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# BROWNFIELD SYSTEMS DEVELOPMENT: MOVING FROM THE VEE MODEL TO THE N MODEL FOR LEGACY SYSTEMS

**By**

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# Brownfield Systems Development: Moving from the Vee Model to the N Model for Legacy Systems

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**Abstract**. Most systems engineering standards, references, and textbooks consider systems development from a "greenfield" (i.e., clean-sheet, new development) perspective. There are several development (or life cycle) models used for greenfield developments, with the "Vee" model being a popular choice. Many development efforts are better considered from a "brownfield" perspective (i.e., improving upon or replacing legacy systems). This paper proposes an extension of the Vee model, called the N model, which adds a site survey and various reconstruction processes to help move from the as-is system to the to-be system for brownfield development efforts. Three examples are provided to demonstrate how the N model can be applied in different situations.

## Introduction and Background

Most systems engineering standards, references, and textbooks, including the INCOSE Systems Engineering Handbook (INCOSE, 2015), consider systems development from a clean-sheet, new development perspective. Many development efforts are better considered from a legacy system perspective (i.e., improving upon or replacing and existing system of interest). We leverage the terms "greenfield" and "brownfield" from real estate developments to distinguish between these two types of developments.

**Greenfield Development.** In real estate development:

> "Greenfield land is undeveloped land in a city or rural area either used for agriculture, landscape design, or left to evolve naturally." (Wikipedia)

When applied to systems engineering efforts, greenfield developments usually have no or limited legacy system constraints, other than system interfaces. Greenfield systems engineering efforts typically have no, or limited, continuity considerations. Greenfield systems engineering is also known as "clean-sheet" systems engineering. Some examples of greenfield develops include:

- New medical device
- New fighter airplane, such as the F-35

**Brownfield Development.** In real estate development:

> “Brownfield land means places where new buildings may need to be designed and erected considering the other structures and services already in place.” “The land may be contaminated … and has the potential to be reused once it is cleaned up.” (Wikipedia) and (Baley and Belcham, 2010)

When applied to systems engineering efforts, brownfield developments usually involve significant modification, extension, or replacement of an existing system in an existing environment. The primary reasons for doing brownfield development efforts are given in Table 1.

Table 1: Reasons for Brownfield Development Efforts
Adapted from: (Seacord et al., 2003)

| Reason for Change | Description |
| --- | --- |
| Corrective | • Changes made to repair defects in the system<br>• Represents approximately 19% of brownfield efforts |
| Adaptive | • Changes made to keep pace with changing environments<br>• Represents approximately 29% of brownfield efforts |
| Perfective | • Changes made to improve/enhancement the system<br>• Represents approximately 48% of brownfield efforts |
| Preventive | • Changes made to improve future maintainability and proactively seek to simply future evolution<br>• Represents approximately 4% of brownfield efforts |

Brownfield systems engineering efforts typically have explicit continuity requirements. A key aspect of brownfield development efforts is moving from the “as-is” initial legacy system to the “to-be” updated legacy system. Brownfield systems engineering is also known as “legacy” or “in-service” systems engineering. Some examples of brownfield developments include:

- In a Product Line Engineering (PLE) environment, Model Year 2020 of an automobile that uses Model Year 2019/2018/… as its starting point
- Adding a new line of service to an existing transportation system, such as the London Underground’s Crossrail project (now the Elizabeth Line)
- Replacing the analog avionics of an existing transport plane with new digital avionics

**Contrasting Greenfield and Brownfield Developments.** The nature of greenfield and brownfield systems drive different development, or life cycle, approaches that reflect different areas of emphasis. Table 2 lays out some of the key differences across a set of aspects important to systems engineering. This impacts not only the system solution, but also the team that is put in place to develop the system. As with all development efforts, systems engineering processes need to be tailored to fit the needs of a given project.

