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A Systems Thinking Based Approach to Writing Effective Concepts of Operations (ConOps)

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Abstract

The concept of operations (ConOps) document is a critical element of system selection, system understanding, and system development. While much work has been done to assess the proper content of ConOps documents, less has been done to develop a particular method for acquiring the required information. This can result in ConOps documents with content based on casual observation rather than rigorous analysis. This paper addresses the analytical basis for ConOps by introducing a step-by-step, “systems thinking” based methodology for conducting the holistic system analysis required to write an effective ConOps document.

Introduction

The term ConOps can be used to describe several types of concept documents ranging from very broad to very narrow in scope (Fleet Forces Command, n.d.). Broader ConOps are those used by the military and other large institutions to articulate the “method or scheme (that is the “concept”) by which the means are applied to achieve the ends” (Schmitt, 2002, p. 3). The most narrowly focused ConOps documents are those that describe the employment of a specific materiel solution in support of the missions, visions, and goals described in the

previously mentioned broader ConOps documents. These solution specific, or *System*, ConOps are “user oriented document[s]” (IEEE, 1998, p. i) and explain how a system will be employed, to include: who will use it, when they will use, how they will use it and for what purpose they will use it (Fleet Forces Command, n.d., p. 7 & ANSI/AIAA, 1993, p. 5). When written effectively, a ConOps communicates the system user’s needs and expectations to the system developer, the system purchaser, and to the other system stakeholders (ANSI/AIAA, 1993, p. 1-2). This shared understanding is an enabler of system success. Likewise, a poorly written ConOps fails to communicate what the user needs and expects, which can have catastrophic results such as: total system concept failure, unmet stakeholder needs, inability to acquire required parts and pieces, and inability to field the system. More often than not, it is not the “writing” that is the problem, but rather the analysis behind the writing that yields a flawed concept of operation

Problem Statement

The writing of ConOps is something that many institutions have already explored. In fact, some institutions, such as those listed in Table 1, have provided great insight into what a ConOps should include by offering detailed guidance on ConOps content and format.

Table 1: Institutions and Documents

Institution	Document
ANSI/AIAA	Guide for the Preparation of Operational Concept Documents (ANSI, 1993)
Carnegie Mellon U. (CMU)	Guidelines for Developing a Product Line Approach (Cohen, 1999)
IEEE	Guide for Information Technology – System Definition- Concept of Operations (ConOps) Document. Standard, 1362-1998 (IEEE, 1998)
Florida State	Florida’s Statewide Systems Engineering Management (SEM) Plan Appx R.(FL, 2005)

The problem with many of these documents is twofold. One, many of these documents or standards are copyrighted and must be purchased, and are therefore not readily accessible. Second, much of their focus is on the *content* of an effective ConOps, and not on the *method* for acquiring the required content. This lack of methodology can result in ConOps documents with content (such as current situation assessments and problem statements) based on superficial observation rather than rigorous analysis. This, in turn, can result in system design problems and solutions that address only symptoms of the problem or, in some cases, fail to address any aspect of the problem at all.

Research Objective

Our goal is to develop a step-by-step process to guide the analysis behind the writing. We propose that a systems thinking-based analysis facilitates a holistic understanding of the problem to be addressed and the solution to address it. From this understanding, a ConOps is generated that: communicates the full range of intended

system uses and use case circumstances to all system stakeholders; assesses, anticipates, and reduces integration and interface problems; predicts operational, organizational, and developmental impacts of system implementation; and establishes key system characteristics that meet stakeholder-identified needs.

Approach and Methodology

To ensure the comprehensiveness of our proposed methodology, we established a three part approach. In Part One we conducted a literature review comprised of both industry ConOps standards and actual ConOps documents. We then assessed these documents for a clearly articulated methodology and for common ConOps document content elements. In Part Two we identified a methodology to guide ConOps analysis and facilitate the development of ConOps documents. In Part Three we validated the proposed methodology to ensure it supplies the information required to populate commonly occurring ConOps elements.

