MP 01W0000154

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Research and Development Maturity Assessment Guide

With Examples from Traffic Flow Management

July 2001

Ved Sud

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Sponsor:	FAA	**Contract No.:**	DTFA01-01-C-00001
Dept. No.:	F045	**Project No.:**	02011308-4B

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MITRE Department
and Project Approval:

Anthony G. Chambliss
Program Manager
TFM Decision Support System Evolution

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Abstract

This paper discusses the four-phased management process for R&D used by the Federal Aviation Administration's (FAA's) Traffic Flow Management (TFM) Integrated Product Team (IPT). It describes these phases at a high level, illustrating the typical activities associated with each phase. The paper also discusses the Readiness Levels model that is currently being considered in the FAA's Free Flight Office to manage research. The paper discusses relationship of the readiness level model to the four-phase approach. The paper then moves on to the more important question: how does the FAA determine whether the research activity is ready to move on from one phase to the next and when is it mature enough to be implemented as part of the operational system. Suggested sets of outcomes/outputs important for transitioning between each phase are shown. The paper provides guidelines to researchers and managers in preparing for the eventual decision points that are expected. The paper does not describe the specifics of research on any particular capability, however it does provide a few examples to illustrate the use of the guidelines proposed.

KEYWORDS: Research and Development (R&D), Concept Exploration (CE), Concept Development (CD), Prototype Development (PD), Full Scale Development (FSD), Readiness Levels–Technical Readiness Level (TRL) and Implementation Readiness Level (IRL), Maturity Assessment

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Section 1

Introduction

Research and Development (R&D) are fundamental activities facilitating creation of new concepts, capabilities, and products in any venture. This is particularly true in air traffic management. R&D programs and activities create and provide the flow of new ideas and concepts into the development stream leading to capabilities, tools, and procedures that improve daily operations in air traffic services.

R&D are inherently difficult to manage both in terms of the products and the timing. The goals are often defined to be open-ended and changing as new facts are gathered along the way, particularly in the early stages of research. In general, research requires plenty of leeway to allow the exploration of new ideas or concept paths without excessive time or financial constraints that may hinder the "free" thinking. A flexible management process is needed in the early stages of research. However, as research matures and progresses into the development stages, more discipline is needed, as more stakeholders (testers, end users, trainers, maintainers, etc.) become involved in the maturity process.

To help organize and manage this difficult and evolving process, the FAA has developed a four-phased management process for R&D in the Traffic Flow Management (TFM) domain. This paper describes these phases at a high level, illustrating the typical activities associated with each phase. More recently, the FAA is also considering using Technical Readiness Levels and Implementation Readiness Levels to manage research. The paper discusses the readiness level approach and its relationship to the four-phase approach.

The paper then moves on to the more important question: how does the FAA determine whether the research activity is ready to move on from one phase to the next and when is it mature enough to be implemented as part of the operational system. Suggested sets of outcomes/outputs important for transitioning between each phase are shown.

The intent of the paper is mainly to describe the process and provide guidelines for maturity assessment. Each R&D program is unique; therefore, this paper provides guidelines (as opposed to hard and fast rules) to researchers and managers in preparing for the eventual decision points that are expected. It is not intended that researchers and managers follow the process exactly. Rather, it is intended to provide guidelines that will help them tailor the process to the needs of their specific research and situation and guide them in the phase transition decisions. The paper is not intended to describe the specifics of research on any particular capability, however it does provide a few specific examples to illustrate the use of the guidelines proposed.

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Section 2

The Four Phases for Research and Development

Figure 1 shows the process flow for R&D through the four-phase structure. The R&D phases are Concept Exploration (CE), Concept Development (CD), Prototype Development (PD), and Full Scale Development (FSD).

