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Cold Regions Research and Engineering Laboratory

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An MCA Linear Additive Method for Research Project Analysis

Katrina Burch

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Abstract

This report describes a business intelligence (BI) model developed by the Cold Regions Research and Engineering Laboratory (CRREL) to evaluate multiple projects simultaneously and help researchers learn descriptive phrases found in alignment sources representative of their projects. The BI model combines the linear additive model with the analytical hierarchy process to take advantage of the qualitative and quantitative nature of both methods. The model has five variations, all built along the same objectives but with different criteria due to the specialized emphasis areas of each variation. The BI model operates around three central concepts for evaluating the projects: Alignment Variables, Timing, and Customer Relationship. A use-case scenario with ten projects shows the effectiveness of the model and compares it with another model from the United States Military Academy. This new BI model will assist researchers in developing and proposing research ideas that are more relevant and fundable.

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Preface

This study was conducted for Headquarters, US Army Corps of Engineers.

The work was performed by the Signature Physics Branch of the Research and Engineering Division, US Army Engineer Research and Development Center–Cold Regions Research and Engineering Laboratory (ERDC–CRREL). At the time of publication, Mr. Paul Kutia was branch chief; and Dr. John Weatherly was acting division chief. The deputy director of ERDC–CRREL was Dr. Ivan P. Beckman, and the director was Dr. Joseph L. Corriveau.

COL Christian Patterson was commander of ERDC, and Dr. David W. Pittman was the director.

Executive Summary

This report describes a new business intelligence (BI) model that can help researchers and program developers at the US Army Engineer Research and Development Center's Cold Regions Research and Engineering Laboratory (ERDC-CRREL) align their projects with the priorities and needs of the DoD and its component services. The BI model uses a multicriteria analysis framework to compare multiple projects simultaneously and to provide a numerical score for each project based on how well it meets five objectives:

1. Alignment of R&D to DoD critical technology areas
2. Alignment of R&D to service priorities
3. Congressional Budget R-Forms keywords
4. Project length
5. Customer relationships

The model also helps researchers learn descriptive phrases found in alignment sources, such as policy statements, capability gaps, and budget documents, that can best portray their projects in proposals.

This report explains the rationale and motivation for developing the BI model, as well as the details of its structure and operation. The model has five variations, each with a different emphasis area: Army, Navy, Air Force, US Army Corps of Engineers (USACE), and Arctic. Each variation has slightly different criteria for the objectives, but all use a combination of the linear additive model and the analytical hierarchy process to derive the weights and scores for each project. The report also describes the fit screening step that precedes the use of the model, which filters out projects that do not meet the basic requirements or strategies of USACE or ERDC.

This report presents a use-case scenario with ten projects that are evaluated by the BI model using each variation. The results show that the overall project scores are generally close to each other, with a narrow range of 22%, except for the Arctic variation, which has higher scores due to the nature of the projects. The report also compares the results with those from a similar model developed by cadets from the US Military Academy and discusses some of the differences and limitations between the two models.

This report concludes that the BI model can supply objective and transparent information for decision-making, as well as guidance for improving project descriptions and alignment. This BI model would be most useful at the technical director's office or at the branch chief level, where it can aid researchers in cultivating their projects and understanding the language and demand signals from potential customers and funding agencies. The report also names some potential future enhancements for the model, such as adding more features or data sources.

1 Introduction

1.1 Background

Several motivations drive the necessity of a business intelligence (BI) model. The Cold Regions Research and Engineering Laboratory (CRREL) technical directors sought an unbiased method to determine the demand signal for technology in the DoD and to help guide researchers towards alignment and future funding lines as they connect projects to "middle lanes" (like the 2022 Arctic Science and Technology workshop) and to the overarching drivers from the Office of the Secretary of Defense (OSD). Additionally, the technical directors wanted a systematic way to look at who might be interested in the deliverables, to identify cross function teams and stakeholders, and to define alignment to nationwide priorities by examining policy statements and identified capability gaps and needs.

One of these alignment materials is the R-Forms, which are congressional budget materials that researchers can use to determine stakeholders who would benefit from their research and who are already funding similar work. Researchers and program developers need a process to gauge funding behavior by using previous and currently funded research, information that is in the R-Forms for each service annually. Yet, many researchers at CRREL do not know that this report exists or where to find it.

The technical directors have led the formation and development of a model that could be used to evaluate multiple projects simultaneously, while also providing a means that researchers can adopt to learn descriptive phrases found in the alignment sources to best portray their projects in proposals. A model began to take form that would fill these gaps, as well as provide some early business intelligence for management and supervisors.

1.2 Objective

The BI model described in this report will assist researchers as they cultivate their projects by assisting them in understanding the language used in the R-Forms. This method will allow researchers to determine the demand signal and help guide them towards programs and future funding lines. Furthermore, the researchers will learn how to align research projects with the terms found in congressional funding that are used repeatedly and funded out for several years.

1.3 Approach

Researchers and program developers need a method for determining research alignment to nationwide priorities by reviewing policy statements and identified capability gaps and requirements. A systematic approach to examining which customers might be interested in project deliverables, as well as a method to identify cross-function teams and stakeholders, is currently lacking at the initial stages of project development. Researchers and program developers require a tool that helps review how certain words in project descriptions fall into product need streams (i.e., what is being funded).

1.4 Report Organization

To further explore this process and model, this report is organized into the following sections: introduction to the multicriteria analysis model (Section 2), the BI model (Section 3), modification information for the model (Section 4), a use-case scenario (Section 5), discussion of the results (Section 6), and the conclusion (Section 7). Additionally, various fonts are used throughout the report to try to aid in clarification of the meaning or use of a word. A font table, found in the Appendix, highlights the concept or condition of the specialized font.

2 Multicriteria Analysis

Decision-making entities, such as governments, businesses, and groups, often compare options or projects by using a cost analysis, which includes a cost-effectiveness analysis or a cost-benefit analysis (Dodgson et al. 2009). Cost-effectiveness analysis compares the costs of developing the same product but in several ways. Cost-benefit analysis looks at an option feature and compares it to the cost to implement. However, this looks at one criterion for each option and cannot accommodate multiple objectives or criteria that would provide more information for decision-making. Furthermore, often the decision makers are a single person or small group composed of either subject matter experts or upper management.

Concerned about reliability, visibility, and providing more information about the decision, many decision makers desire a more systematic, simple, and evident method to evaluate options and choose the best option while also including more people in the decision (Dodgson et al. 2009; Janssen 2001; Syamsuddin and Hwang 2009). Many groups have chosen to use a method known as multicriteria analysis (MCA) or multicriteria decision analysis (MCDA), which lists the options and then analyzes how each meets the nominated required criteria to produce or select the best options. This preferred method operates as a checklist or rating tool for comparing options.

2.1 Multicriteria Decision Analysis (MCDA)

For consistent and transparent decision-making, the BI model draws on the strength of an MCA or an MCDA. The MCA is recognized as an efficient and reliable approach for comparing different options by evaluating their impacts and performances, as well as identifying their advantages and disadvantages. The MCA facilitates narrowing the set of options or categorizing the options into categories (Dodgson et al. 2009; Janssen 2001; Lahdelma et al. 2000). An MCDA is a form of the MCA that arranges the options from least preferred to most preferred.

An MCA evaluates options by referencing a definitive array of objectives that a decision-making group has identified and has established measurable criteria to judge the extent by which the options meet the objectives (Dodgson et al. 2009; da Cruz et al. 2013; Hajkowicz and Higgins 2008; Janssen 2001; Lahdelma et al. 2000). Often an MCA applies a numerical analysis by scoring and weighting criteria with final values reflected in a performance matrix. The MCA is structured to

- reveal the most desirable path upfront,
- identify areas of greater and lesser opportunity,
- rank the projects,
- illuminate the contrasts among the projects,
- assist key players in improving their grasp of the situation,
- help determine the assignment of resources to achieve the organization's goals, and
- develop better communication between an organization's different departments.

A fundamental part of an MCA is the performance matrix, which provides a quantitative analysis on how each option performs against the various criteria within the objectives (Dodgson et al. 2009; Janssen 2001; Lahdelma et al. 2000). The performance matrix obtains its values through a combination of scoring and weighting. Weighting signifies which objectives are most important in the model, and scoring provides a measure of how well the option meets the criteria.

There are several types of MCAs, with each providing an alternative method to measure the options. This BI model combines the linear additive model with the analytical hierarchy process (AHP). The linear additive model combines the values—gathered as each option is evaluated against the criteria—into a single value (Dodgson et al, 2009; da Cruz et al. 2013; Hajkowicz and Higgins 2008; Janssen 2001). This occurs by multiplying the option's score, for each objective, with the weight of that objective, and then summing all these weighted scores in the performance matrix. The linear additive model uses Equation (1) to derive the overall score:

$$S_i = \sum_{j=1}^{n} w_j \, s_{ij} = w_1 s_{i1} + w_2 s_{i2} + \cdots + w_n s_{in}, \tag{1}$$

where

w = the objective weight,
s = the score for the objective,
ij = the summation indices, and
n = the total number of objectives.

This equation shows that two inputs—scores and weights—are used in the model (Dodgson et al. 2009; Liaghat et al. 2013; da Cruz et al. 2013; Hajkowicz and Higgins 2008).

The AHP takes subjective evaluations of objectives' importance to each other to derive the weights and final scores (Syamsuddin and Hwang 2009; Liaghat et al. 2013; Dodgson et al. 2009). A sequence of questions known as pairwise comparisons examines how important one objective is compared to another. The AHP will also use Equation (1) to calculate final scores.

