Proceedings of the Annual General Donald R. Keith Memorial Conference
West Point, New York, USA
May 3, 2018
A Regional Conference of the Society for Industrial and Systems Engineering

Modeling the Growth of Boko Haram Using System Dynamics

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Abstract: This study uses a systems dynamic approach to understand how the attacks conducted by Boko Haram influence the group's growth. Boko Haram originated in the early 2000s under Muhammad Yusuf, but the group did not become known for its violence until 2009 (Oftedal, 2013). In 2013, the United States designated Boko Haram as a Foreign Terrorist Organization (U.S. State Department, 2013). The Nigerian government's efforts to eliminate the group's influence in northern Nigeria and neighboring countries has not been successful. As Africa enters the world spotlight, the need for curbing the influence of Boko Haram strengthens. The system dynamics modeling process provides a method of understanding the relationships within the underlying structures that drive the scope of influence of Boko Haram, including organizational growth, media coverage, and attack efficacy. A formalized system dynamics model provides a basis for policy recommendations to counteract the group's efforts.

Keywords: Boko Haram, Terrorism, Extremist Organizations, System Dynamics

1. Introduction

This study examines the interactions between attacks, casualties, and media coverage to determine their impacts on the growth of Boko Haram over time. Any current counter-terrorism policies or interactions with other extremist groups were excluded from the model in an attempt to understand the internal behavior of the group so that effects of policies on growth could be evaluated. The system studied can be modeled using a stock and flow structure in which non-linear relationships, feedback loops, and time delays determine the dynamics of the system (Sterman, 2010). To further explain the model's structure, this paper will follow the system dynamics modeling process proposed by Sterman (2010): problem articulation, formulation of dynamic hypothesis, formulation of a simulation model, testing, and policy design and evaluation.

Due to the complexity of extremist organizations, the system only examines how Boko Haram's capabilities affects Nigeria's military-aged population. The model uses real world data to determine historical maxes and define values for the number of attacks conducted in a month, the number of articles per month containing specific keywords to relate them to attacks, and the number of casualties per month. The number of attacks and casualties per month where Boko Haram was the primary actor between 2010 and 2018 were found using the Armed Conflict Location & Event Data Project (ACLED) database. For the purpose of this model, media coverage is defined as the number of articles per month that contains the keywords "Boko" and "Haram". The LexisNexis Academic database was used to determine how many articles containing the search words were written between January 2010 and February 2018 using the database's newspaper sources. Articles with high similarity were filtered out to reduce the possibility of duplicate articles.

2. Problem Articulation

The United Nations ranked Nigeria "as one of the most unequal countries in the world" due to the distinct differences in living standards between the North and South (Oftedal, 2013). Northern Nigeria is predominantly Muslim with higher poverty levels than its southern counterpart comprised of mostly Christians (Oftedal, 2013). Since its radicalization in 2009, the group has targeted Nigerian security forces/policemen, Christians, politicians, schools, and other public targets, killing over several thousand people. The group's tactics have evolved from simple raids and shootings to kidnapping innocent children and using suicide bombers as a means to their ends (Onuoha, 2014). Both the Nigerian government and global actors have recognized the importance of stopping the efforts of Boko Haram.

The model examines four key variables- *potential followers*, *attacks per month*, *media coverage*, and *followers*. *Potential followers* is the percentage of Nigeria's military-aged population that becomes dissatisfied, waits some time for the

ISBN: 97819384961-2-7

dissatisfaction to settle in, and then joins a potential recruiting pool for Boko Haram. For the purpose of this model, people who are affected by Boko Haram's actions are able to become *potential followers*. The number of *followers* can only grow if there is at least one *potential follower*. *Followers* models the growth of Boko Haram over time. As this variable increases, the group's potential to carry out attacks, or *attacks per month,* increases. The underlying principle is that as the group becomes larger, more attacks can be conducted which affects the number of casualties and/or the frequency of attacks. Both the number of casualties and frequency of attacks affect *media coverage*. *Media coverage* spreads awareness of the group's existence. This affects the normal population because a certain percentage will become dissatisfied through fear, and some of the potential followers will adopt the group's beliefs and become *followers.*

