Warriors have limited resources and begin to suffer sleep deprivation.	SQ barricades (effective for SQ). Night intimidation (effective for SQ).
16 Jul 90: SQ stop food shipments at the roadblocks they have set up. The circulation of food and medical supplies to the community of Kanesatake experience some delays. Some Mohawks, are refused access, and leave the food they had brought for their family at the barricades. The Mohawks ask for a team of observers from human rights groups across Canada to be present at the barricades, to prevent the police from violating their rights. The Red Cross goes behind the barricades and identifies 200 people needing special attention. Complaints against the police are lodged with the Human Rights Commission accusing the police of harassment, making racial slurs and gestures, and detaining people. These incidents make natives afraid to cross the barricades to buy food or seek medical supplies.	Blocked food shipments (effective for SQ).
26 Jul 90: The police report that the bullet that killed Cpl. Lemay on 11 Jul 90 did not come from a police weapon.	
7 Aug 90: Many Mohawks leave Kanesatake.	Mohawks leave (effective for SQ).
14 Aug 90: Chief of Defence Staff announces the deployment of units to Kanesatake and Kahnawake relieving SQ. The Canadian Forces announce that as many as 4,400 soldiers, backed by armored personnel carriers and heavy weapons would be deployed.	Army coming (effective for SQ).

Table 1: The Time Line for the Oka Crisis (Continued)

Date and Description of Main Incident	Payoff
20 Aug 90: The arrival of the army. 33 troops arrive around 0800. The army moves one of the SQ barricades 400 meters closer to the Mohawks to improve the barricades strategic value to the Army. The Mohawks apparently misunderstand this as an act of aggression. The negotiations are fragile and every time the Army pushes the barricades closer, the talks break off. When the SQ was in Oka the barricades were sometimes separated by as much as 1.5 km. Now at some points the barricades are as close as 5 meters from each other.	Barricades move closer (effective for Army).
24 Aug 90: Four smoke bombs are set off by the Canadian Forces in the morning.	
1 Sep 90: At 1300, some soldiers climbed over the north, east, and west perimeter and made their way into the pines. This was a very tense time. Warriors were trying to provoke the soldiers into firing the first shot. It was only strict discipline that prevented this situation from ending in a bloodbath. The Warriors would not retreat. They were ready to stand their ground. It was finally decided that they would retreat into the treatment center. The night remained tense. The Warriors took turns guarding the entrance of the treatment center. The area was illuminated with high-powered searchlights from across the road. A cacophony of eerie war whoops amplified through Mohawk loud speakers, helicopters hovered above, flares going off only increased the tension on both sides.	Warriors retreat into Treatment Center (effective for Army).
2 Sep 90: Barricades are brought down at Kanesatake.	Barricades brought down (effective for Army).
6 Sep 90: Mercier Bridge is re-opened by the Army after 62 days of Mohawk occupation. The Army completely surrounds the Mohawks at the Treatment Center in Kanesatake using razor wire.	Mercier Bridge re-opened (effective for Army). Razor Wire surrounds Mohawks in Treatment Center (effective for Army).

Table 1: The Time Line for the Oka Crisis (Continued)

Date and Description of Main Incident	Payoff
8 Sep 90: An incident occurred when four soldiers crossed the razor wire scouting a Mohawk in the forest, when they stumbled upon a warrior asleep in a trench. A battle erupted and two soldiers are wounded. The warrior is overwhelmed and beaten.	Beating of Mohawk (effective for Army).
13 Sep 90: The phone lines are cut. The only line the Warriors had was the Hot Line to the negotiation office of the Army. Light towers are set up to see the Mohawk side of the razor wire at night. Warriors put up blankets in the woods so the Army cannot see what they are doing. Soldiers shine powerful lights into the detox center from 110-foot towers. The army steadily pushes its side of the barriers forward, tightening their circle of control; they jam the cellular phones of journalists inside. The Warriors direct loudspeakers at the troops, the music alternating between traditional native songs and the Rolling Stones: "Wild horses cant drag me away . . . ". Later the Warriors find a place where cellular phones are not effected by the blackout and call it the "Phone Booth".	Phone lines cut and light towers used (not effective for Army).
Sep 90: One night a Warrior reached over the razor wire with a long hook and yanked on the Armys tripwires, setting off flares. The soldiers thought a mass breakout was starting. The Army was not about to see this situation get any worse. An officer then gave an order to "lock and load" and shortly after a shot was fired in the air.	Set off tripwires (effective for Mohawks). Army locks and loads (effective for Army).
26 Sep 90: At the local detox center in Kanesatake, the twenty Warriors and their families who had been making a last stand, lay down their arms and turn themselves in. The last barricades are taken down. The Mohawk Warriors burned two fires when they surrendered.	Mohawks surrender (effective for Mohawks and Army).

Table 2: The Time Line for the APEC Protest

Date and Description of Main Incident	Payoff
17 Nov 97: Students begin 'laying siege' for the summit by building a tent city outside the student union building. Named 'Democracy Village', it becomes part of the security zone for the summit. The eleven students, who set up a tent city, wrote slogans on windows and rearranged rocks to spell out a message. The students are warned that if they do not leave they will be arrested. Seven students leave and the remaining four are charged and arrested.	Arrests (effective for RCMP).