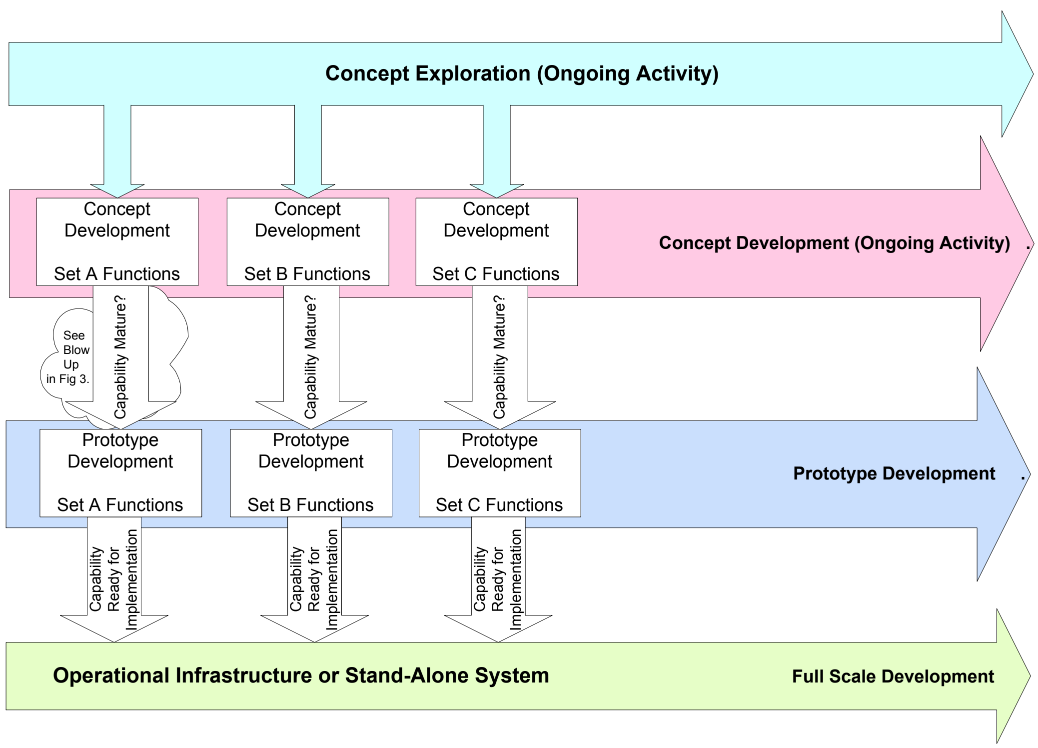

Figure 1. The Four Phased Research and Development process with Incremental Implementation of Capabilities

2.1 Concept Exploration

Research starts with an idea or concept that needs further exploration. This initial stage of research is called the Concept Exploration phase. Generally, a needs document exists or is created even before the research begins. The concept requiring exploration is intended to

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satisfy the requirements outlined in the needs document. In this phase the initial ideas germinate and take on recognizable unique characteristics as a capability or set of capabilities (early operational concept assuming some level of new capabilities and procedures). Amorphous, initial ideas and concepts are clarified, either with or without the aid of some initial, front-of-the-panel lab prototype. When research deals with decision support tools, a straw man operational concept on its use may also be generated. When user interaction is involved in the operational concept, feedback from the user community may be needed on the initial concept and thus feedback from the FAA or the user community is gathered. When the potential for adding value and/or benefit in terms of the mission need is identified, the concept is selected for further development and R&D proceeds to the Concept Development phase. This decision is usually a stakeholder group decision within the FAA.

2.2 Concept Development

The Concept Development phase has the purpose of further developing the idea or capability and demonstrating its potential operational application and benefit. During CD, a specific approach is developed to further refine requirements, develop functional specifications and performance criteria for the system, and evaluate alternatives. In this phase the effort is put into clearly developing the details of the concept. The target architecture and environment are also defined during CD. Lab prototypes, also called "Concept Development" or "Concept Evaluation" prototypes may be built and exercised to evaluate states and modes of operation and operational utility. The concept (and prototype, if built) is also explicitly exposed to operational field personnel and their suggestions are received and reviewed. The feedback is used to further enhance the concept or prototype. It is much easier, quicker, and less expensive to enhance the CD prototype and incorporate operational feedback at this stage than wait for it to be done later with the PD prototype in the PD phase or the full scale system in the FSD phase. A more detailed operational concept is also prepared, taking into consideration the users interactions with it.