Review of Industry Standards. To determine common content we conducted a review of ConOps standards and sample system ConOps documents. We used industry standards as the primary means for comparing content and recommended analytical methods. Many of the documents we reviewed were based on, or were variations of, the same set of industry standards and did not call for new or different content elements. This content redundancy led us to believe that some standards are more readily accepted as ‘the’ standard as opposed to ‘a’ standard. Our review suggests that the content and format recommended by the Institute of Electrical and Electronics Engineers (IEEE) (1998) appears most commonly. From our review of ConOps related standards we chose six ConOps documents to compare. Four of the documents in our comparison are

standards/guidelines for ConOps documents (Table 1). The other two documents used in our comparison are actual ConOps documents (Table 2).

Table 2: Comparison Documents

Institution	Document
Government Printing Office (GPO) Office of Innovation and New Technology	Concept of Operation (CONOPS v2) for the Future Digital System (FDsys). (GPO, 2005)
Department of Navy (DON)	Concept of Operations for an XML Registry (DON, 2004)

Content Assessment. To assess format commonality, we created a relational matrix. We assessed content by noting each document’s major section titles and then noting the type of information included under each section heading. We then entered the data into the matrix and analyzed each section for similar content. Results of this assessment are summarized in the *results* section of this paper.

Creating a Methodology. To identify a methodology for ConOps development, we assessed the scope of information included in a ConOps document. The results of our content analysis served as the basis for this assessment. Assessing the scope enabled us to identify a systems thinking-based framework for our methodology.

To determine the framework components, we independently developed a series of questions that must be answered in order to fill in the ConOps content elements. We then evaluated a combination of systems engineering and systems thinking tools and processes for their ability to help us answer our identified questions. We then compared our proposed methodology to the traditional front end of the systems engineering process. The purpose of the comparison was two-fold. One, it allowed us to verify completeness of our proposed methodology; in order to ensure

we did not deviate from currently accepted standards, we decided to integrate any components included in the traditional process, but not explicitly mentioned by us, into our methodology. Two, it verified that our proposed methodology was not duplicative of existing standards and practices. In this way, we established that our proposed methodology was not a reiteration of past work.

Methodology Assessment. To assess the ability of our methodology and its associated inputs to support the common ConOps elements, we associated each phase, phase-step, and phase-step-input with the ConOps element(s) it supported. Once associated, we evaluated the methodology for its ability to fully support the level of knowledge required to write each element of the ConOps document.

To validate our proposed methodology, we conducted two validation exercises. In the first exercise we walked through each step of the methodology, using the identified tools and techniques, to create a ConOps for a hypothetical system. In the second exercise we used the methodology to retrospectively assess the ConOps for a real-world system: the US Army Future Combat System.

Results

The content analysis process yielded six categories of commonly occurring information. Though individual categories are broad, they serve to organize more granular material into related areas, e.g., “background” and “supportability”. These categories are listed in Table 3. A brief description of the information included in each category is also provided in the “content” column of Table 3. Category 2, which includes content related to system descriptions, can be broken out into sub-categories of current system description and proposed system description. This break-out is specifically called for in the ConOps format recommended by IEEE (1998) and

helps address challenges associated with legacy systems.

Table 3: Common Content Elements

	Content
1	Background: This category includes a description and assessment of the as-is situation, reasons to change, goals of the proposed system, and a description of the desired end state.
2	System descriptions: This category includes a description of the current system, as well as a description of the proposed system
3	Analysis of the system. This category discusses capabilities, limitations, interfaces, integration, and system use-cases for the proposed system.
4	Impacts. This category discusses impacts of the proposed system. Impacts may be on organizations, processes, stakeholders, or context.
5	Supportability: This category discusses how the proposed system will be supported and includes information on maintenance, personnel, and training.
6	Operational scenarios. This category provides narrative stories of the proposed system's use.

Recommended Analytical Methods. The ConOps standards we reviewed provided minimal guidance on the use of analytical methods for data collection. IEEE explicitly stated that the purpose of their standard was to “present format and content” (1998, p. iii) as opposed to a prescribed methodology. Both the IEEE standard and Florida’s SEM Plan recognized the need for an analytically based ConOps, but neither presented an “exact technique,” (IEEE, 1998, p. iii). Instead, these documents suggested some “approaches that might be used” (IEEE, 1998, p., iii). ANSI (1993) provided more guidance, such as assembling an interdisciplinary team, bounding the system, and using scenarios to assess system characteristics, but did not

provide a step-by-step methodology for acquiring all ConOps related data. Likewise, CMU’s guide (Cohen, 1999) walked through each information element of a ConOps document, even providing example text for each section, but again, did not provide a step-by-step process for acquiring the information. Therefore, we detected an opportunity to improve the ConOps development process by creating a step-by-step methodology, enabled by specific tools and processes, for creating a ConOps document.

