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BATTLEFIELD SIMULATIONS FOR CANADIAN ARMY INDIRECT FIRE MODERNIZATION OPTIONS ANALYSIS

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ABSTRACT

Computerized battlefield simulations were conducted for an Operational Research and Analysis study by the Land Force Operational Research Team for the Canadian Army Indirect Fire Modernization project. The goal was to assess the relative strengths of a set of Indirect Fire options. The simulations were designed on Python programming language, with the SimPy package, and utilized data collected in workshops with subject matter experts. The simulation had multiple scenarios, probabilistic distributions of tasks and task frequencies and targets depending on the size and capability of the enemy threat. Options considered in the project consisted of 81 mm mortars, 120 mm mortars, M777 light-weight towed howitzers and rockets. Emphasis was placed on data collection to ensure the inclusion of relevant scenarios and identification of weapons systems specifications for the model. Indirect Fire asset usage, ammunition consumption and task success were the main results.

1 INRODUCTION

The Department of National Defence (DND) and Canadian Armed Forces (CAF) are undergoing several Force modernizations. The Indirect Fire Modernization (IFM) project seeks to modernize the CA Indirect Fire (IF) capability. Currently in the Identification phase, the IFM project aims to deliver new equipment or retrofit existing equipment. The Canadian Army (CA) currently has 81 mm portable mortars and 155 mm light-weight towed howitzers (LWTH). The IFM project director approached the Land Force Operational Research Team (LFORT) with a request for Operational Research and Analysis (OR&A) support.

Past OR&A work relying on preference ranking, value-focused thinking and schools of thought methodologies recommended an IF force structure consist of LWTH, mortars and possibly, if budgets could allow for them, centralized or de-centralized rocket systems (Pond, Cameron and Conod 2008). IFM examined the relative performance of options which are different combinations of assets in various proportions for the deployed IF force structure (between six and 18 LWTH, six and 12 81 and/or 120 mm mortars, and two to eight rocket systems). The simulations results will be used by the IFM project team to plan to deliver an optimal mix of IF assets.

2 METHOD

A method called the “Vignette, Task, Requirement and Option” (VITRO) analyses approach (Dooley and Gauthier 2013) was selected for the OR&A study. The VITRO methodology is a way to map from a space of related options to a numerical measurement or score, such as success percentage. The VITRO methodology works by breaking up the problem into four interrelated analysis steps: 1) Describe potential vignettes involving the equipment/capability under consideration and estimate their relative probabilities of occurrence; 2) in these vignettes, define the tasks to be accomplished. What are their likelihoods and importance? 3) State the requirements for each task or each task/vignette combination, if the requirements are situation dependent; and, 4) provide the options. What are their capabilities and specifications? The option assessments are dependent on accurate data from each step in the methodology.

Once the data is collected, results are weighted across the vignette set using the relative probabilities of the vignettes to derive an overall, vignette-weighted score for each option. The scoring process works by step backwards, beginning at options (4) whose capabilities and specifications may or may not meet the requirements (3) of the tasks (2) in each vignette (1). In the simplest form, the calculations are binary (yes/no) for any given option and particular task in each vignette. However, in IFM, many factors are involved in determining which tasks can be completed by the different options. There is a need for simulations of the battlefield. The principal output of the simulations is the percentage of task success in each vignette.

2.1 Data Collection

Data for the VITRO analyses was collected during two working groups (WG) with experts in the domain of IF support to combat missions, the project team and OR&A scientists; this data became the necessary inputs into the battlefield simulations. An overview of the steps of the process is given in Figure 1.

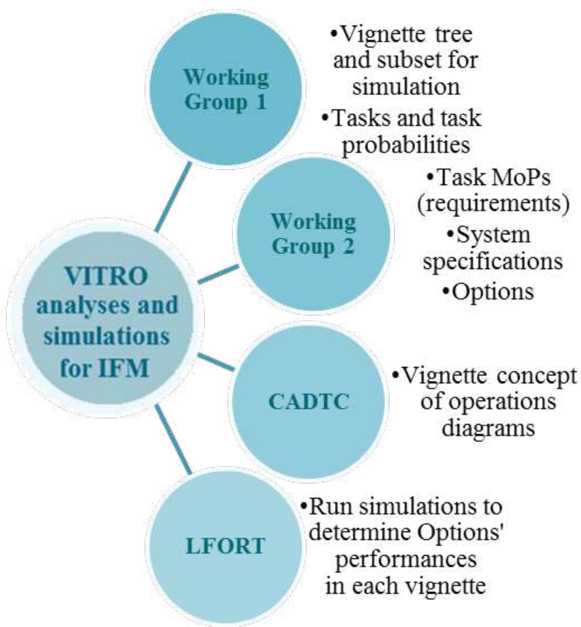

Figure 1: Overview of VITRO analyses with simulations for IFM.