2.3 Prototype Development

The Prototype Development phase takes the capabilities developed in CD phase and gives them a physical manifestation in the form of a prototype that can be considered a first article or beta version of the final system. This prototype is also sometimes called the operational prototype to distinguish it from the Concept Development prototype. It is used to "shake out the bugs" in the hardware and software, assess the performance of the system, and check out the final computer human interface. It is also used to develop the operational procedures that will be used when the capability is implemented. From a philosophical point of view, the line separating CD from PD can be fine. The distinction has been made that although concepts are demonstrated in CD they are really tested operationally and performance issues addressed only during PD. The PD phase becomes more significant when the operational concept involves time critical decisions and actions. Under these circumstances, requirements for ease of use and system responsiveness may change

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significantly in PD from what they were in CD. During both CD and PD there is a focus on testing and evaluation (testing implies stable requirements, while evaluation allows that the requirements are still in flux). It is important to recognize that the purpose and scope of the evaluation varies with the phase. In CD evaluation addresses specific functional requirements and performance standards; tradeoffs may be performed. In PD evaluation is done both to stress the system and verify performance, and to assure user acceptance. In an era of tight budgetary constraints, by the time a concept is selected for PD, only questions of performance and scale-up should prevent it from being deployed in FSD.

Depending on the complexity of the concept, the degree to which operations are changed, and the time critical nature of the operations being affected, the need for and type of prototype can differ. In cases where added complexity and performance issues are expected, the prototype might need to be independent from the full-scale capability in order to allow for rapid modification if necessary. While for other more straightforward concepts, the prototype maybe intended as an early model to evolve into the full-scale capability. Thirdly, concepts completing the CD phase with minimal potential for requirements change, might substitute the PD phase with an early operational assessment of the full scale development system.

2.4 Full Scale Development

In the Full Scale Development phase the final product is made robust and its performance is verified to be operationally acceptable. It is then implemented at a particular site or series of sites. All the FSD activities are geared more towards implementing the capabilities: adapting to the site, installation, training, operational testing, finalizing the procedures, etc. One could say that there is no longer much research to be done at this stage. If any, it is more a case of applied research to ensure an operationally integrated and usable capability. The use of the fielded capability, however, may trigger additional offshoot research in the same or related areas.

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Section 3

Research and Development Readiness Levels

The Readiness Level model is another model for managing R&D. The Readiness Level model consists of two scales: Technical Readiness Level (TRL) and Implementation Readiness Level (IRL). Use of this model is also being considered within the FAA. This model is an adaptation of the Technical Readiness Levels that have been in use at National Aeronautics and Space Administration (NASA) for managing research activities. To incorporate the management of the Development and Implementation aspects that naturally follow the pure research activities, an Implementation Readiness scale has also been incorporated. The model is particularly useful when research is being done by an independent entity and will eventually need to be incorporated within the FAA's operational system. The Readiness Level model showing the technology and implementation readiness levels and their inter-relationships is shown in Figure 2. The levels in both scales rise with increasing readiness for eventual operational deployment of the capability. The wide arrows between the two scales show some correspondence between the TRL and IRL levels. For instance, to achieve an IRL of 4, a concept needs to already have achieved a TRL of 6. The width of the base of the arrow spanning the TRLs 4 to 6 and pointing to IRL 4 indicates that coordination activities between the research organization and the FAA need to occur starting at TRL 4 and continuing through TRL6 for a successful transition to IRL 4. In other words, the research organization and the FAA must overlap their activities in the TRL 4 through 6 timeframe.