Table 2: The Time Line for the APEC Protest (Continued)

Date and Description of Main Incident	Payoff
21 Nov 97: The graduate student's union at UBC raises the Tibetan national flag, a symbolic image of independence, atop its student centre and hangs two anti-APEC banners. The RCMP removes the flag on the morning of 25 Nov 97.	Flags raised (effective for protesters).
24 Nov 97: A protester, Law student Craig Jones, places paper signs reading "Free Speech", "Democracy", and "Human Rights" on fences surrounding Green College. At midnight, police remove the signs.	Signs raised (effective for protesters).
25 Nov 97: At 0750, Craig Jones displays signs that state "Free Speech", "Democracy", and "Human Rights" on the sidewalk on two coat racks in view of the motorcade route that will be transporting the APEC delegates to UBC. An RCMP officer immediately orders the protester to move the signs off the sidewalk and onto the grass 12 feet behind the security fence. The protester complies. After approximately 10 minutes, the same officer informs the protester that the signs cannot remain but he can. The protester does not remove the signs and the signs are grabbed from him. He is handcuffed and arrested. At approximately 0830, Mike Thoms briefly displays a textile banner. Police tell him he cannot do this and the police seize the banner. Police tell other individuals wishing to display signs on the Green College side of the security fences that signs are not allowed.	Signs and banner removed (effective for RCMP). Craig Jones arrested (effective for RCMP).
25 Nov 97: A massive rally peaked on campus at 1230 in a melee of pepper spray and arrests. It is alleged that individuals carrying cellular telephones or amplifying equipment were arrested and that women, but not men were strip searched by RCMP officers. At 1240, protesters reached the 12-foot fence separating them from the wide secure zone around the museum and several protesters grabbed the chain link and tore a section down. The falling fence caught a group of activists and media underneath before waiting police moved in with pepper spray and police bikes, beating back the protesters. Shortly after the security fence is repaired, a group of about 40 activists risk arrest by forming ranks of four and walking slowly into the police line. The police douse the first rank with pepper spray and they spray the substance over protesters heads and into the crowd. Police then threw two-dozen empty bottles back over the fence. The confrontation ended after about a one-hour standoff.	Rally (effective for Protesters). Pepper spray and arrests (effective for RCMP). Bringing down part of chain link fence (effective for Protesters).

Table 2: The Time Line for the APEC Protest (Continued)

Date and Description of Main Incident	Payoff
25 Nov 97: Activists moved on to a trio of roadblocks where they sat on the three routes leading away from the UBC museum. With little warning, the police break up one of the roadblocks by pepper spraying the 50 activists, as well as onlookers and the media, forcing the crowd about 100 meters from site of the motorcade route. Along the same route the APEC motorcade had taken in the morning, some 30 protesters sat on the pavement. Another 200 protesters and onlookers stood on the median in the road, offering support. By day's end, 49 people are arrested. Police also search and release four men with Indonesian accreditation who were photographing protesters.	Roadblocks (effective for Protesters). Pepper spray (effective for RCMP). Arrests (effective for RCMP).

B Model Documentation

B.1 Atkeson Model

(01) FINAL TIME = 500, Units: Day, The final time for the simulation.
(02) Gain = INTEG (Gain Rate,0), Units: **undefined**
(03) Gain Rate = IF THEN ELSE(Updated Strength<Strength Threshold, Payoff, Penalty), Units: **undefined**
(04) INITIAL TIME = 0, Units: Day, The initial time for the simulation.
(05) Mean Strength = 20, Units: **undefined**
(06) NOISE SEED = 23445, Units: **undefined**
(07) Payoff = 10, Units: **undefined**
(08) Penalty = -100, Units: **undefined**
(09) SAVEPER = TIME STEP, Units: Day, The frequency with which output is stored.
(10) Signal Deviation = 1, Units: **undefined**
(11) Signal Threshold = 5.590, Units: **undefined**
(12) Strength Deviaton = 10, Units: **undefined**
(13) Strength Threshold = 7.061, Units: **undefined**
(14) TIME STEP = 1, Units: Day, The time step for the simulation.
(15) Updated Strength = RANDOM NORMAL(-100, 100 , (Mean Strength/Strength Deviaton^2+Signal Threshold /Signal Deviation^2)/((1/Strength Deviaton ^2)+(1/Signal Deviation^2)) , SQRT(1/ (1/Strength Deviaton^2+1/Signal Deviation^2)), 0), Units: **undefined**

B.2 Feedback Model

(01) Adjustment = IF THEN ELSE(Gain Rate<0, -Payoff/(Payoff-Penalty),-Penalty/(Payoff-Penalty)), Units: **undefined**

(02) FINAL TIME = 500, Units: Day, The final time for the simulation.

(03) Gain = INTEG (Gain Rate,0), Units: **undefined**

(04) Gain Rate = IF THEN ELSE(Updated Strength<Strength Threshold, Payoff, Penalty), Units: **undefined**

(05) INITIAL TIME = 0, Units: Day, The initial time for the simulation.

(06) Mean Strength = 20, Units: **undefined**

(07) NOISE SEED = 23445, Units: **undefined**

(08) Payoff = 10, Units: **undefined**

(09) Penalty = -100, Units: **undefined**

(10) SAVEPER = TIME STEP, Units: Day, The frequency with which output is stored.

(11) Signal Deviation = 1, Units: **undefined**

(12) Signal Threshold = 5.590, Units: **undefined**

(13) Strength Deviaton = 10, Units: **undefined**

(14) Strength Threshold = INTEG (Adjustment, 7.061), Units: **undefined**

(15) TIME STEP = 1, Units: Day, The time step for the simulation.

(16) Updated Strength = RANDOM NORMAL(-100, 100 , (Mean Strength/Strength Deviaton^2+Signal Threshold/Signal Deviation^2)/((1/Strength Deviaton ^2)+(1/Signal Deviation^2)) , SQRT(1/ (1/Strength Deviaton^2+1/Signal Deviation^2)), 0), Units: **undefined**