2.2 US Military Academy (USMA) Capstone Project

In 2021, a cadre of US Military Academy (USMA) cadets visited CRREL in preparation for developing their capstone project. Initially planning to redesign the portfolio management tool (PFM) used in analysis of a project's performance, the visit instead led to the idea of developing a system to analyze early-development projects. The cadets developed an Arctic decision model to align project ideas with priorities developed at higher levels and objectively gauge project importance. They used an additive value model that examined three objectives:

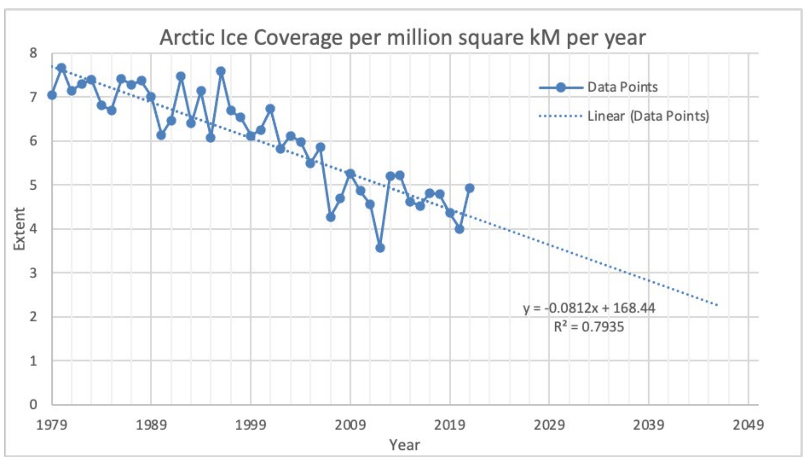
- Fit to Army and Engineer Research and Development Center (ERDC) Arctic strategies
- Fit to national and DoD Arctic strategies
- Scores based on enemy, resources, and climate data, set in the Arctic region

The first two objectives compare the project to research goals outlined in Arctic strategies as defined by the White House, DoD, the Army, and ERDC. Scores are determined by binary answers, ones or zeros, and then summed and normalized to determine the project fit. The three criteria in the third objective examined data that looked at enemy presence by plotting the number of overflights in Alaska from September 2020 to November 2021, the area of ice coverage over a range of years (1979–2021) to track climate change, and the ratio of crude oil recovered in Alaska compared to Russian reserves for 2000 through 2015. Trendlines were fit to the data for each criterion (Figure 1).

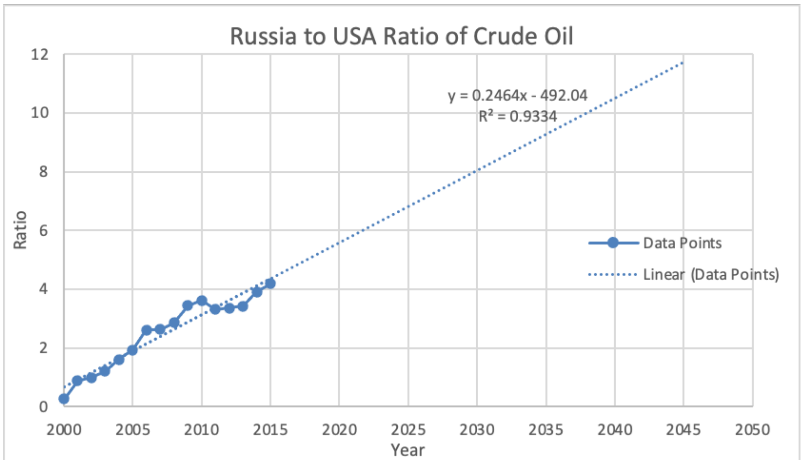
Figure 1. Scores for the three criteria in the last objective are based on the trendlines that best fit the data. Russian overflight forecast (*A*), Arctic ice coverage per million square kilometers (*B*), and ratio of Russian to American crude oil (*C*).

A

B



C



All three criteria compare the estimated project completion date with the generated trendline for each criterion to produce a score. Unfortunately, due to the nature of the data (years), projects that are started now will receive a mid to low score for all three criteria, which will only get worse.

A pairwise comparison was applied to determine the different weights between the objectives, including the criteria in the third objective. The comparison scale had rankings of 0.25 to 4, where 0.25 indicated the objective is "much less important," while a 4 specified the objective is "much more important" (USMA model). These weights are then used in the additive model to obtain a weighted score.

To provide scores for the model, the raw data was gathered from the criteria sheet and manually entered into the raw data matrix. The scores were accumulated in the solution value matrix, which included the weighting, and were summed to provide a total value, where a perfect score is 100. None of the projects scored above a 78, and a perfect score is nigh impossible due to the data problem previously discussed.

A Kendall's tau (τ) correlation analysis was then performed to compare the USMA model with the PFM scores. In the Kendall's τ analysis, values close to zero have weak to no correlation, and the closer the value is to ±1, the stronger the model and the PFM are correlated or not correlated. The τ result was 0.3636 with a standard error of 0.221. These results showed that the model results were nebulously correlated to the PFM results on the same projects.

The cadet's model was presented to the US Army Corps of Engineers (USACE) leadership and was well received overall. CRREL's Office of Technical Directors (OTD) determined that a similar model based on the USMA cadet's model should be produced for use in BI at the beginning of project development. This led to the generation of the BI model.

3 Business Intelligence (BI) model

The BI model uses a combination of the linear additive model and the AHP in the MCA to take advantage of the qualitative and quantitative nature of both methods. This section is organized to provide details on the various aspects of the model. The first subsection describes the fit screening to select projects to analyze. The following subsections define the prescreening, review how the model works, and specify the five objectives in the model. The subsections also detail the criteria, weighting in the model, project scoring and scaling, and the performance matrix.

3.1 Initial Screening

Before the model is used, the projects are processed through a Fit Screening step. This screening removes projects that are unlikely to be completed due to a lack of resources or that do not align with USACE or ERDC objectives. The screening is composed of two stages: a strategy fit and then a resource check. For the strategy fit, the project is compared to the USACE and ERDC research strategies, shown below, and must meet one of these criteria to move to the next stage.

USACE R&D strategies:

- Mitigate and adapt to climate change.
- Win future wars.
- Modernize our nation’s infrastructure.
- Support resilient communities.
- Enable smart and resilient installations.
- Ensure environmental sustainability and resilience.
- Secure reliable installation energy.
- Revolutionize and accelerate decision-making.
- Improve cyber and physical security.
- Protect and defend the Arctic.

ERDC strategies:

- Protect and defend the Arctic.
- Revolutionize and accelerate decision-making.
- Understand operational environment.
- Predict outcomes.

- Reduce uncertainty.
- Accelerate mission delivery.

The second check determines if there are resources available at the lab to successfully conduct the research. This stage determines if there is the appropriate technology, number of people, and lab capability for the research to be performed, as well as if any products developed during the project's timeframe will meet the needs of stakeholders or threats. If during either stage a project receives a "No" on one of the criteria, then the project does not proceed through the model. At this point, the researcher or principal investigator would need to rework the research plan and resubmit the project later. Otherwise, if all stages and criteria receive a "Yes" or "Go," then the project moves forward to be run through the model.

3.2 How Does the Model Work?

The model has five variations, all built along the same objectives (Section 3.4) but with different criteria due to the different emphasis areas of each variation. These variations are aimed at identifying either a customer or end user for the project or aimed at examining descriptions for phrases used in funding streams that customers look for when screening proposals. The following are the five variations, each with its own page in the model:

- Army
- Navy
- Air Force
- USACE
- Arctic

The first three variations focus on the three services as the principal stakeholder and funding agency for the project. CRREL and ERDC have successful research collaborations in each service, with the Army being the largest customer. The USACE variation is set up to provide information on USACE R&D and to assist researchers in developing research projects to support USACE R&D. The model focused on USACE research has three components in the third objective (Army, USACE, and ERDC) instead of the single used in the service models.

The model dedicated to Arctic-focused research varies in the objectives in that the first objective is replaced with priorities from the National Arctic Strategy down to each service's Arctic Strategy, and the second objective has been replaced by capability gaps identified from the 2022 Arctic Science and Technology workshop. The next two subsections further describe both variations.

3.2.1 US Army Corps of Engineers (USACE) Model

The USACE model variation is an attempt to help CRREL researchers move towards the R&D needs that USACE has identified. The commander of USACE recently declared that R&D is integral to the Corps' mission and requested a substantial budget to include more research at USACE. Modest research efforts, principally in the civil works side and focusing on navigation, have occurred within ERDC, with CRREL playing a supporting role.

Because of this new research directive, pursuing USACE as a customer will require researchers to better understand what the customer needs. While ERDC frequently does work for USACE, CRREL researchers often do not seek out USACE as a customer. Of all the USACE R&D research performed by ERDC researchers, CRREL accounts for only 0.6 percent of the work (ERDC, n.d.). The USACE commanding general has produced a list of the top ten areas to increase R&D within the Corps. In the USACE variation, the first, third, fourth, and fifth *objectives* are the same as described below in Sections 3.4.1 and 3.4.3–3.4.5, with the third *objective* utilizing the Army *keywords* counts. Therefore, only the second *objective* has been changed.

The main difference in the USACE model is the use of the USACE and ERDC strategies for the second *objective*. ERDC does follow USACE guidance and strategy, so there are some similarities. The criteria used in the USACE model are listed in Section 3.1, and while these criteria are the same as those used in the fit screening, there the project needs to meet only one criterion to move forward whereas in the USACE model all the criteria are used. In the second *objective*, the number of criteria that are met are then summed. The scores from this *objective* provide guidance on how applicable the project would be towards USACE needs.