The availability of data for Boko Haram is limited because there is not a direct measure of the number of followers over time. However, the ACLED database provides historic data for the number of casualties, attacks, and media coverage of attacks (as a count of articles related to attacks) from 2010 to 2017. This data is depicted in the reference modes in Figure 1. In July 2014, at approximately the same time as the peaks in both graphs, it was estimated that Boko Haram had "approximately 15,000 to 20,000 members" (Zenn, 2014). Using this estimate with the ACLED data provides an estimate of attack capacity relative to the group's population: the data show that a change in followers over time corresponds to a change in the number of attacks in the same direction. It is important to note, however, that the number of attacks per month does not necessarily correspond to the number of casualties in that same month.

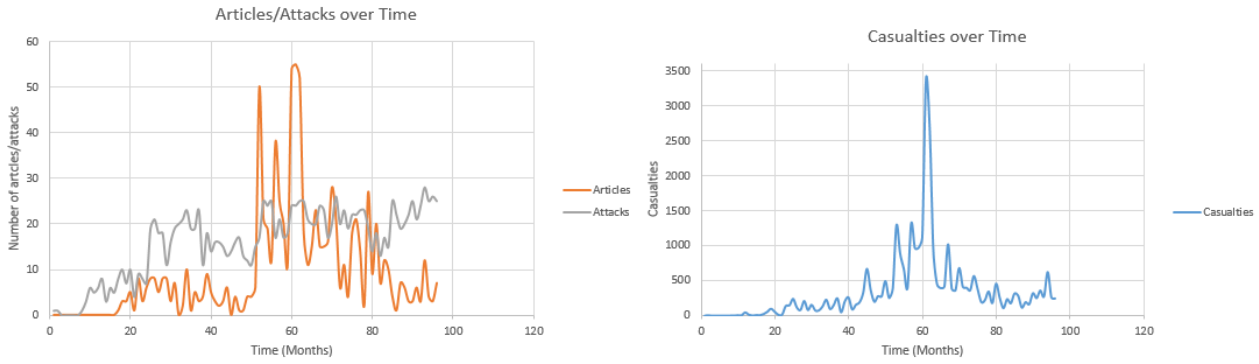

Figure 1. Reference modes for the number of articles, attacks, and casualties per month between 2010-2017

3. Formulation of a Dynamic Hypothesis

3.1 Initial Hypothesis Generation

Boko Haram capitalizes on northern Nigeria's corrupted state, and recruits members from "disaffected youth, unemployed high school and university graduates, destitute children, and some wealthy people" (Onuoha, 2014). The average age of membership is estimated to be 30 years, but children "rang[ing] from nine to fifteen" have been known to help traffic weapons (Onuoha, 2014). Without any policy implemented by the government to improve Nigeria's standard of living or security, the entire military-aged population of Nigeria is subjected to becoming dissatisfied. As *followers* increase, the group's ability to conduct more attacks will increase. As the frequency and severity of attacks increase, the media will focus its coverage on Boko Haram. This increased coverage will increase the fear within the general population (dissatisfaction within the model) and increase the amount of people who become followers.

3.2 Causal Loop Diagram

The reference modes discussed in the preceding sections provide the observable behavior of the system, which provides critical insight into the underlying structures that must interact in order to produce the modes. A causal loop diagram (CLD) is a visual representation of a mental model; it employs the observable behaviors of key variables to provide the basis of a system's structure. Figure 2, shown below, provides the foundational structure for Boko Haram's activity in Nigeria. Each

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variable is connected by an arrow which represents a causal relationship between the two variables. Links can be either positive or negative indicating polarity. If a link is positive, an increase or decrease in one variable causes the other to move in the same direction. If a link is negative, an increase or decrease in one variable causes the other to move in the opposite direction. Feedback loops are also represented in CLDs; loops can be balancing or reinforcing.