Systems Thinking Enabled Methodology. Because ConOps address the entire spectrum of problem and solution space, we realized any proposed analytical methodology for ConOps development had to be broad enough to not only assess the current state of affairs but to also assess the desired future state, and to include if and how the introduction of a specific system or system change facilitates a transformation from current situation to desired end state. A system’s thinking based approach, which identifies, observes, and analyzes patterns and cause-effect relationships (Lamb, Nightingale, Rhodes, 2008, p., 2) yields sufficient breadth of analysis to achieve the comprehensive problem and solution space exploration required to support development of a ConOps document. For this reason, we chose a systems thinking based approach as the foundation for our methodology.

Traditional Systems Engineering. The proposed methodology draws upon and is consistent with the initial stages of the traditional systems engineering process. The systems engineering process calls for: a need to be identified, stakeholder requirements to be gathered, and a system to be selected (Verma & Pennotti, module 2, p., 4,2006).

The methodology we present includes these first three steps as well as eleven additional steps, to create a three-stage, four phase, fourteen-step methodology. This methodology walks the ConOps author(s)

step-by-step from problem definition through to ConOps document publication. The first two phases of our methodology are analytic-based. We complement each of the steps of the first two phases with applied systems thinking. The systems thinking is further enhanced by our use of systems thinking and systems engineering tools that facilitate the processes of analysis, synthesis, and inquiry. Each of these tools serves to enhance overall understanding of the problem space and to ensure the proposed solution is the appropriate solution. The following section provides an overview of the tools we propose.

Systems Thinking Applied. The Conceptagon framework for systems thinking (Boardman & Sauser, 2008) provides a series of mnemonic cues that ignite and sustain the process of comprehensive analysis. These cues occur as a series of seven “triplets” of related words; with each triplet directly related to a system characteristic (Edson, 2008). An illustration of this framework, as provided by Edson (2008), is pictured in Figure 1.

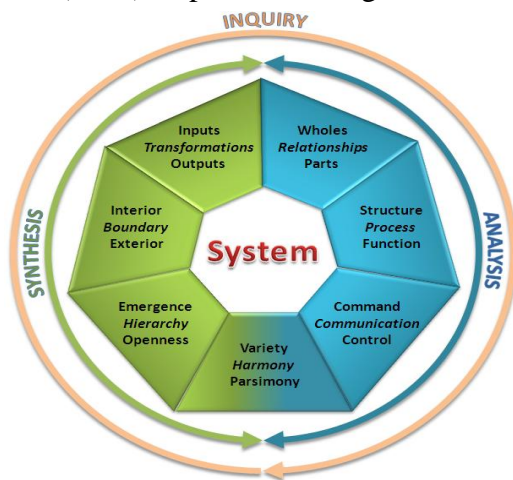


Figure 1. Conceptagon (From Edson, 2008)

We recognize this framework as a structural foundation for problem and solution space exploration. In order to use the Conceptagon effectively, and to inspire its use by others, we have operationalized its triplets by assigning a series of sample questions that each triplet inspires an analyst to ask. While these questions are not all inclusive, they

demonstrate the considerations associated with each triplet. The questions are also not mutually exclusive and may relate to multiple triplets. Sample questions related to each triplet appears below.

Inputs, Outputs, Transformations. *Have I considered what the system is receiving, emitting, and doing?*

Boundary, Interior, Exterior. *Do I have a clear understanding of the system’s scope? Have I considered with what the system will interface and how these interfaces will be managed? Can I identify what is and is not a responsibility of the system?*

Emergence, Hierarchy, Openness. *Do I understand subordinate and superior systems and structures external to, within, and related to the system? Have I considered the porosity of the system boundary? Do I understand the system’s ability to absorb, adapt, and reconfigure, as well as its ability to release and reset? Do I understand how adaptation, reset, and an adapt-reset cycle can change the system’s properties, processes, or relationships? Can I anticipate and leverage these changes?*