3.2.2 Arctic Model

The Arctic model variation measures a project against Arctic-focused criteria that describes not only Arctic strategies, developed from the White House down to ERDC, but also recognized capability gaps in current Arctic preparedness and defense. Due to the wide-ranging requirements at the federal levels, the Arctic model has a setup that is different from the other model variations. However, the fourth and fifth *objectives* are the same as found in the other models with no current adjustments for an Arctic emphasis.

The first *objective* focuses on the following Arctic strategies: national, DoD, Army, Navy, and Air Force. Each strategy is similar, as they follow the national strategy first and the services will also follow the DoD strategy but are different as each organization seeks to provide the most favorable goals for their warfighters. Table 1 lists the criteria for each component of this *objective*.

Table 1. Arctic strategies found in the first *objective* in the Arctic model.

National Arctic Strategy	Army Arctic Strategy
• Secure and stabilize the region. • Safeguard national interests. • Defend the United States Homeland. • Encourage international cooperation. • Fit the strategic environment. • Ensure sustainability.	• Build Arctic capability across the force. • Address persistence problems from Arctic-stationed organizations. • Anticipate and mitigate impacts of a changing environment on infrastructure and operations. • Achieve a strengthened network of allies and partners to compete in the Arctic. • Deter or defeat land threats to the far north. • Experiment and advance MDO (multi-domain operations); Project multidomain effects. • Project power across the Arctic in crisis and conflict.

Table 1 (cont.). Arctic strategies found in the first *objective* in the Arctic model.

National Arctic Strategy	Air Force Arctic Strategy
• Improve Arctic capability. • Compete in the Arctic and globally. • Defend the far north in crisis and conflict. • Build Arctic multidomain operations. • Project power across the Arctic and in conflict.	• Strengthen threat detection and missile defense. • Command, control, and communicate ISR (intelligence, surveillance, and reconnaissance). • Pursue space capabilities. • Improve weather forecasting and prediction. • Agile operations and logistics. • Infrastructure development. • Interoperability and cooperation. • Prepare for Arctic operations.
Navy Arctic Strategy	
• Infrastructure. • C5ISR (Command, Control, Computers, Communications, Cyber, Intelligence, Surveillance, and Reconnaissance). • Manned and unmanned naval forces. • Science and Technology Research. • Prepare our People.	

The second *objective* in the Arctic model concentrates on identified capability gaps for the services in Arctic and cold regions. These gaps developed as attention to research and technology focused on current operating theaters, which over the past couple of decades primarily occurred in hot, arid regions. In May 2022, an Arctic Science and Technology workshop was held at CRREL to discuss current capabilities and to identify gaps and requirements for operations and defense located in cold or Arctic regions. During the workshop, groups concentrated on three principal areas: Arctic Environment, Resilient Materials and Infrastructure, and Operational Readiness, which were further broken down into specifics as seen in Table 2.

Table 2. The second *objective* contains these Arctic-focused capability gaps.

Main Areas	Focused Capability Gaps
Arctic Environment	Sea Ice, Icebergs, Coastal Interfaces, Permafrost, Snow
	Arctic Weather Forecasting
	Observations
Resilient Materials and Infrastructure	Energy and Fuels
	Infrastructure
	Communications
Operational Readiness	Human Performance
	Polar Medicine, Search and Rescue
	Information Dominance

The workshop brought together subject matter experts from across the DoD and ERDC to describe the current state of research and to determine where there are deficiencies for staging troops and engaging in combat in extreme low temperatures and the Arctic.

The third *objective* in the Arctic model also employs *keywords* from the R-Forms but with a focus on Arctic or cold regions research funding. Thus, there are fewer *keywords* used in the Arctic model than in the other model variations. The *keywords* used in the Arctic model are permafrost, snow, cold/cold region, ice, weather/cold weather, and Arctic. The *keyword* counts combine the count values from the Army, Navy, and Air Force R-Forms.

3.3 Objectives Used in the Model

The BI model uses three central ideas to calculate a score for each project: alignment variables, timing, and customer relationship. The alignment variables encompass three *objectives* to assess how the project meets the requirements or strategies set forth by the DoD and the component military branch to align proposed research with current and planned research projects. Timing looks at how long the project will take for completion and the delivery of a product to fill a capability gap. Customer relationship provides information on the status of working with the potential customer from no relationship to a regular customer. The following are the listed *objectives*:

- Objective 1: Alignment of R&D to DoD Critical Technology Areas
- Objective 2: Alignment of R&D to Service Priorities

- Objective 3: Service R-Forms Keyword
- Objective 4: Project Length
- Objective 5: Customer Relationships

The Excel sheet is set up for each *objective*, with the model occupying the left rows and each *objective* table beginning with teal-colored cells (

Table 3). The criteria for each *objective* have gray-colored cells with the scoring in orange-colored cells. This helps to make the evaluation and locating the *objective* and scoring easier to find. The project columns are positioned to the right of the criteria cells. The columns for each project are currently shaded with a different light color (to help differentiate the numerous projects), but this feature is not necessary and can be removed if not desired.

Table 3. How the Excel sheet is set up to ease identification of the different objectives and projects.

DoD Critical Technology Areas		Project						
[0 = false; 1 = true]		A	B	C	D	E	F	G
	Biotechnology	1	0					
	Quantum Science	0	0					
	Future Generation Wireless Technology	0	0					
	Advanced Materials	1	0		1			
	Trusted AI (Artificial Intelligence) & Autonomy	0	0					
	Integrated Network Systems of Systems	0	0					
	Microelectronics	1	0					
	Space Technology	0	0					
	Renewable Energy Generation and Storage	0	0			1		
	Advanced Computing and Software	0	0					
	Human-Machine Interfaces	0	0					
	Directed Energy	0	0					
	Hypersonics	0	0					
	Integrated Sensing & Cyber							
Total		3	0	0	1	1	0	0
Score		0.214	0	0.00	0.07	0.07	0.00	0.00
Project Score		1.8	1	1	1.266	1.2666	1	1
Army Priorities		Project						
[0 = false; 1 = true]		A	B	C	D	E	F	G
Modernization	Long-Range Precision Fires	0	0	0				
	Next Generation Combat Vehicles	0	0	0				
	Future Vertical Lift	0	0	0	1		1	
	Network	0	0	0				
	Air & Missile Defense	0	0	0				
	Soldier Lethality	0	0	0				

Table 3 (cont.). How the Excel sheet is set up to ease identification of the different objectives and projects.

Arctic	Build Arctic capability across the Force	1	1	1	1	1	1	1
	Address persistence problems from Arctic-stationed organizations		1	0	1	1	1	1
	Anticipate and mitigate impacts of changing environment on infrastructure and operations		1	0	1		1	1
	Achieve a strengthened network of allies and partners to compete in the Arctic			0				
	Defer or defeat land threats to the far north	1	1	1	1	1	1	1
	Experiment and advance MDO/Project multi-domain effects	1	1	1	1	1	1	1
	Project power across the Arctic in crisis and conflict	0	1	1	1	1		1
Climate Change	Resilient Energy and Water Supply	0	0	0		1		
	Carbon-Pollution-Free Electricity	0	0	0		1		
	Efficient Structures	0	0	0				
	Non-Tactical Fleet Electrification	0	0	0				
	Land Management	0	0	0				
	Enhanced Planning	0	0	0				
	Advanced Technology	0	0	0				
	Future Contingency Basing	0	0	0	1			1
	Clean Procurement	0	0	0				
	Resilient Supply Chains	0	0	0				
Total		3	6	4	8	7	6	7
Score		0.14285714	0.28571429	0.19047619	0.38095238	0.33333333	0.28571429	0.33333333
Project Score		1.53333333	2.06666667	1.53333333	2.33333333	2.06666667	2.06666667	2.06666667
Army R-Forms Keyword		Project						
[0 = false; 1 = true]	Weights	A	B	C	D	E	F	G
None	0	0.00	0.00	0.00				
Remote Sensing/Lidar	0.0160	1.00	1.00	1.00			1.00	
Materials & Manufacturing	0.0196	0.00	0.00	0.00	1.00	1.00		
AR/VR	0.0231	0.00	0.00	0.00				
Cold	0.0285	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Weather	0.0391	1.00	0.00	0.00		1.00		1.00
Complex Environment	0.0463	0.00	0.00	1.00				
Energy	0.0907	0.00	0.00	0.00		1.00		
Multi-Domain	0.1459	0.00	0.00	0.00				
UAV/UAS (unmanned aerial vehicle/unmanned aerial system)	0.1744	0.00	0.00	0.00				
Neural Network/ML (Machine Learning)	0.1940	0.00	0.00	0.00				
Mobility	0.2224	0.00	1.00	1.00	1.00		1.00	1.00

Table 3 (cont.). How the Excel sheet is set up to ease identification of the different objectives and projects.

