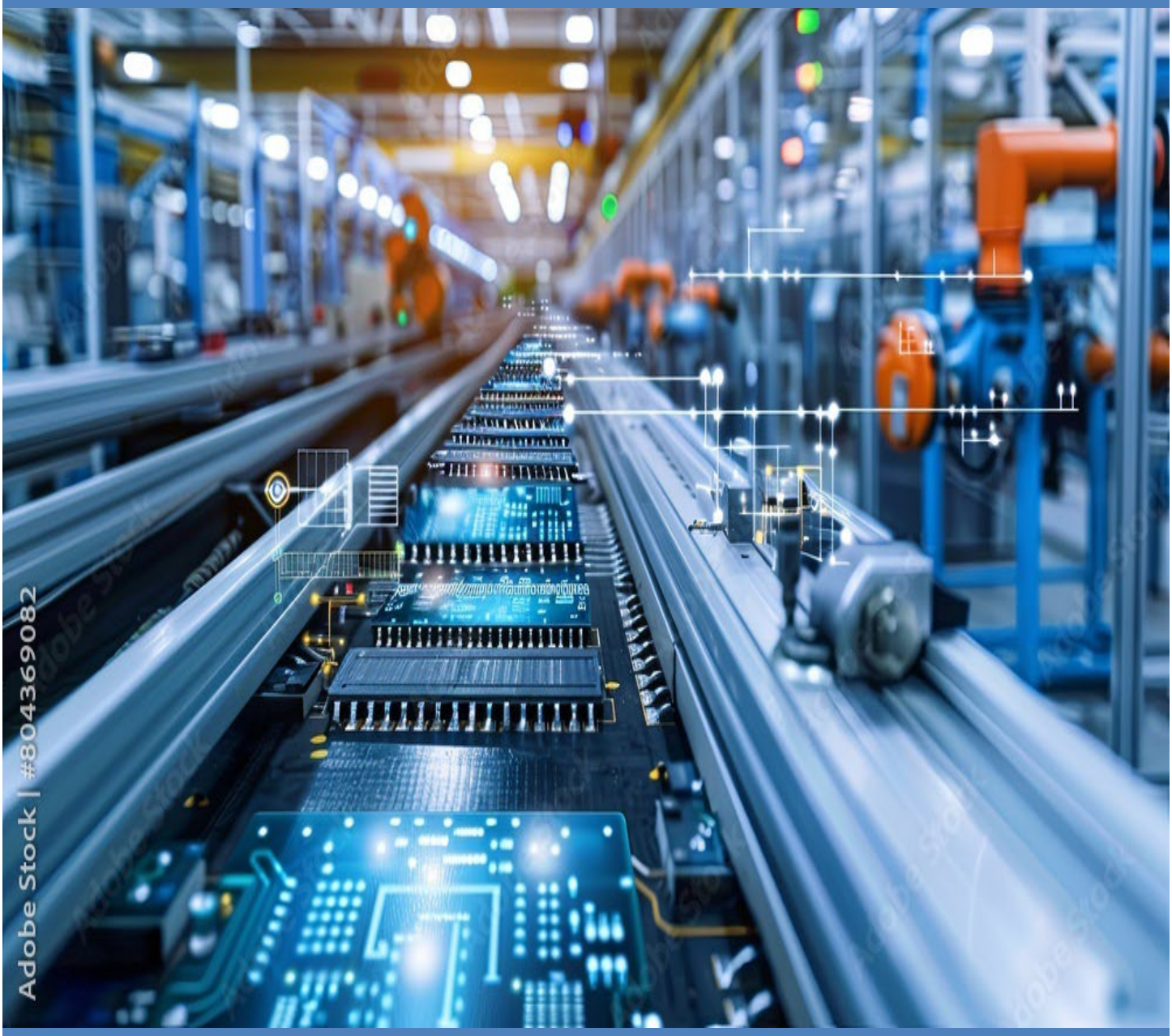
WORKFORCE READINESS LEVEL (WRL) DESKBOOK (V1.01)



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Introduction

The Need for Workforce Readiness Levels

Manufacturers in the United States in nearly every sector and region find it difficult to fill openings for skilled technical workers, especially middle-skilled workers such as engineering technicians. For emerging technologies, such as those that are key to Department of Defense's (DoD) modernization priorities (Office of the Under Secretary of Defense for Research and Engineering, n.d.), this shortage will be more acute and will lead to production and deployment delays due to unfilled critical worker positions and/or excessive labor costs unless active steps are taken to address it. The DoD has invested substantial funds in technology development as a means to continue to dominate future battlespace and it is critical that it can advance these technologies from concept toward full scaled production. To succeed, a capable technical workforce – from scientists to engineers to technicians – is required.

However, for over half of employees, it can take up to three years to upskill into their roles, particularly with the changing nature of work and jobs (Jones et al., 2020). While early efforts in developing technology are led by highly skilled, specialized workers, typically holding doctorate degrees, large scale manufacturing requires a much larger workforce of technicians - not creators. Leveraging highly skilled specialized creators as manufacturing technicians is, ultimately, a costly and unsustainable solution. Traditionally, the focus on building the technician workforce comes later in the technology development lifecycle, such that workforce availability typically lags technology readiness. As a result, manufacturers may overspend in hiring overskilled workers, or may face delays in hiring a sufficient number of qualified technicians as the workforce development processes are created (Moore et al., 2024).

To avoid inevitable delays and/or excessive labor costs, steps to build this workforce need to begin earlier in the technology development process with an eye on vectoring technology deployment with a capable technical workforce, so these activities are synchronized. To make this possible, the Conducere - MIT Collaboratory (CMC) has developed a workforce development overlay that maps workforce development onto the widely recognized and used Technical Readiness Levels (TRL) and Manufacturing Readiness Levels (MRL) frameworks herein referred to as Workforce Readiness Levels (WRL). Building on this overlay, the CMC has also mapped critical workforce developmental activities onto the Workforce Readiness Levels.

In addition to creating a novel Workforce Readiness Level (WRL) overlay and mapping critical workforce developmental activities onto the TRL and MRL frameworks, the CMC developed a Workforce Assessment: a generalizable process by which novel and adapted technician work roles can be identified for

emerging technologies. As part of assessment, we provide a process by which to identify key tasks, skills, and competencies essential for success in these roles, including a process by which to determine what is required at entry for success and what can be trained on the job.

This Deskbook lays out these activities and a path toward intentional and proactive workforce development. Using this Deskbook should accelerate workforce development efforts by identifying the available and actionable information and progressive workforce development actions needed at each TRL or MRL stage to ensure workforce development proceeds in coordination with technology development. In other words, the WRL and associated assessment will accelerate the development of technician workforces such that training will be ready and available when production needs to scale. While the MRL model currently includes workforce development in the Personnel Thread specific to the production environment, a standard process for determining new skill sets, worker roles, and training requirements for the future manufacturing workforce of an emerging technology has not been developed.