Variety, Harmony, Parsimony. *Have I thought about modes of operation? Does the system have sufficient flexibility to achieve its operational goals? Are transitions between modes and interfaces smooth? Does the system have the proper balance of flexibility and rigidity? Does the system meet the operational needs without exceeding them?*

Command, Control, Communication. *Have I identified organizations or laws that govern the system and its use? Do I understand the means by which these exert control on the system? Have I properly assessed the constraints on the system and its use? Do I understand the type of information being exchanged by or with the system and do I understand the pathways that enable that exchange?*

Structure, Function, Process. *Do I know the purpose of the system, how system*

activities are managed and how the system is organized or constructed to achieve its purpose and manage its activities?

Wholes, Parts, Relationships. *Have I considered the system components, how they fit together, and their connection to one another?*

These triplets are the backbone of our methodology and enable a comprehensive analysis of each aspect of the ConOps development process.

A second powerful communication and analytic tool we use is a system diagramming tool called the Systemigram (Boardman & Sauser 2008). This tool is based on a model originally built by Peter Checkland (Boardman & Sauser, 2008, p., 87-89) and captures the critical ideas, themes, and processes of previously written text, and quickly communicates them in the form of a graphic. The Systemigram related process of boiling down language to its most fundamental words not only enables quick communication, but also provides additional insight into the problem and solution spaces. Further information on the development and use of Systemigrams is found in “Communicating Strategic Intent with Systemigrams: Application to the Network Enabled Challenge” (Blair, Boardman, & Sauser, 2007).

We augment the Systemigram with a third tool, a CATWOE (Checkland, 1999) analysis. This analysis can provide information and details needed to create a Systemigram when previously written text is either not available, or is difficult to understand. This analysis also provides tremendous insight into the stakeholders and their motivations.

CATWOE is an acronym that stands for: Customers, Actors, Transformations, Worldview, Owner, and Environment. Analysts can use the acronym to identify and categorize system related roles, processes, and activities as perceived by each stakeholder. Once identified and categorized, these can be

fed back into a Systemigram or channelled into other tools, such as context diagrams and high-level enterprise architectures, which are also part of our methodology.

Other tools we use include the Pugh Matrix. This matrix is a traditional system engineering tool used during system selection activities. The Pugh Matrix provides a means for rating proposed systems on their ability to support critical stakeholder requirements and other selection criteria; our methodology supports the process of determining these criteria. System ratings are then compared to determine which system concept best supports the stated criteria.

Rather than using each of these tools and graphics in an independent setting, our process regards them all as parts of a larger whole that is the problem and solution space. Using the Conceptagon as a lens through which to view the system of interest, and the analytical tools for assessing the system of interest, we can “zoom in” and “zoom out” in order to observe each of the triplets on a very broad scale – viewing each as they relate to the larger picture within which our system of interest sits- or on a very narrow scale – viewing each as they relate to specific system characteristics at the component level.

We couple analysis outputs, which are built on background research, with stakeholder feedback. Using the Conceptagon lens to view the full body of analytical work, each set of triplets is applied to gradually reveal the harmony amongst the differing viewpoints. Eventually, this merging of perspectives yields a comprehensive understanding of the problem and the appropriate solution, which allows the ConOps author(s) to identify relevant feedback loops, system interfaces, and system constraints.

This analysis also produces two levels of data. The first level of data is system specific and focuses on items such as current and future system architectures, use cases, and

operational modes. The second level of data views the context in which the system sits and focuses on understanding how and why the system operates in the manner that it currently does or soon will. This includes identifying and understanding constraints, particularly those that will apply to any future system. This also includes understanding how and why entities external to the system but part of the system's context interact with one another, and the impact of these interactions on the system of interest.