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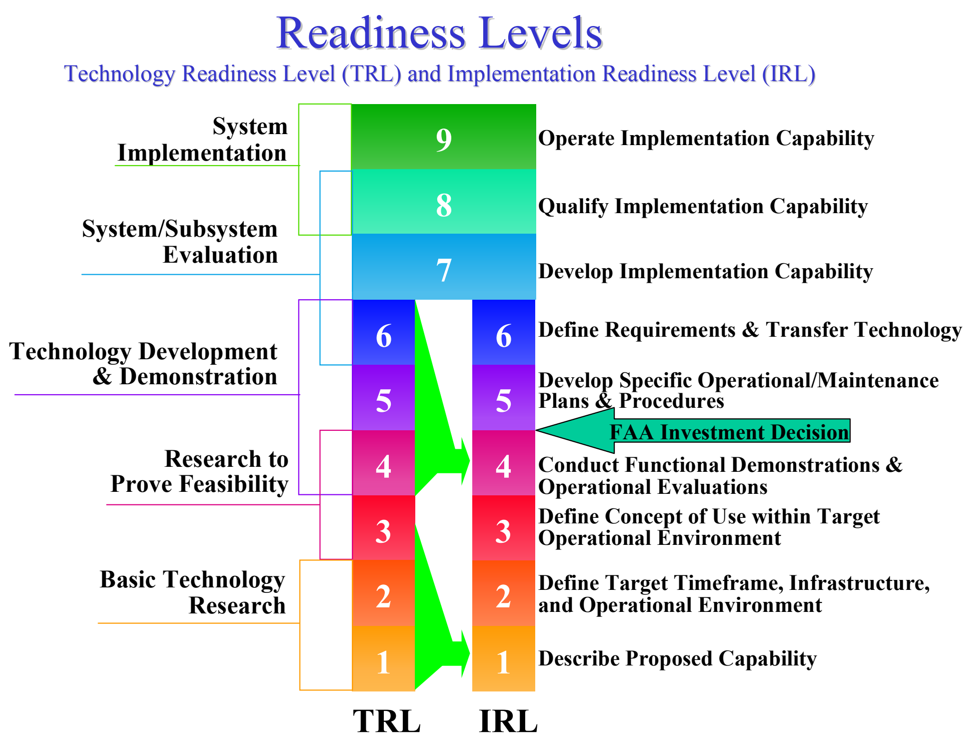

Figure 2. Technology and Implementation Readiness and their Inter-relationships

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Section 4

Relationship between the Four Phases and the Readiness Levels

The relationship between the CE/CD/PD/FSD phases and the readiness levels is depicted in Figure 3. Although the figure depicts sharp demarcations for the four phases to the readiness levels, this relationship is somewhat fuzzy and often overlapping. The CD to PD/FSD maturity is essentially the decision taken after an IRL level of 4 is achieved. PD is an activity that may span from an IRL 5 to 6 and sometimes even partly into IRL 7. For the purpose of clarity, the CE, CD, PD, FSD phases and terminology will be used in this paper although this graphic will allow for translation.

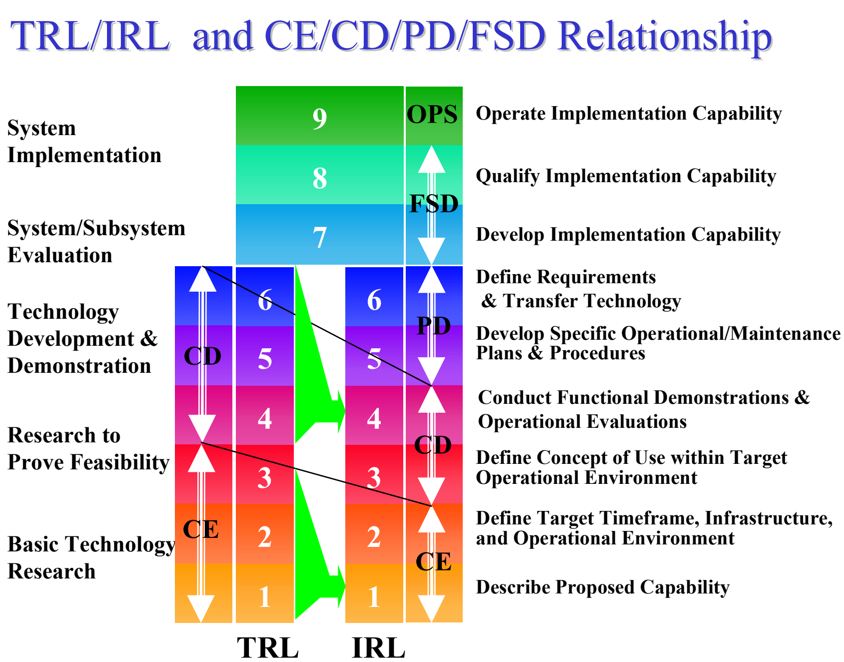

Figure 3. Relationship Between the Four-Phase Model and the Readiness Level Model