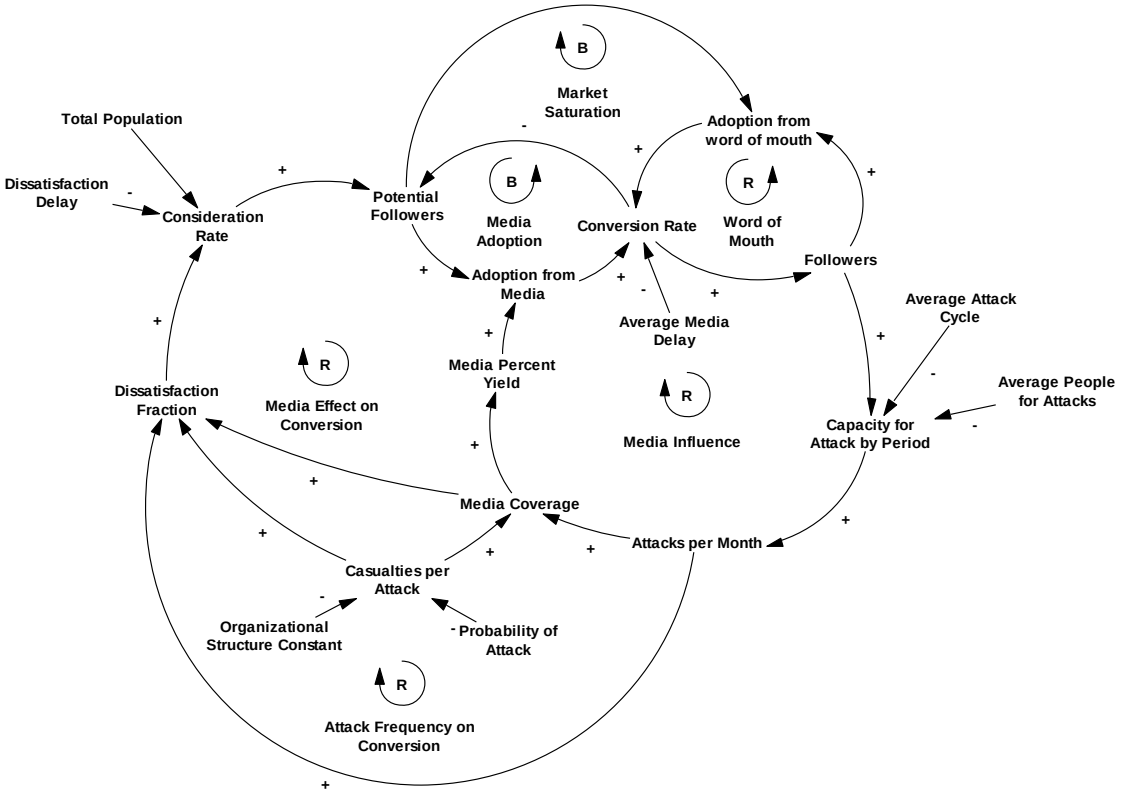

Figure 2. Causal Loop Diagram

There are two balancing loops and four reinforcing loops shown in Figure 2. There are two significant assumptions that derive the structure of the model: (1) the organization's extremist ideas are contagious and spread only through the country's population; and, (2) since the model is only concerned with growth constrained by a given population, any negative effects of media are not included within the scope of the model. These assumptions provide the basis for the Bass diffusion structure shown in the market saturation, media adoption, and word of mouth loops (Sterman, 2010). As potential followers increase, adoption from media and adoption from word of mouth increase causing followers to increase through the conversion rate. As potential followers turn into followers, there are fewer people remaining for Boko Haram to convert.