Table 2: Characteristics of Greenfield and Brownfield Development Efforts
Adapted from: (Baley and Belcham, 2010)

| Aspect | Greenfield | Brownfield |
|---|---|---|
| Life Cycle Stage(s) (of Initial System of Interest) | Concept, Development | Utilization, Support |
| Focus | New or novel features | Maintenance or adding new features while retaining select legacy functionality |
| Maturity (of Initial System of Interest) | Low to Moderate | High for maintenance;<br>Mix for existing system and environment, plus new development for upgrade or replacement |
| Architecture and Design Review | Reviewed and modified at multiple levels | Reviewed only when significant updates |
| Verification & Validation | The entire system of interest typically needs to verified and validated | Only parts of the system need to be verified and validated (there may be regression testing for the unchanged parts) |
| Manufacturing/Production | May be in place if using the existing line, or is developed (or tailored) as development progresses | Mostly in place |
| Maintenance and Logistics | Developed (or tailored) as development progresses | Mostly in place |
| Practices and Processes | Developed (or tailored) as work progresses | Mostly in place, though not necessarily relevant to the new team |
| Team Composition | Newly formed group | Mix of old and new, bringing both historical biases and fresh ideas |

## *The Vee Development Model*

There is no shortage of development, or life cycle, models used in systems engineering. Many of them have names that sound like letters of the alphabet, a veritable alphabet soup of development models (Walden, 2017). Although opinions may differ, we contend there is no “one, right” development model, or we would all be using it. Each development model has its strengths and weakness (see, for example, Section 3.4 of the INCOSE Systems Engineering Handbook (INCOSE, 2015) for guidance on choosing between sequential and incremental & iterative methods).

Notwithstanding the above, the “Vee” development model (because it looks like the letter “V”) has proven useful for numerous greenfield development efforts. Originally introduced for software in (Rook, 1986), it was codified for systems engineering in (Forsberg, et al., 2005). There are many instances of the Vee model. When you see a Vee in systems engineering, you “start” at the top-left, go down the “left-hand-side” of the Vee, then goes up the “right-hand-side” of the Vee.

Implementation of system elements (e.g., hardware, software, services) happens at the “bottom” of the Vee. The left side of the Vee is typically called system definition. The bottom and right side of the Vee is typically called system realization. The Vee also allows for iteration and recursion. Many times, iteration is accommodated by “going off the Vee” or looping back to earlier process areas. Recursion is accommodated by applying multiple Vees at the “bottom” for non-atomic system elements in the context of your system hierarchy.

The version of the Vee we will use is shown in Figure 1. The process areas of ISO/EC/IEEE 15288 (ISO, 2015) and the INCOSE Systems Engineering Handbook (INCOSE, 2015) are superimposed on the Vee. Needs and Technology are the primary inputs to the Vee. In addition, the organization provides a certain amount of funding and has a certain tolerance for risk. The primary output of the Vee is the system of interest. As one starts at the top-left of the Vee, the three primary requirements process areas (BMA, SNRD, SRD) appear first. Next the architecture and design areas are listed (AD, DD). Systems Analysis (SA) is shown along the left side of the Vee to indicate it can be done as needed throughout system definition. Implementation (IMPL) is shown on the bottom of the Vee. Moving up the right side of the Vee, Integration, Verification, Validation, and Transition (INT, VER, VAL, TRAN) are shown.