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Section 5

Transition through the Research and Development Phases

As can be seen from Figure 1, R&D is a continuous process. The products from R&D activities flow into the field capabilities in an incremental manner. For managing the R&D properly, it is important to transition through the phases in a clear and explicit manner. Although the capabilities could be eventually deployed in the field in a stand-alone fashion, if conditions warrant them, generally they will be implemented on the Operational Infrastructure. For example, for the Traffic Flow Management domain, the capabilities would be incorporated into the Traffic Flow Management Infrastructure (TFMI). The Enhanced Traffic Flow Management System (ETMS) is the current implementation of the TFMI. The TFMI itself will be evolving with time. The target platform is discussed further in the next section.

5.1 Concept Exploration to Concept Development Transition

A research activity in the CE phase might show promising results on certain capabilities to warrant further development. These capabilities are then transitioned to the CD phase while concept exploration continues with the remaining capabilities. The transition between the CE and CD phases is based on satisfactory completion of three broad sets of activities:

- **Create Operational Concepts**

  There should be a clear definition of the problem being addressed and a description of the concept. An operational needs document should either exist or be created at this stage. Other things that could be relevant at this stage are a look at current products or capabilities that have similar functions, and some distinction of the differences in operational need being addressed with the new product that are not being addressed otherwise. There should also be an assessment of interdependencies and relationships to the other products.

- **Start Costs/Benefits Analysis**

  An initial description and a preliminary estimate of the benefits of the capability should be made. Other things that may be useful to consider at this time would be an initial Life Cycle Schedule, an initial Life Cycle Cost Estimate and if it makes sense, an initial outline of approach to Integrated Logistics and Support.

- **CE Wrap Up and Transition**

  A list of the open issues that need to be further researched should be documented. Also identified risks should be captured. A CD Phase plan should be generated and

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should have details on broad functional requirements and any operational evaluations planned with the associated entrance/exit criteria.

A decision to move on from the CE to the CD phase should be made collectively with the research and the sponsoring organizations, after considering the above guidelines. At that time the research organization should present the analysis and documentation relating to the exit guidelines. The resulting decision could be to proceed with CD, terminate the research, merge it with another capability, or re-scope it.

If the decision is made to proceed with CD, the analysis and documents used for the assessment should be retained, as they will need to be reexamined and perhaps updated for the next decision point.

5.2 Concept Development to Prototype Development Transition

The decision to move the capability from the CD to the PD phase is more involved and complex. Figure 4 depicts the process for this decision.