The four reinforcing loops are all similar in nature. An increase or decrease in one variable forces all others to move in the same direction. Using the media influence loop as an example, an increase in followers leads to an increase in the capacity for attack by period, which increases the group's overall attacks per month. As attacks per month increase, media coverage increases which spreads awareness of the group's actions. More people will become exposed to the group through media, and adoption from media will increase the amount of potential followers that convert to followers. Since the Bass diffusion structure is limited by Nigeria's military-aged population, the amount of followers can grow until the total military-aged population becomes a part of Boko Haram.

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4. Formulation of a Simulation Model

4.1 Specification

There are two main structures incorporated into the model that help dictate the behavior. As mentioned before, the primary structure is the Bass diffusion model (Sterman, 2010). There are two ways that non-members can join Boko Haram: 1) by personal interactions with members, and 2) by media influence. The model does not currently account for any recovery rate so any *potential follower* that converts into a *follower* cannot exit unless they participate in a suicide action. *Followers* will increase until every military-aged person in Nigeria is converted.

The second structure is the first-order material delay at *consideration rate* and *conversion rate*. The outflows of the *unaffected population* and *potential followers* are proportional to the number of people within each stock. Any person within the stock has an equal chance of moving into the next stock (Sterman, 2010). The *dissatisfaction* and *average media delay*s are the times a person needs to feel the effects before transitioning to the next stock.

4.2 Estimation and Assumptions

The model operates under the assumption that only Nigerians can join Boko Haram. The initial value of *followers* is set to one person to represent the group's existence. Table 1, shown below, elaborates on the initial conditions for all exogenous variables in addition to some of the linear regression relationships determined through data analysis. The limited availability of data for Boko Haram made it necessary to assume initial values for seven exogenous variables. Those variables are marked with an asterisk and were tested to determine which had a greater effect on the model. This will facilitate future work efforts to concentrate on refining variables that carry the most weight in the model.

Table 1. Explanation of exogenous variables

Variable	Value (units)	Description
Total Population	122,200,000 *(People)*	The current estimated population of Nigeria between the ages of 10-54 (Central Intelligence Agency, 2018)
Dissatisfaction Delay*	1 *(Month)*	The amount of time it takes for someone to become dissatisfied as a result of the combination of frequency of attacks, severity of attacks, and media coverage
Average Media Delay*	2 *(Months)*	The amount of time it takes a potential follower to process media coverage and decide that they want to convert
Probability of Joining*	0.30 *(Dimensionless)*	The likelihood that a potential follower will become a follower
Average Attack Cycle*	0.5 *(Months)*	This is the average amount of time between attacks conducted by the terrorist group
Average People for Attacks*	10 *(People/Attack)*	The average number of followers it takes to conduct one attack. As groups become more efficient (i.e. use suicide bombers in crowded places, the average should decline)
Contact Rate*	2 *(People/People/Month)*	The rate at which potential followers interact with followers per month
Exit Rate*	2 *(People/Month)*	The monthly rate at which a follower leaves the group through suicide bombings or other self-inflicting measure
Historical Max for Attacks per Cycle	28 *(Attacks/Month)*	The amount of attacks an organization wishes to conduct in one month is based off the highest amount of attacks carried out previously (ACLED, 2018)
Historical Max for Casualties	3374 *(People/Month)*	The max number of casualties between 2010 and 2018 in a month attributed to Boko Haram (ACLED, 2018)
Historical Max for Media	55 *(Articles/Month)*	The highest number of articles in a month containing the key words "Boko" and "Haram" between 2010 and 2018 (NexusLibrary Database, 2018)
Media effect coeff	0.7122 *(Articles/Attack)*	The linear regression coefficient for the linear relationship between attacks per month (x) and articles per month (y) (ACLED, 2018)
Media effect coefficient	0.017268 *(Dimensionless)*	The linear regression coefficient for the linear relationship between casualties per month (x) and articles per month (y) (ACLED, 2018)
Probability of Attack	.80 *(Dimensionless)*	The likelihood of an attack creating *x* number of casualties (Gourley, 2009)
Organizational Structure Constant	2.5 *(Dimensionless)*	The organizational structure of the insurgency. Distribution of the group's strength. Unstable organizations that are more fragmented have slopes between 2.5 and 3.0; stable organizations that are more solidified have slopes between 2.5 and 2.0 (Gourley, 2009)