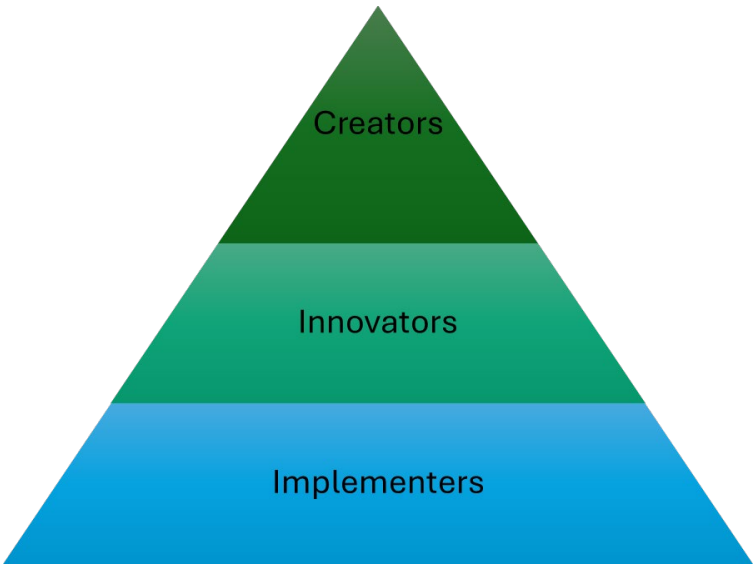
The Evolving Nature of the Workforce

As a specific technology (and its associated manufacturing ecosystem) matures, the roles required to create the technology evolve. One way to break down these roles is into three categories: Creators – the scientists and engineers pushing the technology boundaries (typically doctorate and masters level education). Creators are often researchers and scientists, and frequently work out of academic institutions. Creators can also be conceptual engineers. An emerging technology necessarily is initially driven by the creator workforce.

Next, innovators take the emerging technology into its next phase of development. Innovators are the designers and (industrial) engineers that make a new creation commercially viable (masters and bachelors); they translate the creator-driven concepts into commercially viable technology products. Innovators often work in start-ups, or in small teams connected to academic research laboratories or occasionally larger-scale manufacturing firms.

Finally, implementers are the technicians responsible for manufacturing, producing, installing, and maintaining the product or system. Typically, these technicians may have Technical 1 and 2-year certificates or degrees with specialized training provided on the job specific to the equipment they most frequently work with. Figure 1, below, depicts these three different levels.

Figure 01. Workforce Levels



Kenneth Gray and Edwin Herr in their book “Other Ways to Win”, observed a “Critical Workforce Ratio,” driven by education levels, that has been consistent within manufacturing since the 1950s. Typically, fewer graduate degree workers are required than bachelor’s degree workers, and fewer bachelors degree workers are required than 2-year degree or less workers to manufacture technology. Of course, depending on the technology that is being manufactured, the skills and type of worker needed may differ (c.f., Combemale, Whitefoot, Ales, and Fuchs, 2021). Regardless of the exact breakdown in proportions, the “implementer” workforce has by far the largest staffing requirements within the manufacturing workforce.

As a technology is developed to production, the most critical role to staff and understand will be high these volume roles that will require a more substantial workforce, a more standardized set of skills, and likely do not require a particular higher level degree. This Deskbook therefore focuses primarily on preparing for the “implementer” workforce, the technicians and technologists, because it represents the largest group within the technical workforce. Focusing on these middle skilled technician roles allows for more rapid scaling, as it will impact the largest number of hires in the manufacturing process, as well as provide the deepest insight as to broad based training and skills that will be required for effective at-scale manufacturing of the novel technology. As noted previously, the CMC is therefore focused on understanding workforce preparation for *middle skilled technician roles.*

Unfortunately, the U.S. education system for implementers is not as effective, specific to advanced technologies, as it is for creators and innovators (Arthur-Mesah, 2020; Grover & Miller, 2019). This creates a major problem for DoD’s modernization efforts. With today’s advanced technologies, a basic high school

diploma no longer provides the knowledge and skills needed for implementers. Instead, technical training (e.g., associate's degree, certificates, or equivalent) in advanced technologies is needed to augment high school education. The CMC's intent in offering the processes provided in this Deskbook is to enable more structured and rigorous development of needed training to prepare this critical workforce.

Note that while this Deskbook has been prepared to address workforce preparation for the implementor workforce, the processes outlined here may also be helpful in workforce preparation for other job roles that will be needed when an emerging technology reaches higher MRL and TRL levels. For creator, innovator, and other roles that require higher-level degrees, the process may include reviews of PhD programs, curriculum vitae/resumes, and so on.

Purpose and Organization of this Document

This document describes how WRLs can be used as a critical part of the strategic development of manufacturing processes for emerging technology. WRLs are designed to align with TRLs and MRLs, and conducting Workforce Readiness Assessments will enable organizations to intentionally prepare their manufacturing workforce. Our Deskbook is offered as a companion to the MRL and TRL Deskbooks to assist industry leaders in following a holistic and integrated approach to technology and workforce readiness.

We anticipate that WRL assessments will be conducted by both industry leaders as they prepare for workforce transition and expansion, and by researchers and consultants supporting the emergence of innovative and cutting-edge technologies. The outcomes of these assessments will inform not only recruiting and hiring for manufacturing organizations, but also training and development both within organizations and in community colleges and vocational schools.

This document provides any team working on a workforce planning assessment:

- A review of where workforce preparation currently exists within MRL and TRL frameworks (Section 1)
- An introduction to and description of WRLs (Section 1)
- A guide for the process for conducting assessments to prepare for the manufacturing technician workforce (Section 2)
- An outline of best practices in the workforce planning assessment (Section 3)
- Best practices in preparing the final report (Section 4)

Definitions

We use several key and technical terms throughout this document. They are defined below:

Archival Data: Archival data is pre-existing data, typically publicly available or curated from other sources. Information that is archival existed before the assessment team; it may be accessed by the team but it was not created by the team. We will discuss several forms of archival data in this Deskbook.

Competency Modeling: Competencies are groups of knowledge, skills, abilities, and other characteristics (KSAOs) essential for effective job performance and are intended to distinguish between high and low performers (Campion et al., 2011 p. 226). The process of competency modeling results in a list of competencies for particular job roles or professions that distinguishes between high and low performers for that job role.

Experts: In this document, we may refer to "experts." When we use this term, we are referring to the researchers who are specially trained in and involved in the leading edge development of the emerging technology product. Frequently, these individuals hold PhDs and work in academic or other research-intensive settings.

Incumbents: The word "incumbents" refers to individuals currently working in the focal position, for example, manufacturing technicians. Incumbents provide critical information about their roles and responsibilities, which is essential for developing accurate job descriptions and specifications (Brannick, Levine, & Morgeson, 2007).

Interviews or Focus Groups: The process of gathering information relevant to a particular job role leverages multiple forms of information gathering. One form is the interview (one subject) or focus group (multiple subjects). Interviews and focus groups should be semi-structured and employ predominantly open-ended (narrative) questions.

Job Analysis: Job analysis is a systematic process of understanding the nature of a job by breaking it down into smaller units. The process results in one or more written products aimed at describing what is done in the job or what capabilities are needed to perform the job effectively. This information typically includes responsibilities, tasks, skills, competencies, education, experiences, work conditions, and more. Job analysis is used to: a) develop job role descriptions, b) create lists of critical tasks and skills for job success, and c) understand what is required at entry to be successful in the job. The output of a job analysis can drive recruiting, hiring, and training. (Morgeson, Brannick, & Levine, 2019, p. 9).