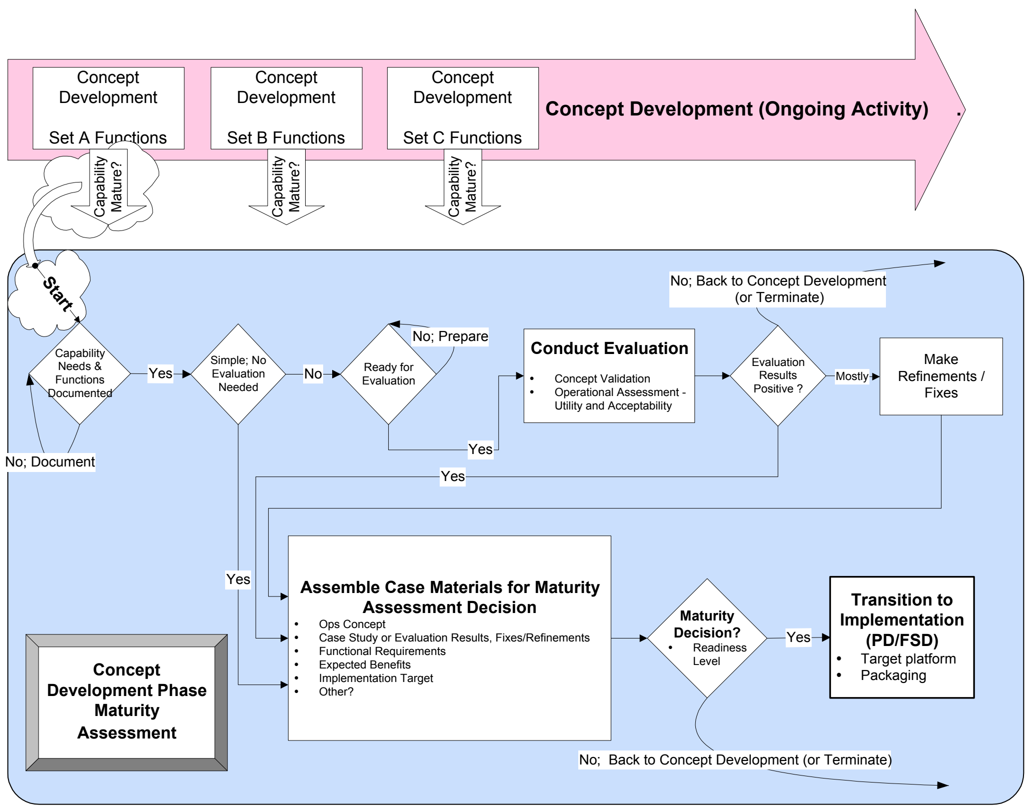

Figure 4. CD to PD/FSD Decision Process Activities

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The operational needs for the capability should have been documented in the CE stage. Early in the CD stage, the functional capabilities are clearly and concisely documented and one of the necessary tasks is to verify that they satisfy the operational need(s). To do this one needs to consider the nature of the capability itself. Is it something simple and straightforward enough that one can readily tell how it will behave in actual operations? If this is the case, then no field evaluations may be necessary and one may directly move on to the maturity assessment decision. If the capability is not a simple one, the researcher will probably need to develop a prototype and plan to conduct evaluations. The evaluations should focus on the validation of the operational concept and the operational assessment in terms of the operational utility as well as user acceptability. CD Evaluations will involve a certain amount of preparation activities. These may be the preparation of training materials, preparation of operational scenarios, perhaps questionnaires for the pre and post evaluation steps, and the conduct of training. The questionnaires will help clarify the information that is being sought from the evaluation activity. An example in the TFM domain is the CD evaluations that are currently being conducting for the Collaborative Routing Coordination Tools (CRCT) rerouting capabilities. One of the evaluation aspects introduced is the questionnaire tied to the TFM Capabilities Acceptability Rating Scale (TCARS). The questionnaire and scale are based on the Controller Acceptability Rating Scale[1] (CARS) which has been successfully used in assessing user acceptability in other Free Flight programs. TCARS is a technique that provides some rigor to the evaluation process.

Once the evaluations are conducted, the results are examined and assessed. The outcome may be that the capability is not acceptable and that further development and refinement is necessary, i.e., CD needs to continue. The outcome could also be that the capability is either redundant or does not satisfy the need and the research needs to be modified or terminated. A third possible outcome could be that the capability is useful and satisfies the need but some minor refinement or tweaking must be done prior to proceeding. Finally, it could be that the capability is useful in its current state. Even so, the decision to move on to the next phase should be a formal one and explicitly made. As shown in Figure 4, all the materials needed for the decision are assembled and the decision is made in a joint session with the researchers and the sponsors. Sometimes other stakeholders, like the airline users, may be involved if deemed necessary.

Some of the other factors that weigh into the maturity decision are:

- Affordability
- Performance
- Evolution Opportunities
- Urgency or Intensity of need of capability for operations (Potential benefits)

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In the TFM domain for example, affordability and urgency of the need to apply it to the resolve operational issues were key factors in the decision in mid 2000 to transition some CRCT concepts from CD on to implementation on the ETMS. It was obvious that the Flow Constrained Area capability was mature at that point and should transition, whereas the rerouting capability needed additional user involvement and evaluations.

A concept is generally ready to move from CD to PD when it is clearly defined, the operational requirements are documented and evaluated under laboratory conditions, performance metrics have been established, and the cost benefits analysis indicates that development and implementation of the concept will have a positive return. The activities that should be completed for the CD to PD maturity assessment decision are the following:

- **Update Operational Concepts/Requirements**

  An operational needs document should have been created in the CE stage. This document should be reviewed for currency and relevancy. Once this is done and approval is gained, this is now the operational requirements document. This document is the baseline with which the capabilities being accomplished will be evaluated in deciding how well the capabilities are covering the stated needs. There should also be an updated and approved operational concept description document.