Table 1 shows the list of data factors, what they entail and method of collection. Data types could be researched or analytic; the difference being whether experts' opinions were involved. Researched data tended to be more reliable but time consuming to collect. Analytic data could fill in where numerical quantities were required but were not available in the literature. Scale-based and ratio-based data collection methods (e.g., pair-wise likelihood assessments) were employed when the experts could not provide numerical estimates directly.

Table 1: Data factors, types, sources and method of collection with examples.

Factor	Source of data	Data type and collection method	Example(s)
Options	Project sponsor	Analytic and researched data (numerical)	Baseline option has six LWTH and 12 81 mm mortars.
System specifications	Manuals or industry	Researched data (numerical)	For 81 mm mortar, Burst rate of fire: 20 rounds per minute; Maximum range: 5600 m.
Vignette tree/subset of vignettes for simulation	WG steering committee	Analytic data. Tree adopted by WG. Subset selection by group consensus.	See Figure 2
Vignette probabilities	WG	Analytic data (numerical). Pair-wise likelihood method to estimate relative probabilities.	Against Near-peer enemy threat, COIN is four times more likely than Conventional Operation.
Vignette parameters and target type probabilities	WG	Analytic and researched data (numerical). Scale-based. Group consensus. Pair-wise with eigenvector method to estimate target type probabilities.	For relative task frequency, on a scale from 1 to 7, Vignette X is a 7, Vignette Y is a 4 and Vignette Z is a 2. Armored targets are 3 times as likely as Structures in Vignette X.
Vignette concept of operations diagrams	CADTC	Analytic data. Project sponsor adopted.	See Figure 3
Task list	(DND 2012)	Researched data. WG revised and adopted	Suppress, Neutralize, Destroy…
Task probabilities	WG	Analytic data (numerical). Scale-based using seven-point scale. Group consensus.	Suppress rated: “as likely as not (30% - 70% probable)” in the COIN Operation, against a Less-than-peer enemy threat.
Task requirements	(DND 2004)	Analytic and researched data (numerical). Group consensus, where applicable.	Task Areas are scaled based on Enemy Threat. Sustained time: 2 – 4 min.

2.1.1 Vignettes

A set of 36 vignettes was proposed by the WG steering committee. The relative probabilities were estimated by the pair-wise likelihood method. For the simulations the WG selected six of the vignettes. Figure 2 presents the vignettes on a plot with relative probabilities on a logarithmic scale on the vertical axis and vignette number on the horizontal, category axis. The simulations consisted of two vignettes against each of the Peer, Near-peer and Less-than-peer enemy threats and were either Counter Insurgency (COIN) or Conventional in nature. None of the Peace Support vignettes were considered for simulation in the study due to the small role IF would play in that type of operation. Four of the selected vignettes (8, 20, 32 and 35) were in a large Area of Operation (AO) (70 km × 70 km) as opposed to a medium AO (35 km × 35 km) for the other two vignettes (10 and 22). Vignette parameters were developed in the second WG. They included task frequency, enemy counter battery capability, direct fire threat and dispersion of IF assets and were assessed using a relative scale from 1–7.