ConOps Development Methodology

Together, our combined use of systems engineering and systems thinking methods and processes results in a three stage, four phase methodology of which the first two phases are an analytical process of defining and refining. The third and fourth phases are traditional processes of writing, validating and publishing. Unique to our methodology are the systems thinking tools and methods associated with each step. Figure 3 graphically depicts the relationship between the methodology inputs and the methodology steps. Figure 3 also illustrates the Conceptagon framework as the backbone for each analytical step. Applied in this manner, each methodology step

considers each set of the Conceptagon triplets. Thus, this methodology allows analysts to integrate Conceptagon considerations at each step of analysis

The methodology draws on the holistic systems thinking based analysis previously discussed. This analysis is subsequently shaped at each step to flesh out specific ConOps related information, such as a concisely stated problem and explicitly stated stakeholder roles. This underlying systems-thinking based analysis is depicted (Fig 3) as inputs feeding into individual methodological steps. Though in Figure 3 inputs appear to have a one to one relationship with individual methodology steps, in actuality products and analyses from each input are applicable to multiple steps across the entire methodology. The illustrated input-step relationship should be thought of as a means to show the application of inputs to methodology steps, and should not preclude the user from a broader application of analytic results.

Methodology Stages, Phases, and Steps.

The Analysis Stage, Phase 1 "Definition", is consistent with the front end portion of the traditional systems engineering process and consists of six steps that are focused on identifying and defining the problem, the

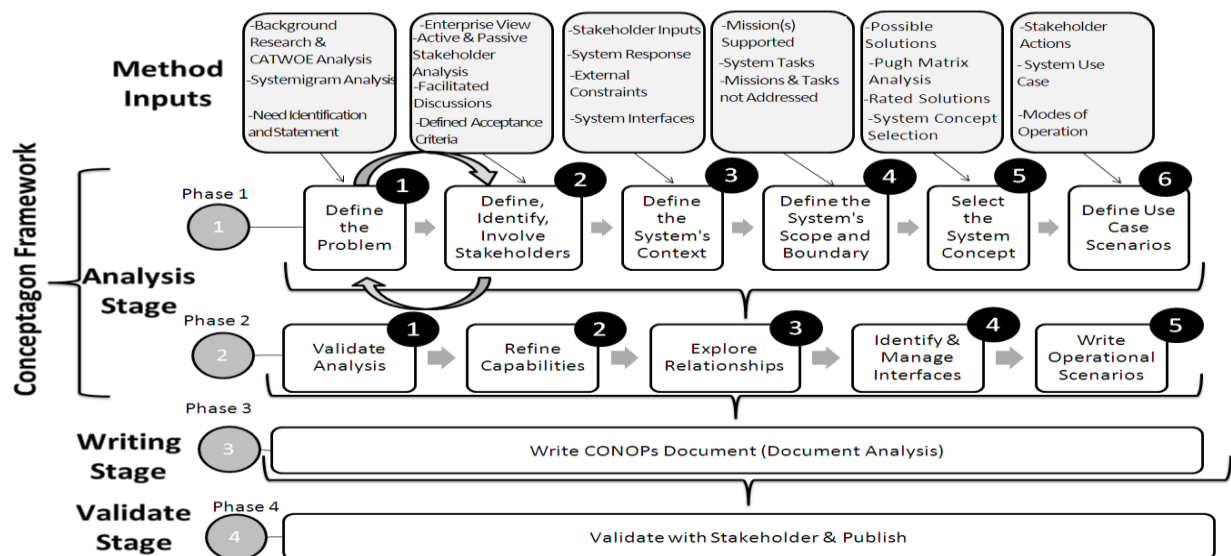


Figure 3. ConOps Development Methodology

solution, and the parties and processes related to both. These six steps are: define the problem; define, identify, and involve stakeholders; define the system's context; define the system's scope and boundary; select the system concept; and define use case scenarios. A feedback loop is present between steps 1 and 2. This loop identifies the iterative process of identifying and interacting with stakeholders, and defining the problem; as the problem becomes more defined, the stakeholders are easier to identify, likewise, as stakeholders are identified, the problem becomes more defined.

Systems thinking tools and processes that augment each step of the Phase 1 analysis are represented by methodology input bubbles. The first input includes conducting background research. This research is funneled into tools such as the Systemigram and high-level enterprise architectures. All of this analysis is combined with stakeholder feedback to assess and articulate the need(s) and to identify key acceptance criteria.

System context, which aids in evaluating missions, tasks, and activities that impact the system's scope and boundary, is revealed by combining stakeholder inputs and desired system responses with known constraints and assessments of the as-is and to-be states.