- **Generate Specifications, Models/Algorithms**

  Functional requirements should be completely documented and approved prior to the transition decision. Sometimes these are documented as System Level Specifications (also called "A" Level Specification). Specific algorithms and modeling assumptions maybe critical to the definition of the concept. If so, these should be clearly documented. If a prototype was developed for evaluating the concept, the code should be well commented and documented, such that it can be used for understanding the function, in case the details are not clear from the Functional or the Algorithmic Specifications.

- **Review/Revise Costs/Benefits Analysis**

  The description and estimate of the benefits of the capability should be revised during this stage, incorporating information gained. Other things that may be useful to consider at this time would be a revised Life Cycle Schedule, a better Life Cycle Cost Estimate and an initial approach to the Integrated Logistics and Support.

- **CD Wrap Up and Transition**

  An update to the issues from the CE stage should be done, documenting the resolution for those that have been resolved. A revised list of the still open issues that need to be further analyzed or researched should be documented. The remaining identified risks should also be captured. A PD Phase plan should be generated which should have details on planned field evaluations with associated entrance/exit criteria.

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5.3 Prototype Development to Full Scale Development Transition

Typically, if a prototype has not been built in the CD stage, the PD phase will involve building the prototype and conducting the evaluations described for the CD stage. If one had been built, the prototype is now made robust or rebuilt if necessary and made ready for field implementation in the FSD stage. This is now a full fidelity prototype. The prototype may actually consist of a version of the operational infrastructure (a "test string") that now includes the CD capability being transitioned. In unusual circumstances, the PD stage may be skipped and the capability implemented directly on the operational infrastructure. This course of action is not recommended, unless it is obviously clear that the capability is very simple, that it can be turned off without affecting the rest of the system, and that it is easy to fall back to the pre-capability state of the system. In transitioning from PD, it is important to have performance test results that demonstrate that the system adequately performs the task it was designed to do (i.e., meets all requirements). Equally important are specifications that can be used for the development of production system. The activities that should be completed for the PD to FSD stage transition are the following:

- **Update Operational Concepts/Requirements**

  There may be an update made to the operational requirements document, if any of the operational needs have changed. The operational concept description document must be updated also.

- **Update Functional Specifications**

  The functional specifications should be updated as well as the system level specifications. Going into the FSD stage, the lower level specifications will also need to be created. These provide the details for building the system to be fielded.

- **Updated Life Cycle Costs/Costs/Benefits Analysis**

  The Cost Benefits Analysis should be refined incorporating the information gained in this stage. Generally, there should be a much better estimate on the expected benefits. There should be a revised life cycle schedule; a better, more definitive life cycle cost estimate and a revised integrated logistics and support plan.

- **Create Prototype Documents**

  The prototype developed should have most of the following documents to support it. Description of first five documents can be found in the Data Item Descriptions for MIL-STD-498:

  Software Requirements Specifications (SRS)

  System/Subsystem Specifications (SSS)

  Software Design Document (SDD)

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Software Test Report (STR)

Software User Manual (SUM)

Prototype Operational Evaluation Report

Prototype Algorithms (as Implemented)/Code

- **Create Acquisition Documents/FSD Transition Plan**

  The following documents may need to be created to transition on to FSD.

  The Investment Analysis Report

  Acquisition Program Baseline

  Acquisition Strategy Plan

  Integrated Program Plan

  Issues and Risks Identification and Resolution Report

  FSD Phase Plan

Table 5 summarizes the guideline activities and documents for all the phase transitions.

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Table 5. Guideline Activities/Documents for Research and Development Phase Transition