Traditionally, job analysis is conducted on existing jobs, making it a well-established process that provides clarity on job requirements and the qualifications needed for success. However, for emerging technologies, the traditional job analysis process must be adapted to learn about jobs that do not yet exist. This adaptation is necessary to accurately capture the evolving nature of these roles.

Jobs, Functions, and Competencies (JFC): Refers to the cluster of job roles and associated tasks, skills (collectively, functions), and competencies needed to be successful in those job roles. Understanding manufacturing technician JFC is a primary output of a MWP process.

LightCast**:** Lightcast functions as a labor market analytics firm, actively aggregating millions of job postings and career profiles daily to provide nearly real-time insights into the labor market. Their extensive database exceeds 1 billion entries, comprising job postings, career profiles, and data from diverse sources. Using Lightcast, the team should develop queries that cross-reference technician positions manufacturing parallel products and contributing (PC) technologies, revealing commonalities in skills across these roles.

Needed at Entry: The term “needed at entry” refers to the essential skills and competencies that employees must possess from the start of their job to ensure immediate and effective performance. These foundational skills are crucial and cannot be delayed until after hiring. Competencies such as the ability to access and utilize information effectively are critical from day one and are cultivated through formal education and early learning experiences (OECD, 2013; Baumert et al., 2009). This distinction between entry-level and trainable skills is vital for workforce planning, especially in fields like emerging technologies (Morgeson, Brannick, & Levine, 2019).

O*NET: O*NET is a large, publicly available database that provides curated results of job analysis as performed on a variety of different jobs across occupations. Developed by the U.S. Department of Labor that provides detailed descriptions of various occupations. The data it provides are organized hierarchically, building from very specific tasks up to competencies. It organizes data into six domains, including Worker Characteristics and Occupation Requirements, offering insights into the skills, abilities, and knowledge needed for different jobs (Lewis & Rivkin, 1999). O*NET's tools, such as the Interest Profiler and Work Importance Locator, help individuals match their interests and skills to potential careers (National Center for O*NET Development, 2021). Regularly updated, O*NET remains a vital resource for job seekers, workforce development professionals, and researchers (Peterson et al., 1999; Mumford, Peterson, & Childs, 1999).

Organizational Leadership: In this document, we may refer to “organizational leadership” or in short form, “leadership.” When we use this term, we are referring to the top leaders within organizations, or leaders of functions, including roles such as Chief Executive Officer (CEO), Chief Operating Officer (COO), or Chief Administrative Officer (CAO).

PC Technologies: Emerging technologies are rarely created entirely independently of other existing technologies. Generally, emerging technologies reflect evolutions of or unique applications of existing technologies. Additionally, new technologies are often composed of existing technologies. We refer to the technologies that the novel technology is derived from as “parallel products,” and the technologies that inform the development of the novel technology as “contributing technologies.” Together, these technologies are called parallel products and contributing (PC) technologies and understanding them is a key part of preparing for the manufacturing workforce.

Semi-Structured: Semi-structured interviews and focus groups draw from a core set of key questions with possible follow-up questions. While there is a core set of questions to draw from, semi-structured interviews often follow slightly different tracks depending on the subject(s) in the interview/focus group and their experiences. There is some level of standardization across interviews/focus groups, but also a level of emergence and differentiation in response to the different information that emerges with each subject.

Site Observations: During a site observation, one or more members of the assessment team would visit the workplace or work site at which the emerging technology was being developed. Site observations involve visually observing people creating the technology as well as asking questions of those people to better understand their work conditions, what they are doing, and why. This method is used in the field of Industrial and Organizational (I/O) Psychology to help understand workplace dynamics, employee behaviors, and organizational culture, which are crucial for improving work environments and productivity (Koskela, 2000).The goal is to collect accurate and reliable data to understand the situation better, including its environmental, social, and timing aspects (Becker & Geer, 1957; Yin, 2017).

Subject Matter Experts: Subject matter experts (SMEs) are people who are able to provide insight to the assessment process. Collectively, experts, leadership, supervisors, and incumbents represent the primary groups of SMEs likely to be accessed during this process. Other SMEs may include operations, Human Resources (HR), and other administrative professionals.

Supervisors: When we refer to “supervisors” we are referring to line-level leaders of the individuals who are directly creating the emerging technology, for example, the direct supervisors of manufacturing technicians. They ensure that the team's tasks are done efficiently and meet the company's standards and goals. Supervisors act as the bridge between the workforce and higher management by implementing instructions from upper management and sharing feedback from the team.

Surveys: Finally, the assessment team may use surveys to gain a better understanding of JFC, including what is critical and what is needed at entry. A survey is a method for

gathering information from or about individuals to describe, compare, or explain their knowledge, attitudes, and behavior (Fink, 2003). Often, surveys employ typically close-ended questions (multiple choice, Likert scale, etc.), although they may also use open-ended short response or narrative questions. Surveys are typically distributed online or on paper, although they may at times be used during the interview/focus group process.

Section 1: Workforce Development Readiness Levels

Introduction

Next, we summarize the Technology Readiness Levels (TRLs) and Manufacturing Readiness Levels (MRLs) frameworks and discuss critical gaps in workforce development activities at the different development stages. While the TRL and MRL levels have gained considerable currency across many domains, it is appropriate here to remind readers of some basic principles of these measures that are not generally brought up when these metrics are used to discuss a stage of technological development or manufacturing capabilities.

This review identifies the threads and sub-threads that are relevant to workforce development for both frameworks. The goal of this effort is to inform opportunities for a standard, repeatable process that can be applied to various technologies and identifies progressive workforce development actions possible at each TRL or MRL stage to ensure that workforce development proceeds in coordination with technology development, such that training is ready and available when production needs to scale. By identifying opportunities to introduce new workforce activities or activities earlier in the frameworks, a standard process for determining new skill sets, worker roles, and training requirements can be developed alongside the technology and help guide critical development decisions.

Technology Readiness Levels

Technology readiness levels (TRLs) are an outgrowth of NASA's program development processes – specifically, the development of program confidence that components and systems that relied on advanced technologies were "flight ready" (Héder, 2017; Sadin, Povinelli, & Rosen, R., 1989). NASA's managers devised these readiness levels as a way to develop and communicate a shared understanding of the maturity of a technology within their organization, and NASA's success with these kinds of developments led observers to recommend that other institutions confronting similar challenges should adopt similar methods (Olechowski, Eppinger, Jogelkar, & Tomaschek, 2020). In particular, a July 1999 U. S. Government Accountability Office (GAO) Best Practices report to a subcommittee of the Senate Armed Services Committee included the following recommendation:

> *GAO recommends that the Secretary of Defense adopt a disciplined and knowledge-based approach of assessing technology maturity, such as TRLs, DOD-wide, and establish the point at which a match is achieved between key technologies and weapon system requirements as the proper point for committing to the development and production of a weapon system. GAO also*

recommends that the Secretary (1) require that technologies needed to meet a weapon's requirements reach a high readiness level (analogous to TRL 7) before making that commitment, (2) extract lessons from successful technology inclusion cases for application to future technology inclusion efforts, and (3) empower program managers to refuse to accept key technologies with low levels of maturity by making decisions on individual programs that reinforce a best practice approach to technology maturation and inclusion.