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4.3 Stock and Flow Diagram

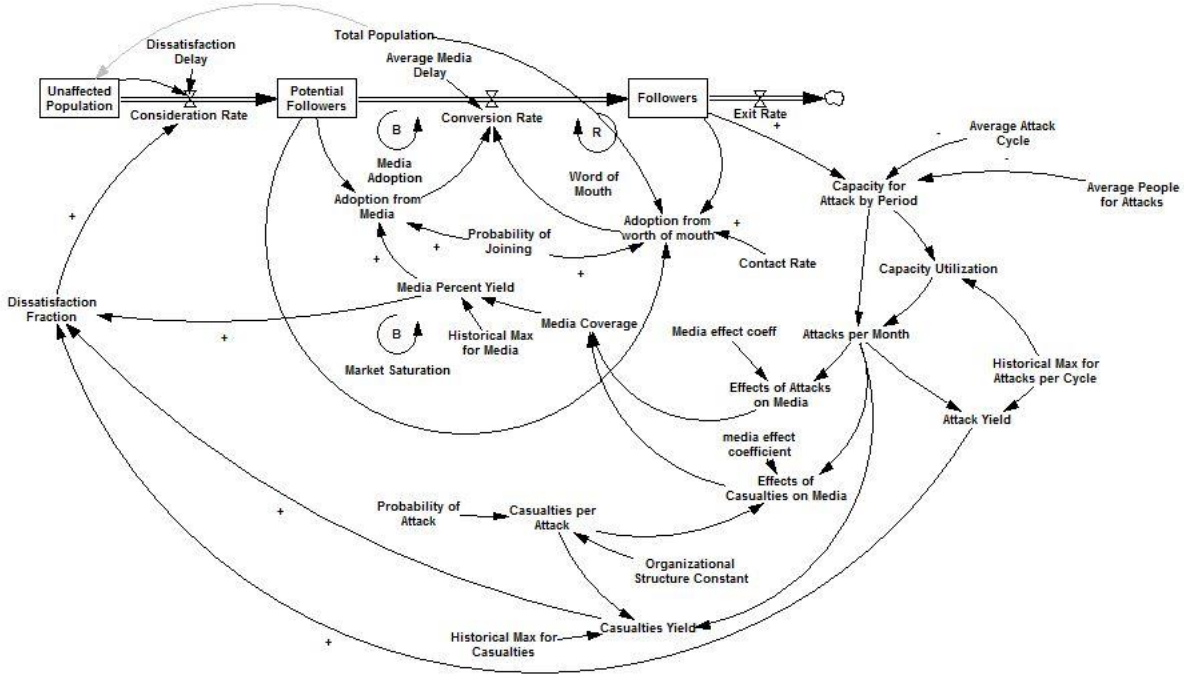

Figure 3. Stock and Flow diagram

The stock and flow diagram in Figure 3 is converted from the CLD in Figure 2. The initial values for the *unaffected population, potential followers,* and *followers* are set to the *total population,* zero, and one respectively. Unlike the CLD, Figure 3 contains the linear regression relationships created using real world data taken from ACLED. The linear regression equations for both *effects of attacks on media* and *effects on casualties on media* will need to be refined in future work to produce a better fitting model.

5. Testing

5.1 Model Behavior

Model testing should focus "on the limitations of the model so it can be improved and so clients will not misuse it" (Sterman, 2010). In order to understand the limits of this model, a structure assessment, extreme conditions test, and sensitivity analysis were conducted.