Concept Exploration (CE) to Concept Development (CD) Transition	Concept Development (CD) to Prototype Development (PD) Transition	Prototype Development (PD) to Full Scale Development (FSD) Transition
• Create Operational Concepts/Requirements Problem Definition/Clarification Description of Concept Initial Operational Needs Document Operational Concept - Strawman • Start Costs/Benefits Analysis Initial Description of Benefits Benefits Estimate - Preliminary Life Cycle Schedule - Initial Life Cycle Cost Estimate (ROM) Integrated Logistics and Support (Initial Outline) • CE Wrap Up and Transition List of the open issues Identified risks CD Phase Plan	• Update Operational Concepts/Requirements Operational Requirements - Baselined Operational Concept - Updated • Generate Specifications, Create Prototype/Models/Algorithms Functional Specifications Draft System Level Specifications Models (if applicable) Algorithms (if applicable - documented) • Review/Revise Costs/Benefits Analysis Benefits Estimate - Detailed Life Cycle Schedule - Draft Life Cycle Cost Estimate - Budget Integrated Logistics and Support - Initial • CD Wrap Up and Transition List of the open issues Identified risks/Resolution PD Phase Plan	• Update Operational Concepts/Requirements Updated Operational Requirements Document Updated Operational Concept Description Document • Update Functional Specifications Updated Functional Specifications System Level Specifications Lower level specifications may also be needed • Update Life Cycle Costs and Costs/Benefits Analysis Benefits Estimate - Refined Life Cycle Schedule Revised Definitive Life Cycle Cost Estimate Integrated Logistics and Support Program - Revised • Create Prototype Documents Software Requirements Specifications (SRS) System/Subsystem Specifications (SSS) Software Design Document (SDD) Software Test Report (STR) Software User Manual (SUM) Prototype Operational Evaluation Report Prototype Algorithms (as Implemented)/Code • Create Acquisition Documents/ FSD Transition Plan. The Investment Analysis Report Acquisition Program Baseline Acquisition Strategy Plan Integrated Program Plan Issues and Risks Identification and Resolution Report FSD Phase Plan

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Section 6

Suggested Post Assessment Activities for Implementation

Once the Maturity Assessment Decision has been made for the transition to FSD, there are several other tasks that need to be done to prepare for a successful implementation period. If it has not already been accomplished by this stage, one of the first activities is completing the determination of the target system on which the capability will be implemented. It is quite common to have this activity start way before in the CD stage. In fact, this can also be considered an indirect factor in the maturity assessment decision. The choice may be to implement it on the existing operational system infrastructure. An option may be to implement it as a stand-alone system that may or may not interface with the operational system. Another option may be to implement it on an existing stand-alone system. This is an overall systems engineering activity and will need to consider various factors like development and implementation costs, system life cycle costs, system performance, implementation time-scale and the urgency for the capability, etc. These factors themselves involve activities to collect and analyze data and to conduct trade-off studies to formulate the information that is needed to drive the decisions.

If the capability is to be implemented by an entity other than the research organization, a Technology Transfer activity will also have to be initiated. An example of this activity is the technology transfer work that is currently ongoing with MITRE/CAASD transferring the CRCT capabilities to the Volpe National Transportation Systems Center.

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Acknowledgements and References

- CAASD Working Notes generated during the period 1997-1998 were reviewed in formulating these guidelines.
- A briefing by Mr. Steven Alvania, now a retired FAA employee, titled "CE/CD Day Exercise" dated January 22, 1998 was also used as a basis for the transition guidelines.
- The Readiness model is an adaptation of the Technology Readiness levels used by NASA, Ames. The adaptation was worked with the FAA's Free Flight Office.
- Much of the material used here was developed during meetings with the TFM Integrated Product Team (IPT) members, in particular conversations with Mr. James Wetherly (FAA, TFM/IPT) and Mr. Anthony G. Chambliss (MITRE/CAASD).
- The author is thankful to Mr. John Mayo (MITRE/CAASD) for his useful suggestions in reviewing this paper.

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Glossary

CARS	Controller Acceptability Rating Scale
CD	Concept Development
CE	Concept Exploration
CRCT	Collaborative Routing Coordination Tools
ETMS	Enhanced Traffic Flow Management System
FAA	Federal Aviation Administration
FSD	Full Scale Development
IPT	Integrated Product Team
IRL	Implementation Readiness Level
NASA	National Aeronautics and Space Administration
PD	Prototype Development
R&D	Research and Development
RLM	Readiness Level Model
SDD	Software Design Document
SRS	Software Requirements Specifications
SSS	System/Subsystem Specifications
STR	Software Test Report
SUM	Software User Manual
TCARS	TFM Capabilities Acceptability Rating Scale
TFM	Traffic Flow Management
TFMI	Traffic Flow Management Infrastructure
TRL	Technical Readiness Level

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