Weight Score		0.08362989	0.26690391	0.31316726	0.27046263	0.17793594	0.26690391	0.29003559
Total		0.35635717	0.53963119	0.67680362	0.54318991	0.54157231	0.53963119	0.56276286
Project Score		1.53333333	2.06666667	2.33333333	2.06666667	2.06666667	2.06666667	2.06666667
Project Length (Yrs)		Project						
Select row with an "X"	Score	A	B	C	D	E	F	G
1	5.00							
2	4.56							
3	4.11							
4	3.67	X	X	x	X	x	x	x
5	3.22							
6	2.78							
7	2.33							
8	1.89							
9	1.44							
+ 10	1.00							
Project Score		3.67	3.67	3.67	3.67	3.67	3.67	3.67
Customer Relationship Stage		Project						
	Score	A	B	C	D	E	F	G
No Previous Contact	1							
Email	2							
Met in person	3							
collaboration	4	4	4	4	4	4	4	4
regular customer	5							
Project Score		4.00	4.00	4.00	4.00	4.00	4.00	4.00
Solution Matrix		Project						
Parameter		A	B	C	D	E	F	G
Alignment of R&D to DoD Critical Technology Areas		0.13031615	0.07239786	0.07239786	0.09170396	0.09170396	0.07239786	0.07239786
Alignment of R&D to Army Priorities		0.65742514	0.88609475	0.65742514	1.00042956	0.88609475	0.88609475	0.88609475
Army R-Forms *Keywords*		0.37589206	0.50663712	0.57200965	0.50663712	0.50663712	0.50663712	0.50663712
Project Length (Yrs)		0.40360282	0.40360282	0.40360282	0.40360282	0.40360282	0.40360282	0.40360282
Customer Relationship Stage		0.57450451	0.57450451	0.57450451	0.57450451	0.57450451	0.57450451	0.57450451
Project Score		2.14	2.44	2.28	2.58	2.46	2.44	2.44
Ideal Score		5						

3.4 Defining the Criteria

Each objective is composed of explicit, measurable elements or criteria. The project score comes from how many criteria the project encompasses or satisfies. The criteria can be numerical in function, ratings, or a qualitative description (Dodgson et al. 2009). All three types are used in the BI model.

3.4.1 Objective 1: DoD Critical Technology Areas (CTAs)

The Office of the Undersecretary of Defense for Research and Engineering (OUSD[R&E]) has developed a list of critical technologies areas (CTAs) to increase the DoD's technological dominance in the twenty-first century. There are 14 focus technologies grouped under these 3 categories:

- Seed areas of emerging opportunity
- Effective adoption areas
- Defense-specific areas

There is a need for rapid development and prototyping to test and evaluate technology leading to fielding new capabilities. These priority areas are also used as a foundation for the service's modernization priority developments. For this reason, the model includes CTAs as an objective because the researcher should consider these strategic technology areas in their project development. The following are the current CTAs:

- Biotechnology
- Quantum science
- Future generation wireless technology
- Advanced materials
- Trusted AI (artificial intelligence) and autonomy
- Integrated network systems of systems
- Microelectronics
- Space technology
- Renewable energy generation and storage
- Advanced computing and software
- Human-machine interfaces
- Directed energy
- Hypersonics
- Integrated sensing and cyber

3.4.2 Objective 2: Service Priorities and Strategies

Within each service, it is a requirement to meet the demands of modernization needs within the National Defense Strategies. Each service commander develops a vision of how their force will prepare to fight and win future conflicts. The Army has defined six modernization priorities (Table 4) to enable their warfighters supremacy on the battlefield. The Navy has outlined six priorities to build and maintain maritime dominance (

Table 5), while also expanding wartime advantages. The Air Force delineated five strategic priority areas (Table 6) to develop a force that will dominate in future conflicts.

The DoD has followed White House guidance on recognizing the importance of the Arctic domain in the defense of the nation and protection of natural resources. Each of the service's modernization, Arctic, and climate change priorities are listed in the tables below. The priorities used in the model can be adjusted to allow national strategies to evolve. The only required modification would be to adjust the score's cell if there is a change in the number of priority criteria listed.

Table 4. Army priorities in modernization, Arctic, and climate change.

Strategy	Priorities
Modernization	Long-range precision fires
	Next-generation combat vehicles
	Future vertical lift
	Network
	Air and missile defense
	Soldier lethality
Arctic	Build Arctic capability across the force
	Address persistence problems from Arctic-stationed organizations
	Anticipate and mitigate impacts of changing environment on infrastructure and operations
	Achieve a strengthened network of allies and partners to compete in the Arctic
	Defer or defeat land threats to the far north
	Experiment and advance MDO; project multidomain effects
	Project power across the Arctic in crisis and conflict
Climate Change	Resilient energy and water supply
	Carbon-pollution-free electricity
	Efficient structures
	Nontactical fleet electrification
	Land management
	Enhanced planning
	Advanced technology
	Future contingency basing
	Clean procurement
	Resilient supply chains

Table 5. Navy priorities in modernization, Arctic, and climate change.

Strategy	Priorities
Modernization	Expand forward presence
	Enhance warfighting readiness
	Innovate and modernize
	Combat climate change
	Empower our people
	Strengthen strategic partnerships
Arctic	Infrastructure
	C5ISR
	Manned and unmanned naval forces
	Science and technology research
	Prepare our people
	Improve interoperability and collaboration
Climate Change	Fill data, science, tech gaps in climate impacts
	Increase capability and decrease emissions
	Hybridization and electrification
	Consider and update climate data
	Large-scale ecosystem restoration
	Increase resilience in energy generation and water conservation
	Adaptation, resilience, and mitigation solutions
	Resilient and innovative supply chains

Table 6. Air Force priorities in modernization and the Arctic.

Strategy	Priorities
Modernization	Resilient space order battle and architecture
	Network, multidomain command and control system
	Next-generation air dominance
	Moving target acquisition
	Resilient basing, sustainment, and communications
	Long-range strike family-of-systems for B-21
	Readiness for wartime posture
Arctic	Threat detection and missile defense
	Command, control, communications ISR
	Space capabilities
	Weather forecasting and prediction
	Agile operations and logistics
	Infrastructure development
	Interoperability
	Preparation for Arctic operations

3.4.3 Objective 3: R-Forms

The R-Forms detail budgetary information for research, development, test, and evaluation (RDT&E) programs that are provided to Congress as justification for planned expenses. The usefulness of the R-Forms lies in the different program elements that describe currently funded research projects, as well as the objectives and descriptions of the research undertaken to reach those goals. The language located in the R-Forms has been scripted and therefore utilized in the formulation of project narratives that are familiar to funding agencies that align research within certain program elements.

The BI model assists researchers by examining how certain words or "*keywords*" in the project description fall into product need streams (i.e., what is being funded). The following *keywords* are used in all the model variations:

- Materials and manufacturing (M&M)
- Augmented reality (AR) and virtual reality (VR)
- Complex environment
- Remote sensing (RS) and lidar
- Energy
- Weather
- Multidomain
- Unmanned aerial vehicle (UAV) and unmanned aerial system (UAS)
- Mobility
- Cold
- Neural network and machine learning (ML)

As different research priorities and projects come into play and focus areas change, the *keywords*—either the word itself or the number of keywords—can be amended.

3.4.4 Objective 4: Project Length

While research often requires years to develop well thought-out theories and models, the military frequently does not have that long to wait to stay technologically ahead of its adversaries. As such, the quicker the technology or a capability can be passed to the warfighter, the easier the advantage leads to success in a conflict. For this reason, the length of a project is important and often a deciding factor in project selection.

3.4.5 Objective 5: Customer Relationship

This objective looks at the research and funding history between CRREL researchers and the customer or funding agency, as this will often indicate the likelihood of a proposal being selected for funding. Additionally, including the customer relationship increases the probabilities that names of program managers and stakeholder contact information will already be known or will be more easily provided. The following are the various levels of the relationship with a customer:

- No previous contact
- Email contact
- Met in person
- Currently in collaboration
- Regular customer

3.5 Weighting in the Model

The BI model uses pairwise comparisons, as seen in AHP MCAs, to determine the weighting values for both the *objective* weights and the *keyword* weights. The *keyword* weights are numerical based, while the pairwise comparison method uses percentages. However, the *objective* weighting does follow the pairwise comparison method by subjectively rating each objective against another. See Section 4.1 for information on modifying the weights.

3.5.1 Pairwise Comparisons

Pairwise comparisons ask, "How important is criterion A relative to criterion B?" (Dodgson et al. 2009; Liaghat et al. 2013; Syamsuddin and Hwang 2009). A criterion always ranks equally when compared to itself; there are only

$$n(n-1)\ /\ 2$$

comparisons necessary to establish the complete matrix of pairwise decisions for n criteria (Dodgson et al. 2009; Syamsuddin and Hwang 2009).

3.5.2 Objective Weights

The *objective* weights are calculated on the `weights sheet;` and, if modified, the values are automatically updated in the model. Table 7 shows the pairwise comparison matrix for the *objectives*.

Table 7. Pairwise comparison matrix.

	Objective 1	Objective 2	Objective 3	Objective 4	Objective 5
Objective 1	1	<0.25>	0.25	0.5	0.5
Objective 2	{4}	1	2	4	4
Objective 3	4	2	1	2	2
Objective 4	2	1	0.5	1	0.5
Objective 5	2	0.5	0.5	2	1

In the model, the cells in orange (above the ones) are the adjustable variables and where the comparison values are entered. The cells in blue contain formulas and automatically update as the values are input in the yellow cells. For an example of how to perform the comparisons, one score is in "<>" symbols. To find this value, determine how *Objective* 1 compares to *Objective* 2 using the comparison scale below.

- 4: Value of Parameter is Much More Important
- 2: Value of Parameter is More Important
- 1: Value of Parameters are the same
- 0.5: Value of Parameter is Less Important
- 0.25: Value of Parameter is Much Less Important

For the comparisons, the values range from 0.25 to 4, where values less than 1 indicate the objective is less important and values greater than 1 indicate the objective is more important. The higher the number, the more important that objective is in comparison to the other objectives. Discussions with the technical directors determined that *Objective* 1 is less important than *Objective* 2, so "0.25" was entered in the cell. The corresponding or reverse cell, using the "{}" symbols, is calculated by 1/0.25 with "4" being the resulting value. As the comparison matrix is completed, the normalized matrix (Table 8) is filled out automatically and the weights are computed.

Table 8. The *Normalized Matrix*.