The structure assessment test determines if the structure of the model generates the desired behavior (Sterman, 2010). Due to the Bass diffusion structure, *followers* was constructed as to demonstrate S-shape behavior which is produced by the model shown in Figure 4. The reason that *followers* does not reach the total population is due to the low *dissatisfaction fraction* value. Additionally, the *dissatisfaction delay* was structured so that the *potential followers* stock would begin to increase after people had time to feel any dissatisfaction with the current state of Nigeria.

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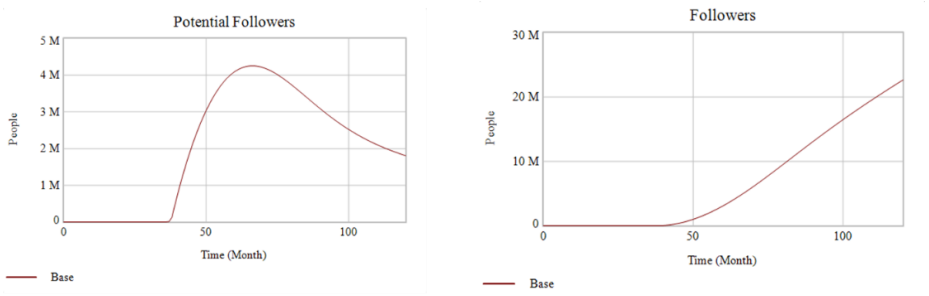

Figure 4. Reference modes for key variables *potential followers and followers*

5.2 Robustness under extreme conditions

Extreme condition tests subject the model to "large shocks and extreme conditions" to ensure that it will behave properly even when exposed to rare cases (Sterman, 2010). Extreme condition tests were completed for the seven exogenous variables identified in Table 1. The extreme values for *dissatisfaction delay* were zero months and 50 months. If there was no *dissatisfaction delay*, the population would be dissatisfied almost immediately and *followers* would reach the maximum capacity within the first few years. If the delay was 50 months (approximately four years), *followers* would grow at an extremely slow rate. The extreme values for *average media delay* were zero months and 50 months. If there was no media delay, *potential adopters* would automatically be persuaded to convert to a *follower*. This would result in *followers* growing at a faster rate. If the media delay was approximately four years, it would take longer for *followers* to increase. The *probability of joining* was set to zero and one. If there was no likelihood that a *potential follower* could convert into a *follower*, followers would never increase. If all *potential followers* converted, *followers* would increase at a faster rate. The *average attack cycle* was set to daily and every other year. If the group conducts attacks every day, the *dissatisfaction fraction* would reach one sooner and therefore more people would transition into the *potential followers* and *followers* stocks. If the group only conducts one attack every other year, *followers* would be close to nonexistent. A*verage people for attacks* was set to one person and 100 people. If the group becomes efficient and uses suicide bombers more often, the group could carry out several more attacks and therefore *followers* would increase faster due to a quicker change in the *dissatisfaction fraction.* If the group needed 100 people to conduct one attack, it would take longer for *followers* to grow. *Contact rate* was set to zero and 100 person/people/month. If there was no contact between nonmembers and members, the only growth would be from the *media adoption* loop, and it would take longer for *followers* to increase. A higher contact rate means interactions between nonmembers and members are more frequent resulting in *followers* growing at a faster rate. Finally, *exit rate* was set to zero and 500 people per month. If no people leave the system, *followers* will be able to grow at a faster rate. If people exit at a faster rate, it would take longer for *followers* to increase. After ensuring the equations in the model functioned with values of zero, the robustness test results matched the hypotheses listed in this section.

5.3 Sensitivity Analysis

Sensitivity analysis can be conducted in order to determine which exogenous variables have a greater effect on the number of followers. Variables with greater effect when subjected to change should be the primary focus of future work to determine more accurate estimations and provide a more useful model. For the purpose of this study, the seven exogenous variables in Table 1 were increased and decreased from the base value by 75% except for *contact rate* which was reduced to one since people must be in whole integers. The variables that resulted in the least amount of change and are not depicted were *average media delay, average attack cycle, average people for attack, exit rate,* and *contact rate.* The results for the variables, *dissatisfaction delay* and *probability of joining*, that demonstrated the largest change are shown below in Figure 5.