These recommendations were, in fact, adopted, with a now quite extensive set of processes and procedures centered upon the development and application of TRLs within the DoD advanced technology development processes.

Technology readiness levels (the predecessor to the related manufacturing readiness levels, MRLs) are themselves the product of a technology readiness assessment, which is described in the GAO's Technology Readiness Assessment Guide (U. S. Government Accountability Office, 2020) as:

… a systematic, evidence-based process that evaluates the maturity of technologies (hardware, software, and processes) critical to the performance of a larger system or the fulfillment of the key objectives of an acquisition program, including cost and schedule. TRAs, which evaluate the technical maturity of a technology at a specific point in time for inclusion into a larger system, do not eliminate technology risk. But when done well, they can illuminate concerns and serve as the basis for realistic discussions on how to address potential risks as programs move from the early research and technology development to system development and beyond. In addition, TRAs help legislators, government officials, and the public hold government programs accountable for achieving technology performance goals.

The basic TRL definitions are included in the table below. There are more extensive tables with greater detail, but they all reflect a common feature of the TRL/TRA process – while products and systems are clearly being devised, tested, and demonstrated, there's no real consideration of the fact that these components and systems are being manufactured or how that manufacturing is being conducted. The focus, instead, is upon the purely technical question of "does it work", rather than on the question of "how did it get here?" As a result, consideration of the workforce needed to manufacture the technology is not explicitly included in the TRL framework even though it is critical for implementation and scaling of the technology.

Table 01: TRL Framework (Office of the Executive Director for Systems Engineering and Architecture, 2023)

TRL	Description
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof-of concept
4	Component and/or breadboard validation in (a) laboratory environment
5	Component and/or breadboard validation in (a) relevant environment
6	System/subsystem model or prototype demonstration in a relevant environment
7	System prototype demonstration in an operational environment.
8	Actual system completed and qualified through test and demonstration.
9	Actual system proven through successful mission operations.

It is important to note that both the history and the GAO description highlight what drives the development of these readiness levels. They are created not as an objective measure of technological maturity or manufacturing capability, although the level measures that are generated are widely employed to suggest that sort of performance. Rather, these measures are mere milestones to mark the advance of a development program in service of the process of “acquisition” for a funding agency. In other words, TRLs and MRLs are assessed in order to be able to ensure that the process for the acquisition of a system or product has been conducted in such a fashion as to be able to offer reasonable assurance that the contract will actually be achieved by the contractor and to provide a record of that assessment so that agencies know how to assign accountability in the case of a program failure.

Thus, each of the levels that are trumpeted by a technology or critical system are the outcome of expert assessments of whether a program acquisition can be expected to succeed, and to provide guidance for “go/no-go” contract preparation by the agency.

The guides to conducting these assessments, therefore, are couched in terms that are, on the one hand, expansive to admit for the wide range of acquisitions that agencies might consider and, on the other hand, imbued with an effort to trace accountability for program decisions that are made along the development process. A consequence of

this duality, widely commented upon in the academic literature, is that much of the language and framings of TRLs and MRLs (and their associated assessment programs, TRAs and MRAs) appear very specific ("our program has achieved TRL 6") while, at the same time, retaining a kind of ambiguity of meaning.

For example, the short form description of what TRL 6 means is "Representative model or prototype system, which is well beyond that of TRL 5, is tested in its relevant environment. This represents a major step up in a technology's demonstrated readiness. Examples include "testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment." On its face, this description seems to indicate that the system is well on its way to a successful deployment. But note, for example, that all this description actually states is that the technology has been "tested" – nothing about the test outcome.

While that kind of ambiguity may not be desirable in many contexts, it's a necessary component of the kind of program development that these assessments are aimed to evaluate. In fact, the TRA/MRA process is specifically structured to resolve these ambiguities within the context appropriate to the acquisition program that motivates the entire exercise. Each program is different, and its development will necessarily proceed according to its specific needs and technical and/or manufacturing developments needed to bring it to fruition.

As such, the TRLs and MRLs alone are insufficient to try to characterize the ways in which workforce capabilities enter into the levels. Rather, our evaluation requires a consideration of the assessment schemes that have been developed to assign these readiness levels, as well as attempting to identify where considerations of these factors MIGHT be incorporated.

NASA's 2016 study of TRAs highlights the importance of this orientation, as well as the fact that the conducting of a TRA is still more art than science (NASA Technology Readiness Assessment Study Team, 2016):

> *The team found that most applications and utilizations of TRL and TRA are appropriate and provide value. However, TRL and TRA results are occasionally used inappropriately. Examples of this include: utilization of TRL alone without association with other parameters (e.g., Advancement Degree of Difficulty (AD2)); self-assessments and liberal interpretations of definitions;...*
>
> *…Ultimately, while execution of TRAs is adequate and even exemplary in cases, it was concluded that TRA results may not always accurately portray technology*

maturity, and that validated accuracy and agreement of the results are not generally high. There are many potential causes of this, but the most common the team found was over-optimistic assessments, where the constituent technology maturities are estimated to be a high-level of maturity more than it actually is. Additionally, the team found that TRAs are frequently self-assessments performed by the respective projects and are not always independently validated. The team also found that uncertainties in TRAs are not well represented in the reports nor communicated to Project Managers.

In other words, while TRLs are the product of TRAs, it's the way in which the TRA is conducted and managed that determines the features that are actually reviewed and considered that will make the difference between a successful and unsuccessful evaluation. Hence, the focus upon how the TRA is conducted, and what components might be considered is needed in order to establish the extent to which workforce enters into consideration in the process.

The word "workforce" formally appears twice in the GAO TRA Handbook (U. S. Government Accountability Office, 2020):

- in the definition of "critical technologies" on page 47: "According to DOD, in general, technologies may also be critical from a manufacturing process or material, measurement, or infrastructure perspective, including **whether an organization has a workforce with the necessary skills, knowledge, and experience to fulfill their mission**", and
- Unsurprisingly, in a table of MRL descriptions (p. 123): "Key performance parameters have been identified as well as any special tooling, special handling, manufacturing skill sets, and workforce requirements and availability of facilities."

There is also a more general statement in Technology Maturity Assessment Strategies (pp. 20-23) where labor is discussed as a component of the TRA that should be undertaken in advance of a Milestone B decision (essentially, the "official start of an acquisition program where major commitments of resources are made". (p.23)). Specifically, "the strategy should address the entire acquisition life-cycle and reflect the resources (labor, materials, and overhead, among others) and consider time or funding constraints for all assessments, whether required to support a decision point or simply to support the need for knowledge."

Beyond the short lists above, all considerations of labor are entirely implicit in the components of a TRA. Specifically, the TRA levels are replete with discussions of whether particular system performance levels are achieved under laboratory, prototype,

or actual operating environments. Where these systems come from is never an explicit criterion of any TRL, merely that they are made available for testing, and that they meet the testing criteria.