Parameter	Parameter 1	Parameter 2	Parameter 3	Parameter 4	Parameter 5	Weight
Parameter 1	0.077	0.111	0.059	0.053	0.063	0.368
Parameter 2	0.308	0.444	0.471	0.421	0.500	2.223
Parameter 3	0.308	0.222	0.235	0.211	0.250	1.257
Parameter 4	0.154	0.111	0.118	0.105	0.063	0.556
Parameter 5	0.154	0.111	0.118	0.211	0.125	0.738

The values for the *normalized matrix* are calculated using Equation (2):

$$n_{ij} = \frac{r_{ij}}{\sum_{j=1}^{m} r_{ij}}, \tag{2}$$

where

r = the value in the comparison matrix,
m = the number of values in that column, and
i and j = summation index values.

This is the sum-based normalization method and the type most used in AHP models. The sum of the weights must equal one (Dodgson et al. 2009; Liaghat et al. 2013; Syamsuddin and Hwang 2009). The five main *objective* weights in descending order are R-Forms, Service Strategies, Customer Relationship (status), Project Length, and DoD CTAs.

3.5.3 Keyword Weights

The third *objective* is pairwise comparison based; but instead of subjective ranking, the keyword weights are calculated from percentages, and the matrix (set up in the model) updates values quickly when the percentages are adjusted. The keyword weight is first computed by

$$counts/(sum\ of\ counts),$$

which produces a percentage. Table 9 provides an example of how the keyword counts and percentages are set up. While it is easy to sort the *keywords* by counts, it is not necessary for pairwise comparison.

Table 9. *Keywords* count example. These are the same keyword counts used in the Army model variation.

Keyword	Count	%
None	—	0.00
Remote Sensing/Lidar	9	1.60
Materials & Manufacturing	11	1.96
AR-VR	13	2.31
Cold	16	2.85
Weather	22	3.91
Complex Environment	26	4.63
Energy	51	9.07
Multidomain	82	14.59
UAV/UAS	98	17.44
Neural Network/ML (Machine Learning)	109	19.40
Mobility	125	22.24
Sum of Counts	562	—

The pairwise comparison matrix uses these percentages to determine the values of the weights for each keyword. The pairwise comparison and normalized matrices for the Army keywords are shown below (Table 10 and Table 11). The higher the number, the more important that keyword is in comparison to the other keywords. Furthermore, the cells contain the correct formulas to automatically perform the calculations, so the cells do not need formulas entered. However, for further information on the matrices set up or any future adjustments see Section 4.1.2.

Table 10. The *Keyword Matrix,* or the pairwise comparison matrix, is the second step used in calculating keyword weights in *Objective* 3.

Keyword Matrix	Remote Sensing/Lidar	Materials & Manufacturing	AR-VR	Cold	Weather	Complex Environment	Energy	Multidomain	UAV/UAS	Neural Network/ML	Mobility
Remote Sensing/Lidar	1.00	0.82	0.69	0.56	0.41	0.35	0.18	0.11	0.09	0.08	0.07
Materials & Manufacturing	1.22	1.00	0.85	0.69	0.50	0.42	0.22	0.13	0.11	0.10	0.09
AR-VR	1.44	1.18	1.00	0.81	0.59	0.50	0.25	0.16	0.13	0.12	0.10
Cold	1.78	1.45	1.23	1.00	0.73	0.62	0.31	0.20	0.16	0.15	0.13
Weather	2.44	2.00	1.69	1.38	1.00	0.85	0.43	0.27	0.22	0.20	0.18
Complex Environment	2.89	2.36	2.00	1.63	1.18	1.00	0.51	0.32	0.27	0.24	0.21
Energy	5.67	4.64	3.92	3.19	2.32	1.96	1.00	0.62	0.52	0.47	0.41
Multidomain	9.11	7.45	6.31	5.13	3.73	3.15	1.61	1.00	0.84	0.75	0.66
UAV/UAS	10.89	8.91	7.54	6.13	4.45	3.77	1.92	1.20	1.00	0.90	0.78
Neural Network/ML	12.11	9.91	8.38	6.81	4.95	4.19	2.14	1.33	1.11	1.00	0.87
Mobility	13.89	11.36	9.62	7.81	5.68	4.81	2.45	1.52	1.28	1.15	1.00

Table 11. The *Normalization Matrix* uses the values calculated in the *keyword matrix* to compute the keyword weights.

Keyword Matrix	Remote Sensing/Lidar	Materials & Manufacturing	AR-VR	Cold	Weather	Complex Environment	Energy	Multidomain	UAV/UAS	Neural Network/ ML	Mobility	Weight
Remote Sensing/Lidar	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
Materials & Manufacturing	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
AR-VR	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
Cold	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
Weather	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Complex Environment	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
Energy	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091
Multidomain	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146
UAV/UAS	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174
Neural Network/ML	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194	0.194
Mobility	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222

3.6 Scoring and Scaling of a Project's Performances on Objectives

As Dodgson et al. (2009) explained how scoring and scaling allows for consistent values among the various objectives, this model uses both. The first three objectives use a nominal score to rate how well the project aligns with the criteria. The last two objectives use a subjective score based on how well the project satisfies the objective. The model then evaluates the score against a predetermined scoring list so all objectives' scores lie in the same range.

Each model worksheet comprises the five objectives and a *solution matrix*. Each objective has four sections with different colors to make evaluations and score collection easier (see Table 12):

- The objective's name and the top teal row (first section) help distinguish the objectives on the worksheet.
- The marking method and the project identifiers (A . . . Z) lie in the orange-colored second section.
- The third section incorporates two subsections: criteria and marking. The first, or gray, subsection lists the criteria for that objective. The second subsection records the marks for scoring, with each project column in a distinct color.
- The bottom and last section, also orange, calculates the Project Score for each objective.

Table 12. The objective section scoring design in the BI model.

DoD Critical Technology Areas		Project						
[0 = false; 1 = true]		A	B	C	D	E	F	G
	Biotechnology	1	0					
	Quantum Science	0	0					
	Future Generation Wireless Technology	0	0					
	Advanced Materials	1	0		1			
	Trusted AI & Autonomy	0	0					
	Integrated Network Systems of Systems	0	0					
	Microelectronics	1	0					
	Space Technology	0	0					
	Renewable Energy Generation and Storage	0	0			1		
	Advanced Computing and Software	0	0					
	Human-Machine Interfaces	0	0					
	Directed Energy	0	0					
	Hypersonics	0	0					
	Integrated Sensing & Cyber							
Total		3	0	0	1	1	0	0
Score		0.214	0	0.00	0.07	0.07	0.00	0.00
Project Score		1.8	1	1	1.266	1.2666	1	1

For each of the alignment *objectives*, the fourth section breaks the scoring algorithm into three parts: the Total, Score, and Project Score rows. Table 13 shows the breakdown of the algorithm in each row. The remaining two *objectives* (4 and 5) have only one row, the Project Score. These two are evaluated based on where the project fits *within* the criteria instead of how many criteria the project description includes.

Table 13. The algorithm calculating the Project Score is broken into three rows for the first three *objectives*. The last two objectives have only the Project Score row.

Score	Description
Total	Sums the number of true or “1” values
Score	Divides “Total” by the number of criteria and normalizes the score
Project Score	Matches the normalized score to the [1, 5] scale range

Each *objective’s* project score ranges between 1 and 5, which is a common range found in MCA models. A score of 5 is the highest score and reflects how well the project meets the alignment *objectives*, the time to project conclusion is short, and a regular customer supports the research. The excel file holding the model has all the scale tables set up on worksheet Sheet6.

The formula *VLOOKUP* helps the model find the closest match between the normalized value and the scale table value (see Table 14–17). The project score cell will automatically populate the *Project Score* as criteria are marked.

3.6.1 Project Scoring and Scaling for CTAs and Priority Objectives

For the first two *objectives* (*CTAs* and *Priorities*), projects get a “1” if they meet a criterion and a “0” if they do not. Equation (3) normalizes the scores to [0, 1]. The project score for each *objective* comes from matching these values to the scale shown in Table 14.

$$m_i = \frac{1}{n}\sum_{i=1}^{n} x_i, \tag{3}$$

where

x = the count of the criteria,
n = the number of criteria, and
i = the summation index.

Table 14. Relationship between the normalized score with the *Project Score* scale.

Normalized Score	Project Score
0.00	1.00
0.07	1.27
0.13	1.53
0.20	1.80
0.27	2.07
0.33	2.33
0.40	2.60
0.47	2.87
0.53	3.13
0.60	3.40
0.67	3.67
0.73	3.93
0.80	4.20
0.87	4.47
0.93	4.73
1.00	5.00

3.6.2 Project Scoring and Scaling for R-Forms

The 2022 Congressional Budgetary RDT&E forms of 6.2-level research for the Army, Navy, and Air Force were initially searched using 20 keywords. Later, similar keywords, such as ice and snow, were combined into one, resulting in the 11 keywords found in the current model. The model recorded the frequency of each keyword and used it in the scoring algorithm.

The *keyword objective* uses binary scoring to select the proper keyword and calculate the keyword score for each project. The algorithm sums the keyword's weight values for each selected keyword, not the quantity of true (or "1") markings, and gives the weight score in row 1.

$$m_i = weight\ score + \frac{1}{n}\sum_{i=1}^{n} x_i, \quad (4)$$

where

x = the count of the criteria,
n = the number of criteria, and

i = the summation index.

Equation (4) normalizes the weight score to the total score in row 2, which has a range of [0, 2] and includes the sum of the number of ones. This gives more weight to the keywords' values. The model compares the total score to the score table (as shown in Table 15) in `sheet6` and obtains the project score between [1, 5] in row 3.

Table 15. Weighted *keyword* values to score scale.