The totality of this understanding creates a foundation for analytically-based system selection criteria that are subsequently fed into a Pugh Matrix in order to evaluate system concepts, and ultimately to choose a system. Then, with a specific system concept identified, further analysis is conducted to ascertain when, where, why, how, and by whom it will be used. This gives insight into use cases and modes of operation.

Coming out of Phase 1, ConOps authors should have sufficient information to complete ConOps elements related to: background and current situation, description of the current system (or context in which an entirely new

system will reside), the proposed system concept, and goals of the proposed system.

Phase 2 "Refinement" is a five step process that is centered on expanding the analytical results of Phase 1 in order to better understand the to-be system and its impact on the enterprise and to further communicate the desired end state to system stakeholders. These five steps are: validate Phase 1 analysis; refine system capabilities; explore system relationships; identify interfaces and interface management strategies; and write operational scenarios. All inputs and steps of Phase 1 feed into and inform the steps of Phase 2.

Coming out of Phase 2, ConOps authors should have a sufficient level of information and analytical results to populate the remaining elements of the ConOps document. These elements include a description of the proposed system, to include items such as:

- interfaces with other systems and interface management strategies,
- system use-cases,
- system capabilities and limitations,
- effects of system implementation (changes to the enterprise, stakeholders, or processes),
- system support strategies.

In addition to these items, ConOps authors should also have in mind the number of operational scenarios they will include in the ConOps document.

The Writing Stage consists of documenting the analysis conducted in the Analysis Stage, Phases 1&2. This stage requires that the documented analysis include, as a minimum, the common ConOps elements identified during the content assessment (Table 3).

The final phase, the Validation Stage involves two steps. Step 1 of Phase 4 requires that the document be validated by stakeholders. This step serves two purposes. First, it provides stakeholders a final opportunity to raise ConOps related concerns. Second, it provides stakeholders with notice of

potential system impacts which, in turn, gives them time to prepare for system-related changes (IEEE, 1998, p., 15). Step 2 involves publishing the validated document. Though published, the ConOps author must understand that the ConOps is a living document (AIAA, 1993, p., 4) that will evolve over time and over the course of system discovery. As such, it is likely that updated versions of the published ConOps will be required.

Methodology Validation

After developing our methodology we conducted two validation exercises. In the first exercise we used the methodology to develop a ConOps for a hypothetical breathing apparatus. In the second exercise we used the methodology to assess ConOps of an existing system, the Army's Future Combat System (FCS). In both instances, our methodology provided us with sufficient breadth of information to assess the problem and identify an appropriate solution.

In the breathing system exercise we demonstrated the effectiveness of the methodology's systems thinking tools in tasks such as assessing the need and properly bounding the system. We also demonstrated the potential cost impacts of improperly assessing and setting a system boundary.

In the FCS exercise we used tools such as the Systemigram to identify which high-order concept FCS supported, who the primary stakeholders were, what the major mission sets and desired end states were, and what the major sub-systems of FCS were. Following our methodology we were able to evaluate step by step, the scope of the system, the goals of the system, and the system's desired end-state.

Summary

According to the American National Standards Institute (ANSI/AIAA, 1993)

ConOps serve four purposes: “[d]escribe the system characteristics from an operational perspective... [f]acilitate understanding of the overall system goals with [stakeholders] ... [f]orm an overall basis for long range planning... [d]escribe the user organization and mission from an integrated user/system point of view” (ANSI/AIAA, 1993, p., 1). Based on the importance of these purposes it follows that a ConOps document is a critical element of system selection, system understanding, and system development. This criticality should be met with a commitment to properly assess the data that will populate the ConOps document. The systems-thinking based methodology for ConOps development presented in this paper provides a means for comprehensive problem and solution space exploration.

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Biography

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Robert Edson is Chief of Corporate Research at Analytic Services Inc., and Director of the Applied Systems Thinking Institute (ASysT). He is responsible for corporate research and development, knowledge management, and technical workforce shaping. In his role as Director of ASysT, he leads an institute whose mission is to advance the application of systems thinking principles in the fields of national security and homeland security. He has over 25 years of experience in dealing with complex systems issues and systems thinking. Robert is an Adjunct Professor at Stevens Institute of Technology and has a BS in Biology from George Mason University and a MS in Physical Oceanography and Meteorology from the Naval Postgraduate School.