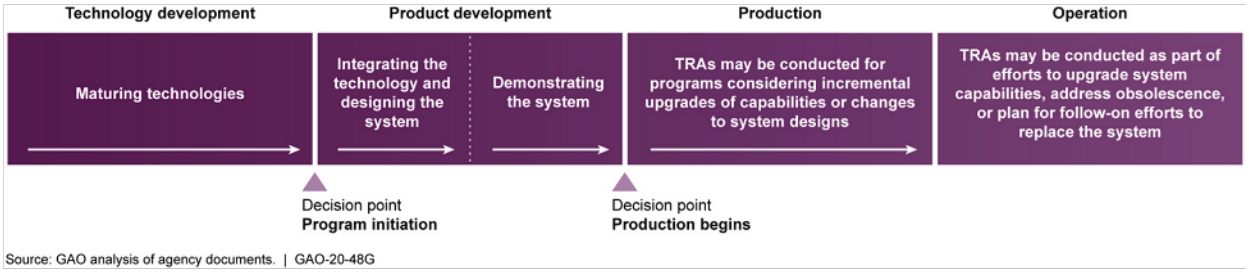
To a certain extent, this approach is unsurprising. The serious business of (defense) acquisitions depends upon an assessment that the supplier/contractor is, in fact, capable of delivering the specified product system. Thus, the TRL represents one of several certification stages that the supplier must satisfy before the contract can/should be awarded. And, thus, the level of readiness is actually far less important than the reliability of the process that was used to develop that level certification.

Inquiry into the process is specifically identified. From “Overview of the Acquisition Program Life-cycle and TRAs” (U. S. Government Accountability Office, 2020, pp. 12-13)

> *In addition to TRAs, organizations use other types of assessments to examine the technical aspects of acquisition, such as critical design reviews to ensure that a system can proceed into fabrication, demonstration, and tests and the technology can meet the performance requirements within cost and schedule. Other assessments include systems engineering reviews used to examine the integration of components into systems, test reports used to detail the outcomes of developmental tests, and manufacturing readiness assessments used to examine the maturity of the processes that will be applied to manufacture the product._ (emphasis added) Each of these reviews provides incremental knowledge during the course of a program and helps managers assess how well a project is progressing. Taken together, the different kinds of reviews and assessments develop a picture of how the project is proceeding and may highlight risk areas.*

Figure 02. Project Life Cycle (U. S. Government Accountability Office, 2020)

Figure 2: Phased Acquisition or Project Life-Cycle with Decision Points



Source: GAO analysis of agency documents. | GAO-20-48G

The above figure (U. S. Government Accountability Office, 2020, p.14) shows that there are plenty of circumstances with a program development where serious crosstalk into workforce topics are clearly relevant, but are left implicit in the guidance. We can see reference to considerations of manufacturability, like:

> *Ideally, product development begins with the transition of mature technologies into the project or system and ends when the product design is complete and developmental testing has shown that the various components can work together as an integrated whole and can be manufactured and sustained within established cost, schedule, and quality goals. (U. S. Government Accountability Office, 2020, pp. 15-16)*

Demonstrating that kind of capability suggests the existence of a workforce that can conduct that kind of manufacturing, but there is no explicit call-out that workforce is a specific criterion for meeting a milestone. Rather, consideration of these types of questions are left to the assessment program managers to incorporate, as needed, into the assessment of the technology's "criticality".

Similarly, the Production phase is similarly laden with presumptions of a workforce, without any explicit call-out for consideration of workforce availability or capability.

In effect, we can see that the workforce is everywhere, but nowhere, within the TRA Guidance. Experienced program managers will know to include TRA team members who are aware of the importance of workforce, but the formal guidelines are largely mute when it comes to workforce considerations.

The deficiencies (cited above and widely in the literature) have led to the introduction of other assessment methods to try to fill these formal gaps in program assessment. Pre-eminent among these when it comes to workforce is the Manufacturing Readiness Level and its associated Manufacturing Readiness Assessments.

Manufacturing Readiness Level (MRL)

MRL is a framework followed by the DoD to guide whether a technology is ready to move from development to production. MRL is guided by the Manufacturing Readiness Assessment (MRA) which is a process that helps the DoD to understand the level of manufacturing risk for producing a technology. The MRL stages are summarized in the table below.

Table 02: MRL Framework (Office of the Secretary of Defense Manufacturing Technology Program, 2022)

MRL	Description
1	Basic manufacturing implications identified
2	Manufacturing concepts identified
3	Manufacturing proof of concept developed
4	Capability to produce the technology prototype in a laboratory environment
5	Capability to produce prototype components in a production relevant environment
6	Capability to produce a prototype system or subsystem in a production relevant environment
7	Capability to produce systems, subsystems, or components in a production-representative environment
8	Pilot line capability demonstrated; ready to begin low rate initial production
9	Low rate initial production demonstrated; capability in place to begin full rate production
10	Full rate production demonstrated and lean production practices in-place

As technologies progress through the MRL stages, the workforce responsible for designing, developing, and producing the systems and components need to acquire new skills and knowledge. To address this need, there is an MRL thread G, Manufacturing Workforce Engineering & Production, that identifies workforce development as a part of the process for identifying risk. While much of the MRA guide focuses on assessing the readiness of a technology for production or a manufacturing process, there are guiding questions that consider the workforce at each stage. However, the assessment of the workforce using the MRA will vary depending on the organization or agency implementing the MRA.

In Chapter 4 of the MRL Deskbook (Office of the Secretary of Defense Manufacturing Technology Program, 2022), the process for conducting MRL assessments is explained. In Section 4.3, the phase “Determine Assessment Taxonomy and Schedule” involves identifying what will be assessed, where the assessments will take place, and who will lead the assessment. Questions are included to guide which elements should be assessed for informing the level of technical and manufacturing risk. These questions include the following:

· **Materials:** Does the item include materials that have not been demonstrated in similar products or manufacturing processes?

· **Cost:** Is this item a driver that significantly affects lifecycle cost (development, unit, or operations and support costs)? Is the technology or product new with high cost uncertainty?

· **Design:** Is the item design novel, or does it contain nonstandard dimensions or tolerances or arrangements?

· **Manufacturing Process:** Will the item require the use of manufacturing technology, processes, inspection, or capabilities that are unproven in the current environment?

· **Quality:** Does the item present historical or anticipated yield or quality issues?

· **Schedule:** Does this item present lead time issues, or does it significantly affect schedule?

· **Facilities:** Does this item require a new manufacturing facility or scale-up of existing facilities (*i.e.*, new capability or capacity)?

· **Supply Chain Management:** Does the item present anticipated or historical sub-tier supplier problems (*e.g.*, cost, quality, delivery)?

· **Industrial Base:** Does the item's industrial base footprint include critical shortfalls, or is this a critical item manufactured by a sole or foreign source?

The guidebook suggests that if the answer to any of these questions is "yes", it should be included in the MRL risk assessment. While assessment of workforce capabilities may be implicit in the manufacturing process and supply chain management question, adding a question that explicitly addresses the manufacturing and supply chain workforce could help reduce potential risks of the delay from the onset. An example question to address this risk factor is the following:

- **Workforce:** Are there currently workers with the knowledge, skills, and attributes needed to manufacture the technology or product? Is there capacity to rapidly train a workforce to be prepared?