R-Forms *Keywords*	Score
0.00	1.00
0.13	1.27
0.27	1.53
0.40	1.80
0.53	2.07
0.67	2.33
0.80	2.60
0.93	2.87
1.07	3.13
1.20	3.40
1.33	3.67
1.47	3.93
1.60	4.20
1.73	4.47
1.87	4.73
2.00	5.00

3.6.3 Project Length Scoring and Scaling

For the *Project Length objective*, the project score depends on the length of time it takes to complete the project. An "X" marks the proper choice, and the `Project Score` cell displays the score. The relationship between the score and project length is inverse, meaning that a shorter project length results in a higher score. The score is scaled to a range of [1, 5] due to the simplicity of this relationship. Table 16 provides more details on how project length is scored.

Table 16. The scaling utilizes the *FILL* command to generate the steps between the high and low score.

Project Length (Years)	Score
1	5.00
2	4.56
3	4.11
4	3.67
5	3.22
6	2.78
7	2.33
8	1.89
9	1.44
+10	1.00

3.6.4 Project Scoring for Customer Relationship

For the *Customer Relationship objective*, there are five criteria to choose, ranging from no relationship to regular customer. The project score is based on an assessment of the current relationship with the projected customer or funding agency. The appropriate relationship is selected from the available criteria and the corresponding number [1, 5] (as shown in Table 17) placed in the project column. No scaling is necessary for this *objective*.

Table 17. Score and customer relationship used in the business intelligence (BI) model.

Customer Relationship Stage	Score
No previous contact	1
Email contact	2
Met in person	3
Currently in collaboration	4
Regular customer	5

3.7 Performance Matrix

The performance matrix in the BI model is termed *Solution Matrix* and collects all the project scores from the five *objectives*. As the project is evaluated, the cells in the *Solution Matrix* automatically update with Equation (5)

$$O \times w_o, \tag{5}$$

where

O = the *objectives*' project score and
w_O = the weight for the *objective*, as calculated in Section 3.5.

These values are in the cell at the intersection of the project column and the *objective* row in the *Solution Matrix* (Table 18). The `Overall Project Score` (bottom row) then sums all values in the five rows above the cell, also resulting in a range of [1, 5] where 5 is an ideal score. For most projects, obtaining a 5 is unlikely and will instead lie in the [3, 4] range as project descriptions begin to use the terms described in this model.

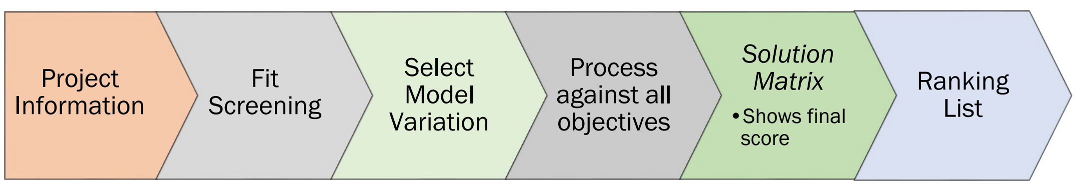
Table 18. The layout of the *Solution Matrix* in the BI model, found on all variations.

Solution Matrix	Project			
Objective	A	B	C	D
Alignment of R&D to DoD Critical Technology Areas	0.07239786	0.07239786	0.07239786	0.09170396
Alignment of R&D to Army Priorities	0.65742514	0.88609475	0.65742514	1.00042956
Army R-Forms *Keywords*	0.37589206	0.50663712	0.57200965	0.50663712
Project Length (years)	0.40360282	0.40360282	0.40360282	0.40360282
Customer Relationship	0.57450451	0.57450451	0.57450451	0.57450451
Overall Project Score	2.08	2.44	2.28	2.58

4 Model Flow

Figure 2 shows the first workflow diagram, which outlines the steps required to run the model without making any adjustments to the weighting or criteria of the five *objectives*. All formulas in the file and worksheets are programmed to update automatically as projects are evaluated. Once the evaluation is complete, the *Solution Matrix* or Rank Order List sheet reveals how the project performs in relation to the criteria or in comparison to other projects.

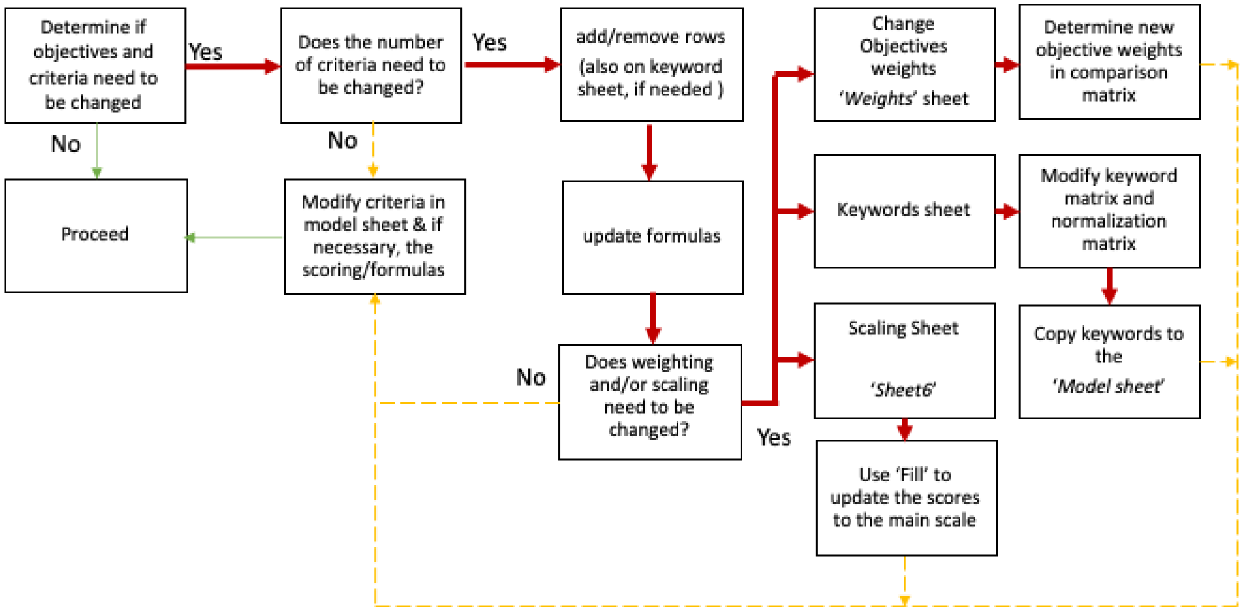
Figure 2. The basic workflow diagram to follow when running projects through the business intelligence (BI) model. Start on the left by gathering project descriptions; move to the right until the *Solution Matrix* and the **Ranking List** are complete.



The second workflow diagram, Figure 3, depicts the steps needed when altering objectives or criteria—including modifying the weighting and scoring values. When altering any objectives or criteria, multiple sheets will need revisions and formula updates, or the model will not perform accurately. Extended descriptions of modifying objectives and criteria or weighting and scaling are found further in this section.

As seen in the modification workflow below, several steps are necessary to ensure any modifications flow throughout the model setup. Three decision points (yes/no) change the complexity of modifying parts of the model from minor to extensive reworking as the path moves to the right.

Figure 3. The modification workflow diagram to follow when adjusting objective, criteria, weighting, or scaling. The colors of the arrows represent the modification stage (*red/bold*, first), updating the model sheet stage (*orange/dashed*, second), and processing with the model (*green/light*, last).



4.1 Modifying the Objectives

When the objectives and criteria require changing, then the scoring and weighting may also need to be recomputed. Since the model is currently operated in Excel, the changes should be straightforward. Adding or removing criteria simply requires inserting or deleting a row. For the fifth *objective*, *Customer Relationship*, changing the criteria is the easiest as there are no scaling or complicated formulas in the model. The fourth *objective*, *Project Length*, is also relatively easy to change although there is some scaling to relate time to the scale range (see Figure 3).

4.1.1 Modifying Objectives 1 and 2

For the first two *objectives*, adjusting the score will require modifying the formula that sums the "1" marks and then modifying the number of criteria in the `Score` cell on the model sheet. The third row, `Project Score`, should not need to be adjusted unless the scale table is moved or enlarged, in which case the *VLOOKUP* reference area would need to be updated.

4.1.2 Modifying Objective 3

For the third *objective*, *R-Form Keywords*, there are more elements that need to be considered, especially when adjusting the *keywords* and their counts. If the number of keywords does not change, the only step will be inputting the new keywords and their counts. The keywords sheet is set up to automatically calculate the weights based on the counts. If the number of keywords changes, then the *Comparison Matrix* and the *Normalized Matrix* will need to be modified and calculations set up in both matrices to allow for a modification in rows and columns. These adjustments should not be difficult and are described below.

The calculations, for the *Keyword Matrix* cells above the diagonal or the "1" values, are based on the comparison value equation

$$(keyword\ 1\ percentage)/(keyword\ n\ percentage), \tag{6}$$

where

$keyword\ 1$ = the keyword for that row, and
$keyword\ n$ = all the other keywords evaluated one at a time.

The cells in red are the results using the equation above (6). The cells in green are computed with

$$1/(keyword\ n_2), \tag{7}$$

where

keyword n_2 = the comparison value for the column of the keyword as the cells move to the right on the keyword row.

For an example, consider the matrix below (Table 19). Note that the variables used in the equation (A1, B1, C1, etc.) show the relation between the *keyword*s in the matrix and are not a cell reference.

Table 19. The equations in the *Keyword Matrix* to use when the number of keywords is altered. RS/lidar = RSL = remote sensing and lidar; M&M = materials and manufacturing.