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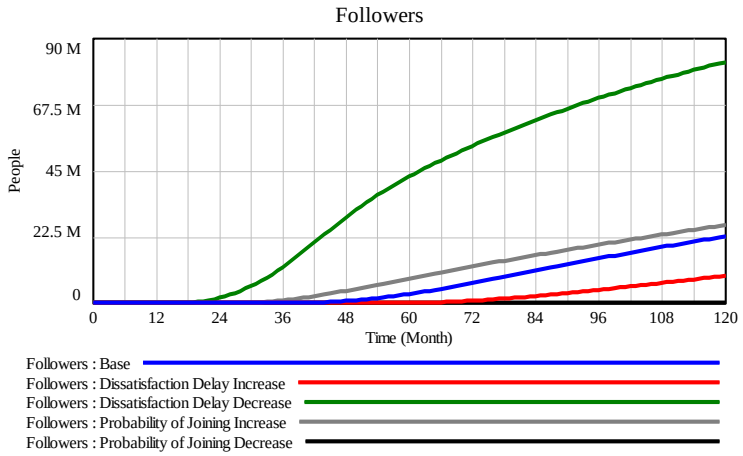

Figure 5. Sensitivity analysis results for increasing and decreasing the dissatisfaction delay and probability of joining variables by 75%

6. Policy Design and Evaluation

Models are "simplifications" that help solve problems given a specific purpose (Sterman, 2010). Given the scope of this model, Boko Haram is only able to grow aside from its natural *exit rate*. This allows policymakers to understand the internal interactions of the group in an attempt to design a policy that limits growth. Given the model's current structure, a policy that reduces the effects of *consideration rate* and/or *conversion rate* would reduce the rate at which *followers* grows. One policy cannot completely eradicate Boko Haram or the ideas the group represents. In an assessment of Nigeria's counter-terrorism policies against Boko Haram, the Nigerian government has identified several areas of improvement that would mitigate the effects of Boko Haram to include poverty reduction, border patrol, increased military and police funding, increased infrastructure, and an increase in education among younger aged citizens (Faluyi, 2017).

In order to demonstrate the effects of a growth limiting policy, an education component is introduced into the model as shown below in Figure 6.

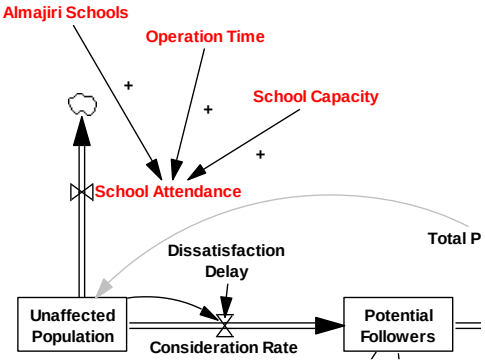

Figure 6. Policy attempt using the creation of Almajiri schools as an attempt to reduce the potential recruiting pool

Northern Nigerian schools are predominantly Quranic, and these schools do not provide food for kids so they are forced to search for food on the streets (Faluyi, 2017). These children, also referred to as the *Almajiri*, are approximately seven and a half million prime targets for Boko Haram recruiters (Isiaka, 2015). To retaliate the group's recruitment in these predominantly Muslim areas, the government began opening up *Almajiri* Integrated Schools where western education and

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Quranic teachings are combined (Isiaka, 2015). A total of 125 *Almajiri* schools are scheduled to be built across 27 states, and 80 have reached completion (Isiaka, 2015). In Sokoto, over 300 students were able to attend an *Almajiri* school (Auwal, 2014).