In Section 4.4, "Form and Orient Assessment Team," the guidebook recommends selecting team members to be a part of the MRL assessment process that have the

knowledge in areas such as manufacturing engineering, industrial base, quality, supply chain, design, systems engineering, and production. It is recommended that sub-teams can focus on components, subsystems, or technologies. At this stage of the process, the guidebook could recommend identifying a team or sub-team member that has expertise in workforce planning, organizational development, industrial-organizational (I/O) psychology, organizational behavior etc. early on to ensure that the existing workforce and skills needed are properly evaluated for potential manufacturing risks.

The next step of this process includes orienting the contractors that are being assessed (Section 4.5). As a part of this orientation, a discussion of workforce development should be raised with the contractors to mitigate risks of delay. For on-site assessments, the MRA details examples of evidence that should be included such as process maps, capability data, yield data, etc. In addition to these data and analyses, an organizational chart or table of key job titles, the quantity of personnel needed, and the likely skills needed could also be added to the evidence to demonstrate the readiness of the existing workforce for this process.

In Section 4.6, the contractors are requested to perform a self-assessment of their manufacturing readiness. They include the following questions to guide a discussion with the assessment lead:

> • What is the current MRL for each of the key technologies or products being developed and each key manufacturing process being used?
>
> • If currently funded activities continue as planned, what MRL will be achieved for each key technology, product, or process by the end of this acquisition phase or program? What activities and schedules are required to achieve this MRL?
>
> • In the case of an advanced technology demonstration, what MRL would be sufficient for the responsible organization to commit to in a product baseline design?

As a part of these discussions, workforce development activities may be implied as a part of the “activities and schedules” required to achieve the specific MRL. To ensure that workforce is explicitly discussed, a question or example could be included such as the following:

- If currently funded activities continue as planned, what MRL will be achieved for each key technology, product, or process by the end of this acquisition phase or program? What activities **(e.g., testing, workforce readiness level, etc.)** and schedules are required to achieve this MRL?

For on-site visits, Section 4.7 includes a suggested agenda. As a part of this agenda, it is suggested that there are shop-floor visits to key areas. Although these visits do not specifically state what should be discussed in each key area, the assessment lead could ensure that these visits include discussions with the personnel in each key area to understand what, if any, worker and skill gaps are currently present for the process. Examples include the following:

- **Direct modes of collection:** With successful employees, learn: a) what does your day look like? What do you need to do daily? What are some of the unique or unusual parts of your job? b) How do you work with others, if at all? c) what do you do now that you had to learn to do once here? d) How did you learn it?
- **With supervisors:** a) what do you praise excellent employees for? What is your best employee particularly good at? b) what do you find yourself having to correct or give critical feedback on?
- **Indirect modes of collection:** a) assess consistency in time to production; b) assess time at each stage and consistency; c) assess errors at each stage; d) quality control analysis at the end – is there consistency in quality? Are certain parts more likely to have errors than others?; e) assess turnover in manufacturing staff (high turnover implies something may not be aligned in expectations and skills)

The next step of the MRA process is Section 4.8, Conducting the MRL Assessment. The self-assessment questions for the workforce-related questions, Thread G, are summarized in the table below.

Table 03: MRA Questions for Thread G

MRL Level	MRA Questionnaire for Thread G
1	Have workforce skill sets to support emerging trends in manufacturing and technology been surveyed?
2	Have workforce skill sets to support emerging trends in manufacturing and technology been evaluated?
3	Have workforce skill set requirements for system concepts been identified?
3	Have workforce skill set capability gaps been identified?
4	Have workforce skill set and production workforce requirements (technical and operational) for the preferred materiel solution been identified?
4	Have workforce skill set and production workforce requirements (technical and operational) for the preferred materiel solution been considered in the AoA?

MRL Level	MRA Questionnaire for Thread G
4	Have workforce training and development requirements to close skill set gaps been defined?
4	Has the availability of the workforce for TMRR Phase been determined?
5	Have the required skill sets to meet prototype and production been identified?
5	Are plans to meet prototype and production workforce requirements developed?
5	Have requirements for special skills certification and training (i.e., included in workforce plans) been established?
6	Are the required manufacturing workforce skills available for the production-relevant environment?
6	Have the number of workers and skill sets for pilot line and production been identified?
6	Have the initial plans to achieve the pilot line and production requirements been developed?
7	Have the manufacturing workforce resources required for pilot line (i.e., number of personnel and skill sets) been identified?
7	Have the plans to achieve the manufacturing workforce resources required for pilot line been developed?
7	Have the plans to achieve the manufacturing workforce resources for LRIP requirements been updated?
7	Has the pilot line workforce been trained in the production-representative environment?
8	Have the manufacturing workforce resources required to achieve LRIP requirements (i.e., number of personnel and skill sets) been identified?
8	Have the plans to achieve the manufacturing workforce resources required to achieve LRIP requirements been developed?
8	Have production personnel been trained on the pilot line where possible?
8	Based on pilot line results, have the plans to achieve the manufacturing workforce resources required for FRP requirements been initiated?
9	Have all workforce requirements for LRIP been met?
9	Have the plans to achieve the manufacturing workforce resources required for rate production (FRP) requirements been implemented?
10	Have all workforce requirements for FRP been met?
10	In spite of any workforce attrition, are required production workforce skill sets being maintained?

To support a user in answering the self-assessment questions, a standard process for evaluating the workforce status at each MRL with clear metrics and tools could reduce

misunderstanding or confusion. Additionally, it may be possible to move some self-assessment questions and steps to an earlier MRL to help ensure that the workforce is being developed as early as possible. One key gap in these questions is the lack of assessment of the availability of outside training for positions at all levels. As a part of the process, vocational schools, community colleges, colleges, and universities can be consulted to help develop training to address any critical gaps. This should be assessed as early as possible since it can take time to update curricula. Direct integration of the AoA, LRIP, and FRP requirements into the MRA framework and assessment tool would also help reduce risk. Finally, it is recommended that risk mitigation strategies are developed at this stage. Examples of strategies specifically related to workforce development and training should be communicated to the team to help in developing a plan of action.

In Section 4.8.2, it is suggested that objective documentation is included to support the assessment results in “key areas” with examples such as plans, yield data, reports, briefings, etc. Examples of objective documentation that could be included to support the workforce assessment include documentation of differences between a novel technology and existing technologies; job role documentation, such as lists of work tasks, needed skills, and competencies; validation documentation of which skills and competencies are needed at entry and which can be trained; skills gap analyses of the existing workforce; and labor market analyses related to required certifications, education, or known training, among others.

Finally, Chapter 5 of the MRL Deskbook focuses on Manufacturing Maturation Plans and Risk Management. After the MRA, one of the resulting products is the Manufacturing Maturation Plan (MMP) for any area where MRL is not at its target level. The best practices for developing MMPs is included in Section 5.3. Under “manage manufacturing risk”, workforce development could be mentioned to ensure that workforce is recognized as part of the “basic fabric of managing the program/project.”