Keyword Matrix	RS/lidar	M&M	AR-VR	Cold	Weather
RS/lidar	1.00	A1 = RSL/M&M	A2 = RSL/AR-VR	A3 = RSL/cold	A4 = RS/weather
M&M	=1/A1	1.00	B1 = M&M/AR-VR	B2 = M&M/cold	B3 = M&M/weather
AR-VR	=1/A2	=1/B1	1.00	C1 = AR-VR/cold	C2 = AR-VR/weather
Cold	=1/A3	=1/B2	=1/C1	1.00	D1 = cold/weather
Weather	=1/A4	=1/B3	=1/C2	=1/D1	1.00

The *Keyword Matrix* demonstrates how the orange-colored cells of the matrix relate a single keyword percentage to another and the green-colored cells equal the inverse of that relationship. Values less than 1 indicate the keyword is less important and has fewer counts, while values greater than 1 denote the keyword is more important. The higher the number, the more important that keyword is in comparison to the other keywords. These values are then employed in the *Normalization Matrix* to determine the weights.

For the next step, the *Normalization Matrix* captures the computed value, as described above, and divides that by the sum of all the values in that keyword's column. This equation is presented in the RS/lidar, M&M, and AR-VR columns below (Table 20) and creates a matrix with all values less than 1.

The *Normalization Matrix*, with calculations, is shown in Table 20. Note the letter-number combinations (A2, B2, C2) reference the cells in the *Keyword Matrix*, where the identifier at the intersection of RS/lidar and RS/lidar is cell A2. Additionally, this matrix was shortened to make the equations easier to read.

Table 20. The formulas in the *Normalization Matrix* to reference when the number of keywords changes and the size of the matrix shrinks or grows.

Normalization Matrix	RS/lidar	M&M	AR-VR	Weights
RS/lidar	=A2/SUM($A$2:$A$6)	=B2/SUM($B$2:$B$6)	=C2/SUM($C$2:$C$6)	=AVG(#s in this row)
M&M	=A3/SUM($A$2:$A$6)	=B3/SUM($B$2:$B$6)	=C3/SUM($C$2:$C$6)	=AVG(#s in this row)
AR-VR	=A4/SUM($A$2:$A$6)	=B4/SUM($B$2:$B$6)	=C4/SUM($C$2:$C$6)	=AVG(#s in this row)

To calculate the weights for each keyword, the row is averaged for that keyword. This results in the keyword with the highest frequency having the highest weight and, conversely, the lowest frequency having the lowest weight.

Following the adjustments on the keyword sheet, the table on the corresponding model variation will also need to be updated, including adding or deleting rows and revising the formulas in the cells that show the weight values as well as the formulas calculating the project score. While the weight values do update automatically from the keyword sheet, the number of rows does not, and this needs to be kept in mind if those changes occur.

4.2 Modifying the Scaling

The worksheet containing all the scaling tables is sheet6 and is the location used in the formulas on the model sheets to convert the `Total` into the [1, 5] `Project Score`. The process for delineating the range of *objective* scores utilizes the *FILL* command in Excel. When the minimum and maximum scores of an *objective* change, the scaling table requires updating for the BI model to function correctly. For instance, the new range of scores becomes [0, 3] from [0, 2]. The method to alter the scaling is:

1. Determine how many bins to divide the score range [0,3] into (e.g., 10).
2. Mark a "0" at the top of the column, count down ten rows, then enter the "3."
3. Select the column from 0 to 3 and click the arrow beside the *FILL* command in the "Home" tab on the ribbon.
4. Choose Series, the program automatically selects the step value, and click "OK."
   a. Make sure "Columns" and "Linear" are selected first.
5. The values automatically populate.

The above method is also used to scale the *objectives*' scores to the range [1, 5]. As the scaling values are used in calculating the `Project Score`, the easiest method to determine the number of bins is to use the same number of rows already set up in the model. This means the cell range, in the formula for `Project Score`, would not need adjusting versus having to correct the range of cells for the score and scale columns.

5 Use Case

As the model was developed for early BI and application at the front end of project development to assist researchers, ten projects were picked for a use-case scenario tested with the model. All the selected projects are currently funded through the Congressional Add program at CRREL and are in their second or third year of funding. The project descriptions used for evaluating each project through the model came from either their 2020 or 2021 project summary work acceptance (PSWA) document, whichever was the latest year funded. The following is the project list:

A. Defense Resiliency Against Extreme Cold Weather
B. Polar Proving Ground and Training Program
C. Climate and Natural Hazards, Snow-Covered and Mountain Environment Sensing
D. Rapid Entry and Sustainment for the Arctic
E. Cold Weather Energy Research
F. Cold Weather Research
G. Frost Heave Effects Monitoring
H. Materials and Manufacturing Technology for Cold Environments
I. Army Visual and Tactical Reconnaissance
J. Cold Weather Research Station

Before running through the model, the projects were put through the Fit Screening, the prestep where projects were all tested for alignment with one of the USACE/ERDC strategies, lab capability of supporting the project, and project completion within a reasonable time. All projects received a "Go" response and proceeded through the model.

The projects were evaluated across all five of the different versions of the model applying the alignment variables, timing, and customer relationship. The results from each model were collected on the Rank Order List sheet and collated into the Rank List table (Table 21). As expected, variation shows in each project's ranking since the model focuses on different capability gaps and requirements, described in Section 3.4.

Table 21. The Rank List table automatically collects and ranks the `Overall Project Scores` across all five model variations for each of the projects. The Project Identifier letter corresponds to the letter and project in the list above.

Project Identifier	ARMY	Rank	NAVY	Rank	AIR FORCE	Rank	ARCTIC	Rank	USACE	Rank
A	2.08	10	2.21	10	1.969	10	2.362	9	2.655	4
B	2.44	4	2.28	7	2.035	7	2.540	8	2.655	4
C	2.28	9	2.51	3	2.100	4	2.923	1	2.655	4
D	2.58	1	2.46	5	2.169	2	2.600	6	2.675	2
E	2.46	3	2.64	1	2.120	3	2.789	3	2.675	2
F	2.44	4	2.51	3	2.035	7	2.567	7	2.521	7
G	2.44	4	2.28	7	2.100	4	2.766	4	2.312	8
H	2.35	8	2.23	9	2.054	6	2.211	10	2.103	9
I	2.52	2	2.58	2	2.697	1	2.848	2	1.913	10
J	2.39	7	2.35	6	2.035	7	2.734	5	2.884	1

6 Discussion

While there are some variations in the rankings, one project does not have a clear dominance over all the options. Except in the Arctic variation model where two projects have scores close to 3, most of the overall project scores lie between 2.2 and 2.5, which is not a wide range. As Table 21 shows, the scores average around 2.36, although the Arctic version averages 11% higher at 2.63. This is unsurprising as all these projects are focused on the Arctic or on cold-based research and should meet more of the *criteria*. Conversely, the Air Force variation has the lowest scores. Additionally, all the scores vary, being higher with one or two models and then lower with the other models.

Of the 10 projects analyzed with the BI model, only two projects were also looked at in the cadet's USMA model: Materials and Manufacturing Technology for Cold Environments (MMTCE) and Army Visual and Tactical Reconnaissance (AVATR). The following were the rating from the cadet's models:

- MMTCE: score 54.26 (out of 100), rank 9
- AVATR: score 49.56, rank 11

The cadet's model gave MMTCE higher scores in alignment to Army and ERDC Arctic strategy, enemy capabilities, and natural resources. MMTCE and AVATR have the same score for climate change, but the BI model gave AVATR a higher score in alignment to national and DoD Arctic strategy. Furthermore, the cadet's model uses project completion year in determining the scores in the enemy, climate, and resources elements; however, it is unclear why AVATR scores lower on two of those elements yet is equal to MMTCE on the third. It is possible that there are more approximations in the cadet's model to match completion year with the trendline when determining a score. The BI model considers the project length in only a single element and puts more weight toward alignment to priorities and what the R-Forms say concerning dedicated research funding. As a result, AVATR scored higher than MMTCE in almost all the variations by the BI model.

Another reason for the difference in the scoring between the BI model and the USMA model is the more complete project descriptions found in the

PSWAs. The USMA cadets lacked this information, and were it available, their scoring for most of the projects would probably look different.

6.1 Future Work

As noted above in the discussion, there is not a wide range in the overall project scores. In the future, another assessment can be added after projects are evaluated with the model. Two options to consider are a cost-benefit analysis or an estimate of whether the project will be a success. Both notions allow for graphing the final overall project score against the option and provide additional data of projects to push for proposal submission versus projects that could use some additional assistance in project development. One example used the overall project score calculated in the use-case scenario against the project cost with the Army variation model.

The results, shown in Figure 4, depict the small range of scores in the project and the wide variability in project cost. From this information, the projects with the highest scores—but on the left side of the graph—would be good candidates for proposal submission even though the scores are below 3. The rest of the projects might benefit from learning to shape their project description with phrases used in the R-Forms or improving descriptions of how their projects align to strategies and priorities. When the projects are compared against their probability of success, a different picture emerges (Figure 5).

Figure 4. A cost-benefit analysis comparing overall project score against project costs.