Using these statistics as a basis for the policy, a *school attendance* outflow was added to the *unaffected population* stock. *School attendance* is defined as the total number of *Almajiri schools* multiplied by the *school capacity* divided by a school's *operation time.* The model was setup so that if the number of schools is zero, there would be no change to the original model. By adding more *Almajiri schools*, school-aged kids are not roaming around the streets of northern Nigeria subject to Boko Haram's recruitment strategies. Long-term schooling effects such as increased literacy and enhanced decision making skills are not depicted by the model but are assumed to reduce the growth of followers over time.

7. Conclusion and Future Work

The model's structure generates S-shaped behavior that is dependent on the size of the country's population. In actuality, Boko Haram is primarily concentrated in northeastern Nigeria and has been suspected of recruiting in neighboring countries (Oftedal, 2013). The initial value for the Total Population variable should be refined to reflect a more accurate number given certain geographical and aging constraints. All exogenous variables should be further refined to assess accurateness, but the dissatisfaction delay and probability of joining are the greatest exogenous variables sensitive to change. If possible, nonlinear transformations should be applied to the current regression relationships defined between the attacks on media and casualties on media variables to improve the regression values. Additionally, the current structure does not account for media having a limiting factor on growth. A variable that reduces potential followers given some media exposure should be included to account for both positive and negative effects of media. Overall, the model provides a general framework for depicting the growth of extremist organizations of any kind, not just Boko Haram, if data is available.

8. References

Armed Conflict Location & Event Data Project (ACLED). (2018). *Africa data from January 2010 to February 2018 with Boko Haram as the actor* [Data file]. Retrieved from https://www.acleddata.com/data/

Auwal, A. (2014, August 7). Two years of sokoto's almajiri integrated school. *The Daily Trust.* Retrieved March 6, 2018, from https://www.dailytrust.com.ng/daily/education/31062-two-years-of-sokoto-s-almajiri-integrated-school

Central Intelligence Agency (CIA). (2018). *The world factbook.* Retrieved March 5, 2018, from https://www.cia.gov/library/publications/the-world-factbook/geos/ni.html

Faluyi, O. (2017). *An assessment of nigeria's counter-terrorism policies against boko haram* [Masters dissertation].

Gourley, S. (2009). *Sean Gourley : The mathematics of war* [Video file]. Retrieved from https://www.ted.com/talks/sean_gourley_on_the_mathematics_of_war

Isiaka, T. O. (2015). A pilot study of the challenges of infusing almajiri educational system into the universal basic educational programme in soko, nigeria. *Journal of Education and Practice, 6(16),* 10-16.

LexisNexis Academic. (2018). *Articles between January 2010 and February 2018 containing words « Boko » and « Haram »*[Data file]. Retrieved from http://www.lexisnexis.com/hottopics/lnacademic/

Oftedal, E. (2013). *Boko Haram- an overview* (FFI-rapport 2013/01680). Kjeller, Norway : Norwegian Defence Research Establishment. Retrieved October 29, 2017, from http://www.ffi.no/no/Rapporter/13-01680.pdf

Onuoha, F. (2014). *Why do youth join boko haram ?* Retrieved from the United States Special Institute of Peace website : https://www.usip.org/publications/2014/06/why-do-youth-join-boko-haram

Sterman, J. D. (2010). *Business Dynamics : Systems Thinking and Modeling for a Complex World* (Indian ed.). New Delhi, Delhi, India : The McGraw-Hill Companies, Inc.

U.S. Department of State. (2013). Country reports on terrorism, chapter 6- foreign terrorist organizations. Retrieved October 29, 2017, from https://www.state.gov/j/ct/rls/crt/2013/224829.htm

Zenn, J. (2014). Boko Haram: recruitment, financing, and arms trafficking in the Lake Chad region. CTC Sentinel, 7(10), 5+. Retrieved from http://link.galegroup.com/apps/doc/A390188246/PPWT?u=nysl_se_usma&sid=PPWT&xid=7b557afc

ISBN: 97819384961-2-7