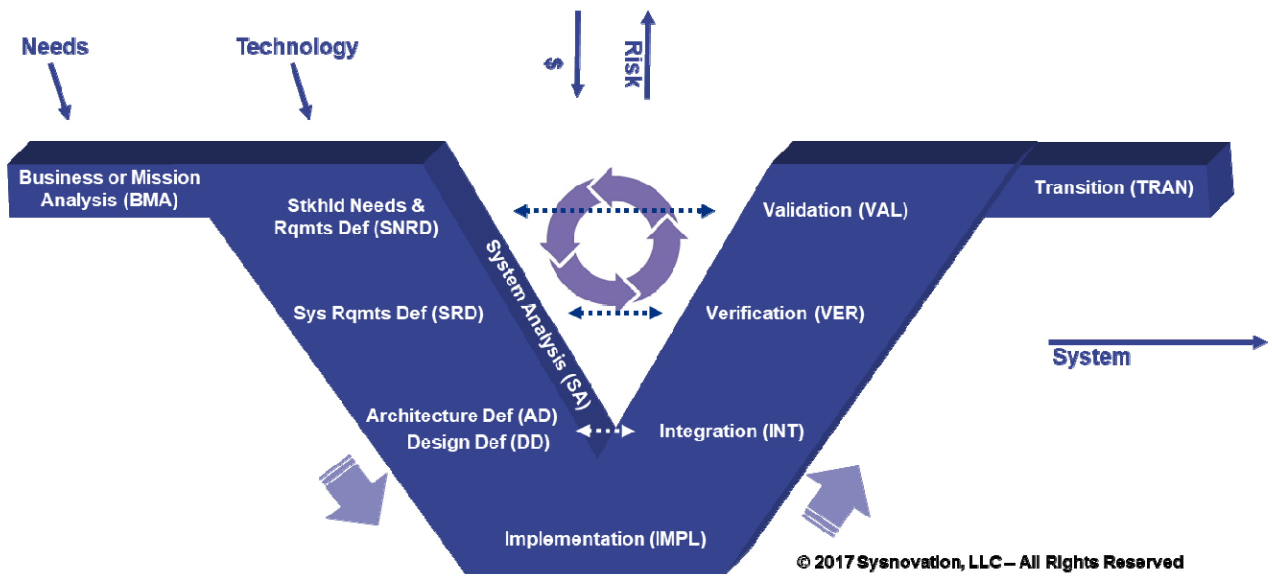


Figure 1. The Vee Development Model

The primary advantages and disadvantages of the Vee development model are listed in Table 3. The biggest advantage of the Vee is the explicit horizontal relationships between the left and right sides of the Vee (e.g., BMA/SNRD – VAL, SRD – VER, AD/DD – INT). Its biggest disadvantage is that it visually implies that one can wait until later in the development process to initiate the process areas on the right side of the Vee. All the process areas can and should be executed in parallel, in an iterative and recursive manner, tailored as necessary.

Table 3: Advantages and Disadvantages of the Vee Model
Adapted from: (Walden, 2017)

| Advantages of the Vee Model | Disadvantages of the Vee Model |
|---|---|
| Depicts top-down definition and bottom-up realization | Reflects a serial view of projects (similar to the Waterfall model) |
| Shows the horizontal relationship between definition and realization | Not easy to account for feedback or changes in the up-front information (need to go "off the Vee") |
| Well-defined phases | Required abstraction to multiple Vee instances for each level of the system hierarchy |
| Well-defined handoffs between phases | |
| Most suitable for projects of moderate complexity in familiar domains | |

## *Extending the Vee to the N*

This paper proposes an extension of the Vee model, called the N model (because it looks like the letter "N"), which adds process areas to help move from the as-is system to the to-be system for brownfield development efforts. The N model is shown in Figure 2.