While existing MRL/MRA documentation requires an assessment of the skills, availability, and number of personnel needed to support the manufacturing effort, there is not a standard, detailed process that can be applied across emerging technologies that identifies workforce needs and content development needs with sufficient lead-time to ensure a workforce is ready when production scales. There are also numerous places in the existing documentation that could integrate workforce activities explicitly to support scaling of new technologies. A process that creates a skilled and adaptable workforce is needed to help mitigate risks associated with manufacturing technology transitions to reduce delays and costs overruns.

Workforce Readiness Level Overlay

The TRL and MRL track progress in the development of emerging and novel technology from the early stages of technology development through full scale manufacturing and maturity. Each of these frameworks progresses across one dimension describing the development of the technology, or manufacturing, respectively. Specifically, TRL progresses from the identification of basic principles of a technology (1) to proving the new system/technology through mission operations (9). Similarly, MRL progresses from identifying basic manufacturing implications to full rate manufacturing following lean production principles (10). These two readiness levels implicitly progress in tandem. As the technology develops, manufacturing and scaling the manufacturing of the technology is possible.

Related workforces must exist and be fostered for technology and manufacturing to develop. While the workforce for creating and manufacturing technology is not explicitly referenced in these frameworks, its necessity is implicit and understated. That is, some workers need to develop novel technology. Eventually, other workers manufacture it. While the MRL Deskbook mentions workforce related activities, as of yet, there is no WRL Overlay to provide additional insight into how the workforce evolves as technology and manufacturing evolve. The CMC presents the below WRL typology, which describes how workforce roles evolve alongside technology and manufacturing. The WRL Overlay is anchored in the language of the creator, innovator, and implementer workforces, with additional description to characterize the nuances in role requirements from stage to stage. This overlay is developed leveraging the three key workforces of creator, innovator, and implementer, to indicate at each stage of development which workforce is dominant in creating the technology. Note that the WRL overlay focuses on the dominant workforce at each level; that is, the workforce responsible for the bulk of the work directly producing or creating the novel technology. However, we recognize that there may - and often, will - be a need for the other workforce categories at each level. For example, lab technicians will be needed to support the process in WRL 3 even though the bulk of the work may be done by creators experimenting. Conversely, creators, innovators, and operational workforces will continue to exist even at WRL when the bulk of the work producing the novel technology will be done by implementers.

Table 04: TRL/MRL/WRL Overlay

Stage	TRL	MRL	WRL
1	Basic principles observed and reported	Basic manufacturing implications identified	Initial creator workforce
2	Technology concept and/or application formulated	Manufacturing concepts identified	Specialized creator workforce

Stage	TRL	MRL	WRL
3	Analytical and experimental critical function and/or characteristic proof-of concept	Manufacturing proof of concept developed	Applied creator workforce
4	Component and/or breadboard validation in laboratory environment	Capability to produce the technology prototype in a laboratory environment	Transition creator/innovator workforce
5	Component and/or breadboard validation in relevant environment	Capability to produce prototype components in a production relevant environment	Generalist innovator workforce
6	System/subsystem model or prototype demonstration in a relevant environment	Capability to produce a prototype system or subsystem in a production relevant environment	Specialist innovator workforce
7	System prototype demonstration in an operational environment.	Capability to produce systems, subsystems, or components in a production-representative environment	Transition innovator/implementer workforce
8	Actual system completed and qualified through test and demonstration.	Pilot line capability demonstrated; ready to begin low rate initial production	Initial implementer workforce
9	Actual system proven through successful mission operations.	Low rate initial production demonstrated; capability in place to begin full rate production	Scaled implementer workforce
10		Full rate production demonstrated and lean production practices in-place	Mature implementer workforce

Workforce Readiness Level Definitions

WRL 1: Initial creator workforce

The initial workforce for an emerging technology is the creator workforce. The early workforce is typically characterized by dispersed, highly educated and specialized researchers, largely working in independent laboratories or research institutions. These (typically PhD level) researchers are often working out of universities and other academic spaces, although some may work in funded private research laboratories. The early work undertaken by this workforce is the creation and initial realization of the novel idea. The initial creator workforce is likely to work more *independently* than *interdependently*, although there may be times at which creators at different institutions do work interdependently to develop a novel technology. At this stage, early research into the manufacturing workforce would come in the form of understanding the characteristics of the novel technology as well as fields from which the novel technology would be derived.

WRL 2: Specialized creator workforce

The specialized creator workforce emerges as technology advances, and initial manufacturing concepts are identified. This workforce is again characterized by highly educated (PhD) specialists who work predominantly out of research institutions and academic spaces. The work of the specialized creator workforce is to realize the technological concept in full, in the laboratory environment. This workforce will be slightly more saturated than the initial creator workforce, which is likely to be sparser. Researchers may devote their own teams, trained within their specialty, to realizing the ideas they have generated for the emerging technology. More creators are required at this stage relative to WRL 1, however, the workforce is still developing. Work remains more independent than interdependent. At this stage, research into the manufacturing workforce would focus predominantly on parallel products and contributing technologies and their manufacturing needs, as well as on the equipment or tools most likely to be needed to manufacture the technology at scale.

WRL 3: Applied creator workforce

The applied creator workforce realizes the critical function of the emerging technology by developing a characteristic proof of concept. This advanced part of the creation of a novel technology is conducted by teams of researchers led by at least one specialist (PhD). Again, this workforce is likely to work out of research institutions and academic spaces, although the proof of concept for novel technology may be developed in think tanks and other privately held research

institutions. This workforce will again be marginally larger than the specialist creator workforce, although teamwork will remain predominantly within existing labs and institutions rather than across institutions. At this stage, research into the manufacturing workforce would focus on understanding any changes to the technologies used, emerging technology itself, or equipment needed between WRL-1 and WRL-3. This is the final stage of technological development that is driven predominantly by academics and pure researchers.

WRL 4: Transition creator/innovator workforce

In WRL 4, the workforce hits the first transition point. Critically, this workforce is preparing the technology to become commercially viable. Therefore, at this stage, the workforce begins to shift from predominantly creators toward innovators. Moving the technology to breadboard validation in a laboratory environment requires stronger collaboration, perhaps even across disciplines, to move toward realizing a commercially viable product. The transition workforce at WRL 4 will include PhD and Master's educated scientists who are focused on fully realizing the idea of the emerging technology in a viable way to prepare for production. This workforce may work out of specialized laboratories in academic or research institutions, may work in a research and development arm of a larger organization, or may work within a smaller start up organization. At this stage, research into the manufacturing workforce would finalize an understanding of the implications of the evolution of this technology to date on workforce needs.

WRL 5: Generalist innovator workforce

The workforce in WRL 5 is the first workforce that shifts decisively toward private sector employment, and toward the innovator workforce. The generalist innovator workforce that characterizes the initial development of the emerging technology in a production relevant environment remains highly educated, with most holding PhDs or Master's degrees. As relatively small teams intently focus on creating a commercially viable product, the workforce must learn cross-cutting skills that allows each specially trained member of the workforce to "stand in" for colleagues, even those who were trained in entirely different disciplines. This workforce works in tightly knit teams of generalists to create a viable product. Research into the manufacturing workforce at WRL 5 will focus on the shift in tasks, skills, and competencies needed to produce the product in a manufacturing environment as compared to in a laboratory environment.