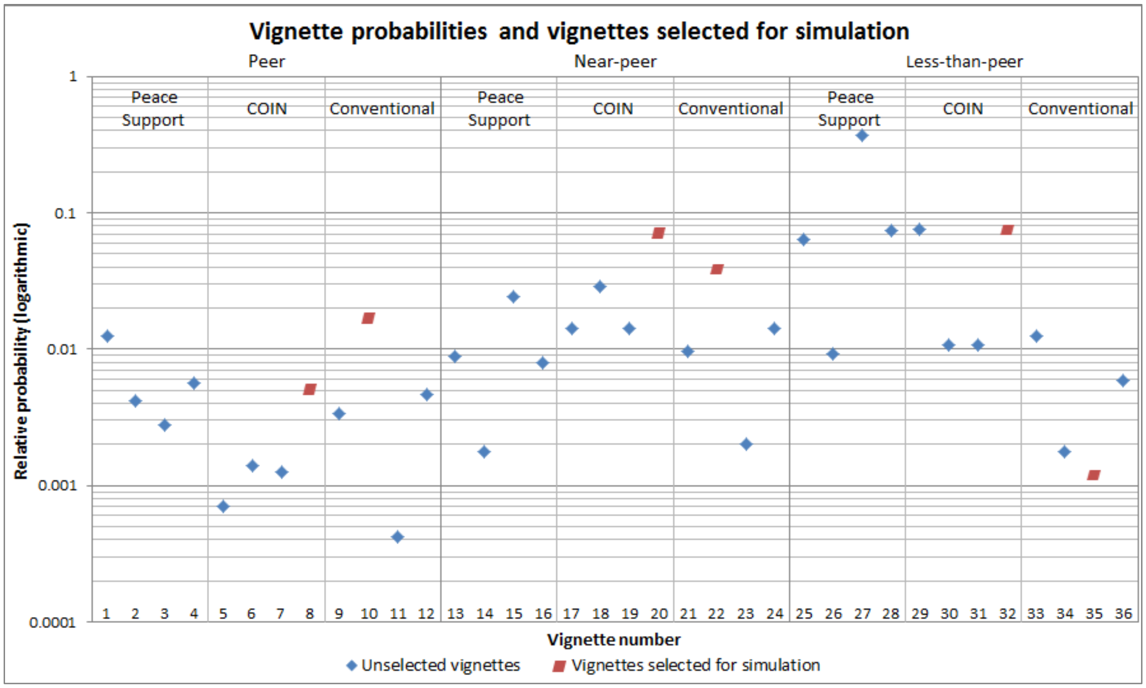

Figure 2: Vignette relative probabilities with selections for simulation.

The Canadian Army Doctrine and Training Centre (CADTC) produced Concept of Operation diagrams for each of the six vignettes selected for simulation. Figure 3 is a concept of operation diagram for the COIN operation against Less-than-peer enemy threat vignette. The diagrams were the foundation to initial battlefield configurations in the simulations.

2.1.2 Tasks and Requirements

A task list proposed by the steering committee was revised and adopted during the WG. The adopted list was: Suppress, Neutralize, Destroy, Disrupt, Illuminate, Deliver Non-lethal effects, Obscure, Mark (Indicate), Deliver Precision effect and Interdict. The tasks were assigned probabilities for each vignette using a seven-point scale. Numerical assessments for the requirements were made by the experts in the WG. The task requirements are: sustained time, task area and whether a particular ammunition type was preferred or required (e.g., smoke, illumination, precision guided). In addition, target types were associated with each task. The target types were Personnel, Armored, Structure and Materiel with different probabilities of occurrence depending on the vignette.

2.1.3 Indirect Fire Asset Specifications and Options

IF asset specifications were collected during the WG. Most of the data was available through various sources. Firing rates, set-up times, ammunition types available, minimum and maximum range are some examples of asset specifications. 66 options were considered, 30 without rockets, 32 with rockets and four options consisting of just LWTH including some long-range, to compare with options with just LWTH and rockets.