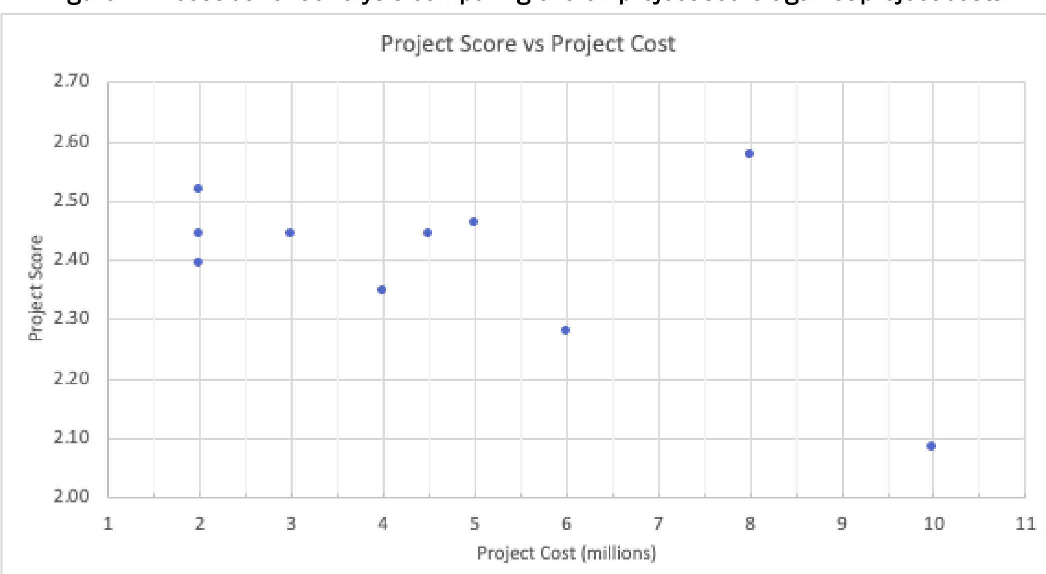
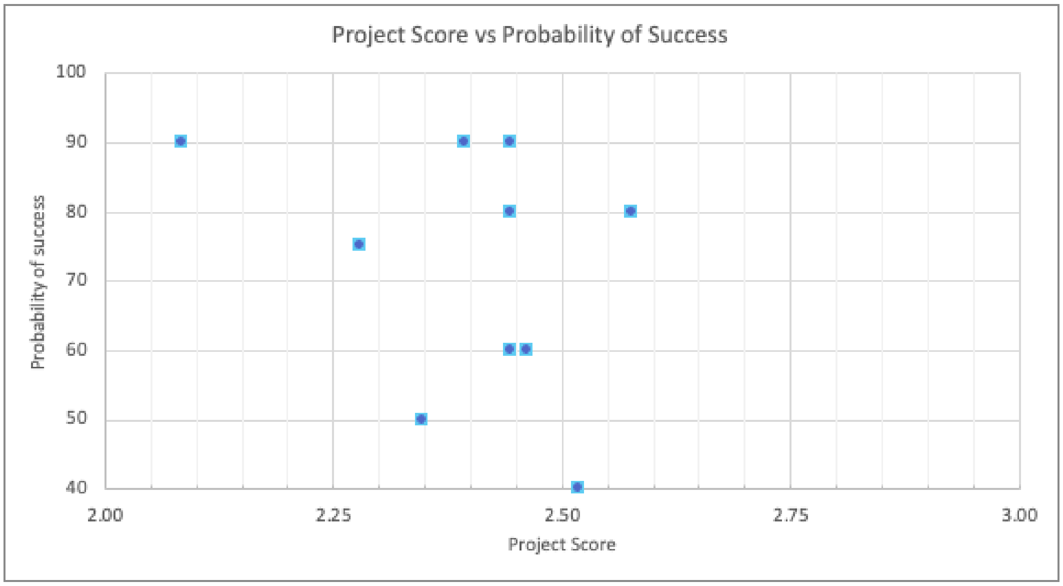


Figure 5. A probability analysis comparing overall project score against the project's risk of failure.



When examining the score against success some of the high-scoring projects look more risky and less acceptable than some of the lower scores. Having this insight provides an alternate view of the project scores, so those with a higher chance of success, but lower project scores, could be chosen to move to proposal with the added caveat of first increasing the phrases and keywords to move to greater alignment. Furthermore, the low-probability project could reduce its risk by altering the scope, timeline, deliverables, etc.

Another option to consider moving forward is developing additional model variations for analyzing how a project fits into a different customer's area of expertise, such as the Department of Homeland Security or the National Security Agency. The BI model is rather straightforward, and due to its use of Excel, users should understand how to manipulate the data in cells and sheets. This makes incorporating additional model variations a simple procedure. Additionally, as multiple model variations already exist, following their structure would assist in developing future variations.

Considering the simplicity of the BI model, moving the model from Excel into code that supports a GUI would be easy to achieve for someone with coding experience. This would allow an easier distribution method and for those with limited Excel experience to feel more comfortable running the model.

7 Conclusion

Researchers and program developers need a process to understand research alignment to nationwide priorities and identified capability gaps and requirements. This report described a new BI model capable of evaluating multiple projects at one time and helping researchers learn descriptive phrases found in alignment sources representative of their projects. Additionally, this BI model will assist researchers in cultivating projects, understanding the language, determining demand signals, and aligning research projects with congressional funding.

MCA provided the framework for the BI model to compare assorted options and provide a numerical analysis. This model combines the linear additive model with the AHP model by weighting objectives through pairwise comparisons and using a performance matrix to collect and generate final scores.

The process begins with a fit screening step that assesses the projects through two stages—a strategy fit and a resource check—before the model is used. This model has five variations—four with the same *objectives* and one with a slight modification—but all contain similarly themed yet different criteria due to the specialized emphasis areas of each variation. The BI model operates around three central concepts for evaluating the projects: alignment variables, timing, and customer relationship. These three concepts give way to five *objectives*: a list of critical technologies for the DoD, services' requirements, budget information to align research, length of a project, and customer relationships.

A use-case scenario with ten projects evaluated the project descriptions against the *criteria*. The results showed a narrow range (22%) as most of the scores lie between 2.2 and 2.7. The results from the Arctic variation were the exception, with scores averaging 10% higher. All project scores wavered between high to low values due to the model variations.

The use-case results were compared to the cadet's model's project scores to observe differences between the two models. Unfortunately, only two projects were used in both, so it was difficult to draw many conclusions. Of note was the use of project length in three of the USMA's model's elements, while the BI model looks at project length only once. Also noted was that the cadet's data fit trendlines all started in the past, either more than 20 years or 2 years ago. This suggests that, moving forward, all USMA model scores will start out lower for these three elements. Not including this type of data in the BI model allows for the possibility of higher scores when looking at project length.

The BI model demonstrated its ability to examine project descriptions against the five *objectives* and provide not only an unbiased score but also highlight areas where improvements, if made, bring more alignment terms and phrases into the narrative. In the future, including additional features would provide another step in the model for assessments or to gain extra information. However, as is, the model performs as intended. This BI model would function best in the organization in either the technical director's office or at the branch chief level as they assist researchers form and propose research ideas. If researchers and project developers utilize this model, they will find it beneficial in aligning their project descriptions with terms used in funding documents and that customers seek for their programs.

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Appendix A: Use of Different Fonts

Table A-1. Text style explanation.

<table>
<tr><th colspan="4">Font Table</th></tr>
<tr><td colspan="2">Proper Nouns
Italicized is referring to the proper noun except when used in a heading (i.e., objective covering the five main groupings of criteria in this model).
Objective
Keywords
Matrix</td><td colspan="2">General Term
Regular text is referencing the term, used as a general model term, as found in textbooks and instruction sources and as used in Section 2.1.
Objective
Keyword
Matrix</td></tr>
<tr><th colspan="4">Excel terms: used to describe an Excel object</th></tr>
<tr><td>Tab Names
Tab names use Helvetica Light font.</td><td>FORMULAS
Formula names (commands) are called out using Perpetua.</td><td>Scoring Calculation Cells
These use Courier New</td><td></td></tr>
</table>

Abbreviations

AHP	Analytical hierarchy process
AI	Artificial intelligence
AR	Augmented reality
AVATR	Army Visual and Tactical Reconnaissance
BI	Business intelligence
C5ISR	Command, Control, Computers, Communications, Cyber, Intelligence, Surveillance, and Reconnaissance
CRREL	Cold Regions Research and Engineering Laboratory
CTA	Critical technology area
ERDC	US Army Engineer Research and Development Center
ISR	Intelligence, surveillance, and reconnaissance
M&M	Materials and manufacturing
MCA	Multicriteria analysis
MCDA	Multicriteria decision analysis
MDO	Multidomain operations
ML	Machine learning
MMTCE	Materials and Manufacturing Technology for Cold Environments
OSD	Office of the Secretary of Defense
OTD	Office of Technical Directors
OUSD	Office of the Undersecretary of Defense
PFM	Portfolio management tool
PSWA	Project summary work acceptance

R&E	Research and Engineering
RDT&E	Research, development, test, and evaluation
RS	Remote sensing
RSL	Remote sensing and lidar
UAS	Unmanned aerial system
UAV	Unmanned aerial vehicle
USACE	United States Army Corps of Engineers
USMA	United States Military Academy
VR	Virtual reality

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14. ABSTRACT
This report describes a business intelligence (BI) model developed by the Cold Regions Research and Engineering Laboratory (CRREL) to evaluate multiple projects simultaneously and help researchers learn descriptive phrases found in alignment sources representative of their projects. The BI model combines the linear additive model with the analytical hierarchy process to take advantage of the qualitative and quantitative nature of both methods. The model has five variations, all built along the same objectives but with different criteria due to the specialized emphasis areas of each variation. The BI model operates around three central concepts for evaluating the projects: Alignment Variables, Timing, and Customer Relationship. A use-case scenario with ten projects shows the effectiveness of the model and compares it with another model from the United States Military Academy. This new BI model will assist researchers in developing and proposing research ideas that are more relevant and fundable.

15. SUBJECT TERMS
Business Intelligence; MCDA; Multicriteria Analysis; Multicriteria Decision Analysis; Project Development; Project Management; Research—Management; Research—Planning

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