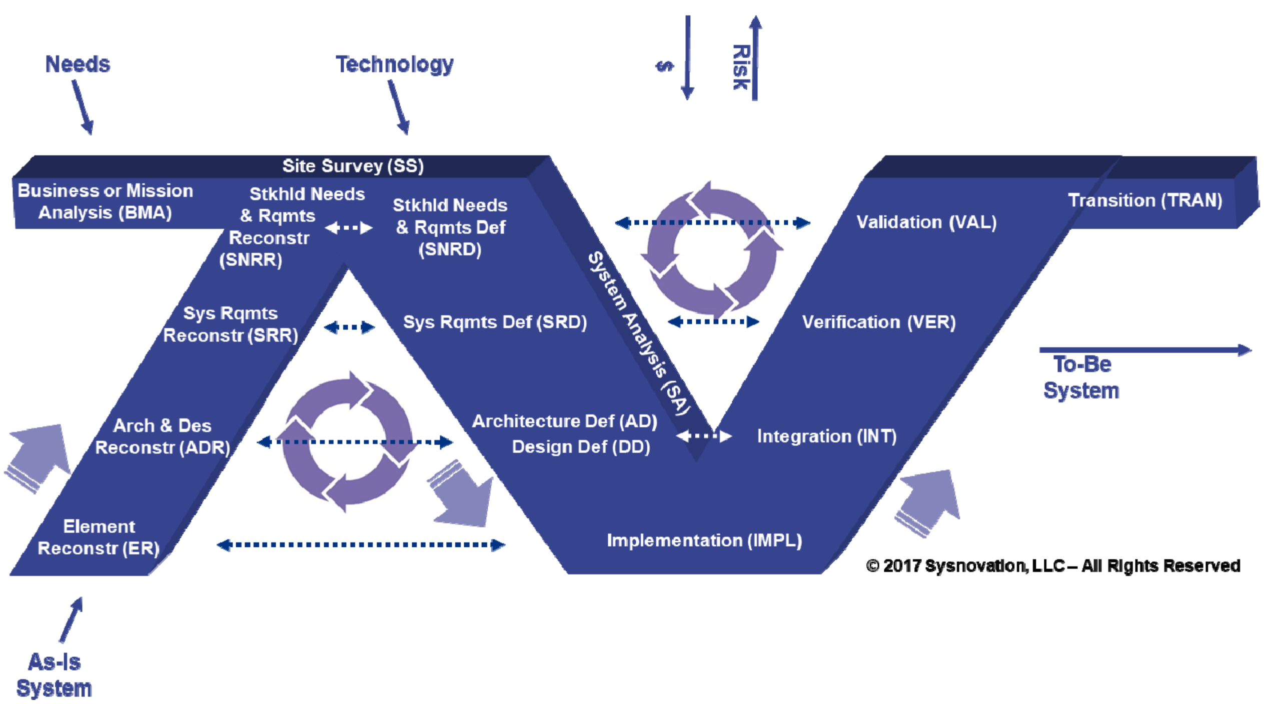


Figure 2. The N Development Model

All of the original Vee inputs and process areas are still present on the N model. An additional as-is system input is present on the N model. A site survey and four reconstruction process areas have been added to create the new "left" of the N. You read the N by starting with an as-is legacy system on the “bottom left”. You then go up the top-left, determine your as-is to to-be gaps, and then proceed down the center and up the right (the original Vee). The output of the N is an updated to-be system.

The Site Survey (SS) should be done early in the brownfield development effort to get a top-level understand of what the team will be dealing with. A systems engineer cannot assume that the system baseline is an accurate reflection of what is currently fielded in the operational environment. The site survey made need to be repeated, or revisited, if in a dynamic environment or if there are multiple variants of the as-is system.

Depending upon the nature and maturity of your as-is system, reconstruction can be done at the Element, Architecture & Design, System Requirements, and/or Stakeholder Needs & Requirements “levels” (ER, ADR, SRR, SNRR). Of course, most development models allow for reconstruction-type activities. However, by making the reconstruction activities explicit, they get better focus and attention for brownfield efforts. The amount of reconstruction needed will vary depending upon the legacy system’s original development effort. If you have no supporting information, you may need to do all four reconstructions. If you are doing incremental improvements on a mature as-is system, you may need to do minimal reconstruction. See the examples provided below.

The primary advantages and disadvantages of the N development model are listed in Table 4. Given its heritage, it is no surprise that the N model shares many advantages and disadvantages with the Vee model. The biggest advantage of the N is the explicit horizontal relationships between the left, center, and right sides of the Vee (e.g., SNRR – BMA/SNRD – VAL, SRR – SRD – VER, ADR - AD/DD – INT, ER – IMPL). Its biggest disadvantage is that it also visually implies that one can wait until later in the development process to initiate the process areas on the center and right side of the N. As with the Vee, all the process areas on the N can and should be executed in parallel, in an iterative and recursive manner, tailored as necessary.

Table 4: Advantages and Disadvantages of the N Model
Adapted from: (Walden, 2017)

| Advantages of the N Model | Disadvantages of the N Model |
|---|---|
| Adds up-front site survey & as-is system reconstruction activities | Reflects a serial view of projects (similar to the Waterfall and Vee models) |
| Depicts bottom-up reconstruction, top-down definition, and bottom-up realization | Not easy to account for feedback or changes in the up-front information (need to go “off the N”) |
| Shows the horizontal relationship between reconstruction and definition and realization | Required abstraction to multiple N instances for each level of the system hierarchy |
| Well-defined phases | |
| Well-defined handoffs between phases | |
| Most suitable for Brownfield projects of moderate-to-high complexity in familiar domains | |

## *Examples of N Model Usage*

The following three examples are provided to demonstrate how the N model can be applied in different situations. All the example companies and systems are fictional.

**Example 1 – Minor Feature Updates with Mature SE.** Honed Systems, Inc. is a high-maturity medical device company. Their flagship product, Apex, has been in service for over five years, with each new Model Year adding additional features. Honed is doing the Model Year 2020 update based on last year's Model Year 2019 successful product. Honed has fully embraced Model-Based Systems Engineering (MBSE) and has an accurate and current requirements database and Systems Modelling Language (SysML) model of Apex 2019.

Honed will have a minimalistic application of the N model for the brownfield development of Apex 2020. The Site Survey reveals that an accurate baseline of the Stakeholder Requirements, System Requirements, and System Architecture and Design already exist. Therefore, the reconstruction activities do not need to be done. The major activity is to determine the gap between Apex 2019 and the requirements for Apex 2020.

**Example 2 – System Replacement Updates with Immature SE.** Middleton Industries is moving towards a systems approach based on past program failures and the increasing complexity of their systems. They need to replace their main product, Albatross, due to parts obsolescence and increased warranty claims. When Albatross was developed, Middleton did not use any formal systems engineering. There was no formally documented architecture or design. What system requirements that currently exist are known to be out of date. Middleton is starting a brownfield development effort to replace Albatross with a new system called Eagle. Eagle needs to do everything Albatross currently does, plus reduce the life cycle cost (LCC) by 25% and reduce the warranty claims by 50%, year over year.