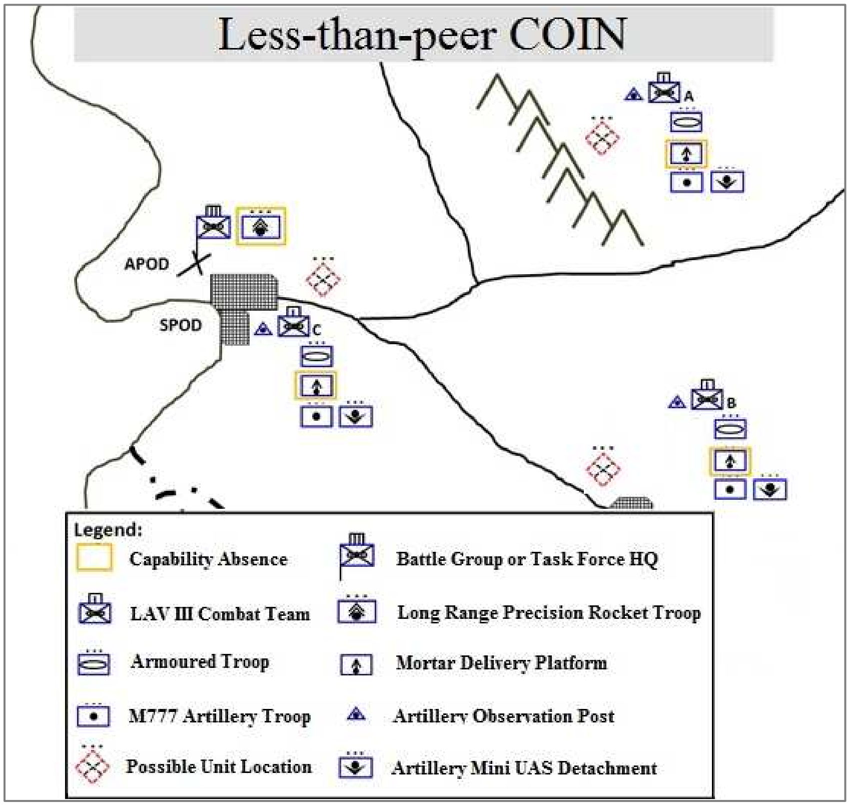

Figure 3: Concept of Operation diagram for Vignette 32.

2.2 Battlefield Simulations

The simulations for the IFM project were developed using Python with SimPy add-on package. Each vignette was a separate simulation with 50 replications run per option. Each simulation run represented approximately 24-hours (1500 minutes) of combat time. Additional runs for all six vignettes had 60% of all tasks involving an urban area in which precision munitions were required and the tasks could result in collateral damage (this was tracked by the number of tasks involving collateral damage).

Since the study relied on its own custom-designed simulation, it was limited to modelling IF system usage, including time spent moving and setting up. The enemy force was not modelled such as movements of individual targets, neither were the Light Armored Vehicles (LAV) nor Unmanned Aircraft Systems (UAS). Also the prioritization of fires is beyond the scope of this study, but may be a topic for further study.

2.2.1 Calls for Fire and Asset Employment

Each combat team (A, B and C; see Figure 3) was identical with respect to IF asset composition. Remainder units (after dividing by 3) were reserved within the Task Force HQ, around the Air/Sea Point of Debarkation (APOD/SPOD) or rear position. The simulations have a unique task generation model that is intended to reflect how IF assets are employed in Adaptive Dispersed Operations (as in Figure 3). The artillery responds to calls for fire. It was posited that 90% of tasks would be calls for fire by combat team commanders, in which the target would be within 10 km of the combat team to which it is associated (regular tasks). The remaining 10% of tasks are targets of opportunity: strategic calls for fire at the Battle Group level that could occur anywhere in the AO.

In general, tasks are completed when sufficient assets to cover the task area with rounds are available and within range. An asset is considered available if it is not currently engaged with a task. However, assets may *still* be considered available if engaged with a task that is in support of a combat team other than its own: the assets may be recalled from tasks in support of other combat teams, in order to complete a task for their own combat team.

For a regular task, at least one asset from the associated combat team must be employed; the task cannot be completed exclusively by other combat teams assets, reserve units, or combination thereof. Perhaps unintuitive, but if all the assets in a combat team are currently engaged, no new regular tasks would be generated for that combat team. This could be a question for future work on priority of fires and task queuing for IF support. It was deemed that Commanders of the combat teams would not attempt to undertake additional tasks if all their artillery units were in use. For targets of opportunity, any available units within range could be employed.

3 RESULTS

Tasks were considered successfully completed if the time the first round on the target was four minutes after the call for fire or less. Other measures of option effectiveness included: amount of collateral damage for urban excursion, total number of tasks completed as well as the percentage of tasks completed without interrupting IF assets from other tasks (a measurement of the confidence of having sufficient weight of fire for given tasks). Additional results include ammunition consumption by asset and ammunition types, histograms that plot the relationship between tasks and distances from the targets to the artillery units that completed them and/or associated combat teams, showing both successful and failed tasks.

A summary of the percentage of task successes for two classes of option in each vignette is presented in Figure 4. The VITRO scores for the options were generated by calculating the weighted averages across the six vignettes, with the relative vignette probabilities as weights. Table 2 and Table 3 present the results for the different classes of option in the case of non-urban and urban vignettes, respectively.