Middleton will have a moderately robust application of the N model for the brownfield development of Eagle. The site survey of Albatross reveals that only a partial, inaccurate baseline exists. There is a solid bill of materials (BOM), so Element Reconstruction will not be necessary. However, it is likely that Architecture and Design Reconstruction will have to be done to approximate the system design and architecture. Also, both the Systems and Stakeholder Requirements will have to be reconstructed. After this reconstruction is done, then the gaps between the reconstructed Albatross and the new Eagle requirements can then be determined.

**Example 3 – Major Updates by a Different Organization.** New Horizons and Past Air are long-time competitors. Past Air originally built the F-123 fighter airplane in the 1970s. The Air Force wants to extend the life of the F-123 by upgrading its analog avionics to digital electronics and touchscreen displays, called F-123+. After a heated competition, New Horizons is selected to lead this avionics upgrade effort. Past Air is not pleased and challenges the award. The award to New Horizons is upheld and they begin the upgrade program one year later than anticipated.

New Horizons will have a robust application of the N model for the brownfield development of F-123+. Given the nature of the award, it is highly unlikely that Past Air will share any detailed technical insight on the F-123 with New Horizons. The site survey of F-123 reveals that the Air Force has only the original drawings submitted in the 1970s. There have been several aircraft changes that have taken place since then. Past Air is not willing to share any of their internal detailed drawings. In addition, it is well known that the warfighters often make unauthorized "changes" so each aircraft tail number may have some unique changes. All these factors point to Element Reconstruction being necessary. Architecture and Design Reconstruction will have to be done to recreate the system design and architecture. Both the Systems and Stakeholder Requirements will have to be reconstructed. After all these reconstructions are done, then the gaps between the reconstructed F-123 and the new F-123+ requirements can then be determined. However, the gaps may have to be determined on an induvial tail number basis.

## *Further Research*

This paper introduces an extension of the Vee model, called the N model. Additional work needs to be done to fully vet and validate the N model. The primary parameters towards selecting the N or Vee model (or some other model) need to be elaborated. Greater detail regarding "how" to do the N model process areas need to be added to answer what should be done during the Site Survey and various reconstructions and to identify the key artifacts (inputs required for each process area, and how the inputs are processed to produce a specific outputs) from each process area. Specific guidance on how to ensure that the current baseline is accurately captured (perform a gap analysis at the system and system element requirement and architecture levels) needs to be elaborated. Details/best practices need to be provided on how the baseline gap analysis (from the site surveys) may be done, including any necessary assumptions. Strategies, guidelines, and process of reconstruction at various levels (e.g., element, architecture, requirements) should be elaborated with more detail and depth. Brownfield development impacts on Verification and Validation should be explored in more detail (e.g., not everything needs to be tested again, although reuse does not automatically mean no need to test). The key benefits of using N-model over V-model in terms of cost, schedule, resource utilization, etc. should be established by defining appropriate metrics. Literature on product variants creation, product architecture selection needs to be reviewed to build robustness into the proposed N model.

## *Wrap-up and Conclusions*

This paper proposed an extension of the Vee model, called the N model, which adds a site survey and various reconstruction process areas to help move from an as-is system to a to-be system in brownfield development efforts. Three examples were provided to demonstrate how the N model can be applied in different situations. Topics for future research have also been identified.

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## Biography

**David D. Walden, ESEP,** is co-owner and principal consultant for Sysnovation, LLC, an SE consulting and training firm he formed in 2006. Previously, Mr. Walden was with General Dynamics Advanced Information Systems for 13 years and McDonnell Aircraft Company for 10 years. Mr. Walden was the PM of the INCOSE Certification Program from 2007-2013. He is an INCOSE liaison to ISO/IEC JTC1/SC7 Working Groups 10 and 22 and the lead editor of the INCOSE SE Handbook Edition. He has an M.S. in Management of Technology (MOT) from the University of Minnesota, an M.S. in Electrical Engineering and in Computer Science from Washington University in St. Louis, and a B.S. in Electrical Engineering from Valparaiso University in Indiana. Mr. Walden was one of the first to earn the INCOSE Certified Systems Engineering Professional (CSEP) credential in 2004 and was awarded the INCOSE Expert Systems Engineering Professional (ESEP) credential in 2011.