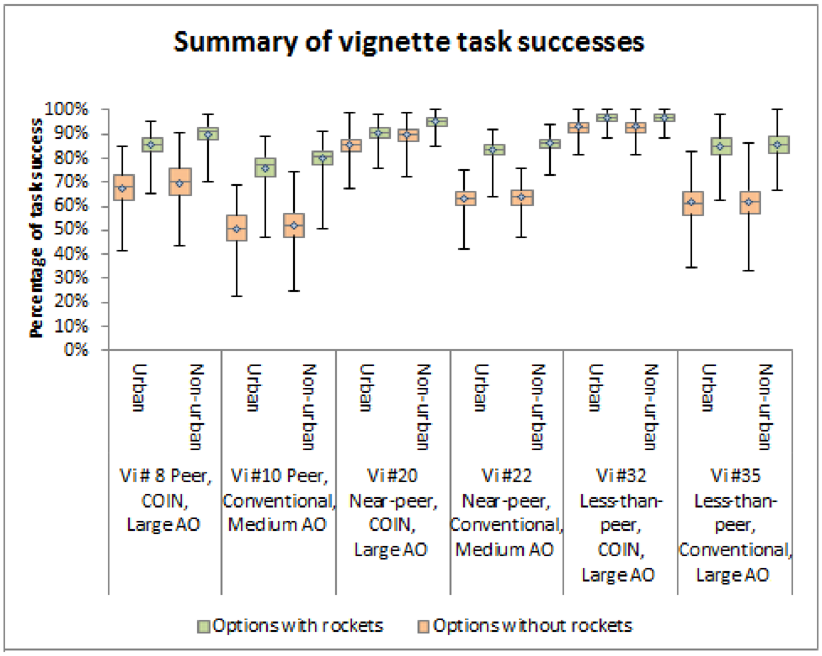

Figure 4: Summary of simulation results with classes of option with and without rockets.

In Figure 4, each box and whisker is representative of 1500 or 1600 data (30 or 32 options × 50 replications—options with long-range LWTH not included). In general, options with rockets performed better than options without rockets. The Peer enemy threat and the Conventional operation vignettes (8, 10, 22 and 35) have lower percentages of success compared to the Near-peer or Less-than-peer COIN vignettes (20 and 32). Percentages of success were lower in the urban excursions except in the Less-than-peer vignettes (32 and 35) for options without rockets. Comparisons were made using the student's *t*-test for two distributions with unequal variance (for the aforementioned comparisons, tests had p-values less than 0.0002).

In Tables 2 and 3, each row provides the range of the result scores for the particular class of option. There can be a different number of options within each class. For example there are just four options with long-range LWTH, but there are 32 options with rockets. The option compositions have a significant effect on the result scores, since results from different classes of option (different rows) differed substantially, in some cases. For instance, the options with rockets class was by far the best performing class of option in the non-urban vignettes. In the urban setting, both the Baseline and long-range LWTH option classes had similar results, and the options with rockets still performed the best but not as well as in the non-urban vignettes.

Table 2: Average percentage of task successes (non-urban vignettes).

Option class	**Result score range**
Baseline and LWTH	76 – 84%
81 mm mortar mounted and LWTH	81 – 83%
120 mm mortar and LWTH	83 – 86%
81 (unmounted) and 120 mm mortar and LWTH	83 – 85%
Options with rockets	89 – 95%
Long-range LWTH	80 – 87%

Table 3: Average percentage of task successes (urban vignettes).

Option class	**Result score range**
Baseline and LWTH	72 – 79%
81 mm mortar mounted and LWTH	78 – 81%
120 mm mortar and LWTH	81 – 84%
81 (unmounted) and 120 mm mortar and LWTH	81 – 83%
Options with rockets	84 – 92%
Long-range LWTH	74 – 79%

4 CONCLUSIONS AND FUTURE APPLICATIONS

The VITRO methodology was invaluable to this study. The inclusion of the subject matter experts in each step of data collection increased the sponsor's investment in the methodology and results. This inherently increased their understanding of the simulation and its limitations, as the style of the results presented was anticipated by the client because of their involvement.

Simple modifications to the process used for this work may allow future work to generate more reliable estimates. It would be possible to obtain the same type of data without group consensus for the estimates of task probabilities and ranges of values for task requirements, and instead collect data from all the experts individually and perform a compilation.

As evidenced by Dooley and Gauthier (2013), not all applications of VITRO will include simulations. That depends on the type of application and the complexity of the mapping between options and requirements and the calculations of task success rates. From experience conducting this OR&A work, the challenges identified were the vignette and requirement steps; that may from other future applications. There was the challenge of creating a set of vignettes that are relevant, plausible and cover as much as possible in the realm of possibility. Requirements posed more of a technical problem; understanding what the specific data to collect was a challenge and collecting it was time consuming.

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AUTHOR BIOGRAPHIES

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