WRL 6: Specialist innovator workforce

As the emerging technology continues to develop, the teams working on the technology need to scale its creation. At this stage, the organizations pushing the

development of a commercially viable product forward begin to hire additional personnel to advance the technology and increase the scale at which it can be developed. The innovators required for this stage begin to shift toward trained specialists holding Master's degrees, with roles becoming more differentiated as tasks can be more clearly assigned to individuals rather than requiring everyone in a team to be able to do others' jobs. Job roles become more distinct and begin to become more structured. Research into the manufacturing workforce at WRL 6 will focus on the shift in tasks, skills, and competencies needed for the different roles that are emerging in the creation of the technology.

WRL 7: Transition innovator/implementer workforce

In WRL 7, the workforce hits the second transition point. This workforce is preparing the technology to scale to manufacturing. Therefore, at this stage, the workforce begins to shift from innovators to including more implementors. Scaling the technology production may include the acquisition of new equipment for the workforce, the division and separation of roles, and the implementation of on-the-job training. The workforce is less focused on creating and innovating, and more focused on doing. The transition workforce at WRL 7 will include Master's and Bachelor's educated practitioners as well as some technicians who hold at most two-year Associates degrees. At this stage, research into the manufacturing workforce focuses on role differentiation and the tasks, skills, and competencies made relevant by the introduction of new equipment. Research into the manufacturing workforce at WRL 8 will focus on both role differentiation and identifying which skills and competencies are needed to be held at entry versus which can be learned on the job.

WRL 8: Initial implementer workforce

The workforce in WRL 8 is the first workforce that shifts decisively toward the implementers. The initial implementer workforce will consist of predominantly Bachelor's and Associate's educated technologists and technicians who are most likely experienced in manufacturing parallel products. This workforce will learn most of what is needed on the job on an ad hoc basis and will work in clearly differentiated roles where standardized processes are emerging. Research at WRL 8 will finalize an understanding of the JFC that are needed at entry, versus those that can be learned on the job. Additionally, research at this stage can begin to address the number of technicians who may be needed to manufacture the technology at scale.

WRL 9: Scaled implementer workforce

At WRL 9, the workforce of technicians continues to grow to meet the needs to produce the emerging technology at a larger scale. This workforce will largely consist of Associate's and other trained technicians. The workforce will be drawn both from manufacturers of parallel products as well as from some technical schools or post-secondary education institutions that provide some level of training and exposure to the emerging technology. Role differentiation and standardization will be quite advanced. On-the-job training will be more developed, formalized, and routinely implemented. Research at this stage will focus on the workforce scaling required for full rate production, recruiting and hiring practices to enable scaling, and the additional training that may be required both before and after entry to skill or reskill technicians. The results of this research should concretely inform training to be provided at post-secondary institutions.

WRL 10: Mature implementer workforce

WRL 10 represents a mature manufacturing workforce, predominantly composed of implementers. This workforce, consisting of Associate's and trained technicians, is responsible for routinely and rigorously producing the emerging technology at full scale. By this stage, education at the post-secondary level will provide relevant exposure to the emerging technology, such that the workforce can be hired directly from educational institutions as well as from manufacturers of parallel products as needed. Roles will be clearly differentiated and standardized, with rigorous, standardized on-the-job training provided. Research at this final stage will dive deeply into any adjustments or changes to the needed workforce brought on by the transition to full scale manufacturing.

Note that the numbers 1-10 used to denote each stage in the WRL reflect ordinal properties. That is, the time and effort required for the workforce for a particular technology to progress from WRL 1 to WRL 2 is not the same as the time and effort required for the workforce for a particular technology to progress from WRL 2 to WRL 3, and so on. Likewise, the time and effort required for the workforce for one technology to progress from WRL 1 to WRL 2 is not expected to be the same as the time and effort required for the workforce for another technology to progress from WRL 1 to WRL 2. Finally, the WRL for one organization or core team may vary from the WRL for another organization or team. That is, during the development of an emerging technology, some organizations may find themselves at WRL 2 whereas others may find themselves at WRL 4, depending on whether their efforts are more oriented toward developing the idea or creating a commercially viable product.

WRL Considerations

The development of the manufacturing workforce occurs alongside several key considerations. These considerations may accelerate or decelerate the progress of both technological and workforce development.

Key considerations include:

1. Cost: The cost of materials used in creating the technology may impact manufacturing and workforce progression. Specifically, high-cost materials or processes (such as those involving a number of other organizations) can make moving toward full-scale manufacturing more difficult. Typically, full scale manufacturing is more attainable as the costs of the materials and the technology come down. The innovator workforce and innovator-driven WRL stages play a large role in preparing a product that can be produced at scale with fewer cost concerns.
2. Scalability: Market need will also drive workforce and manufacturing development. Until there is a clear market for a specific technology, it will not move toward the more advanced WRL stages, where it is manufactured in high volume.
3. Supply Chain: Scaling the manufacturing of a new technology requires a robust supply chain. If the supplies needed to produce the technology at full scale do not exist, there will be delays in starting and scaling manufacturing.
4. Routinization: Full-scale manufacturing requires a standardized and routinized process. To the extent that active, high-effort human-driven composition is needed, manufacturing will be delayed or untenable. When the emerging technology can be created through faster, routine protocols, typically using machines to aid the process, full-scale manufacturing becomes attainable.
5. Vertical integration: Assembling an emerging technology typically requires drawing from and incorporating a variety of existing technologies. The manufacturing process and workforce needs will depend on the integration of parts of the process, as well as the cost and time required to obtain all needed composite technology.

Next, the CMC outlines steps that can be taken at each WRL to prepare for a full-scale implementer manufacturing workforce for an emerging technology. Following this more high-level guide to preparation for a manufacturing workforce, the CMC shares more detailed guidance on best practices in understanding the tasks, skills, and competencies needed for success in this workforce.

Section 2: Preparing for the Manufacturing Workforce

Introduction

The skills and competencies that are required to develop novel technology are fundamentally different from the skills and competencies needed to manufacture it once blueprints for the new technology are fully developed. Specifically, as noted previously, creators must be highly educated and experienced in specialized areas of study. Manufacturing technicians, however, do not need to have the same level of education to successfully produce the novel technology. This progression is evident with a thorough review of the WRL from the initial creator workforce through the mature implementor workforce. Therefore, unless manufacturing workforce needs are anticipated and identified in advance, it is likely that manufacturers will rely on over-educated, over-skilled, and more expensive workforces than necessary once the technology reaches full manufacturing readiness. Furthermore, it is likely that many more manufacturing positions must be filled than there are highly skilled workers to fill them.

Below, we present a process for preparing for the manufacturing workforce as a technology (and its workforce) is developed. This process maps onto the previously provided workforce readiness level (WRL) overlay that progresses alongside the TRL/MRL levels. The Manufacturing Workforce Preparation (MWP) process progresses along two dimensions: context and workforce development. Stages in understanding *Context* refers to activities related to understanding the workforce implications of technology and manufacturing development for a specific technology, such as understanding similar industries and critical variables that impact how a technology will be manufactured. Stages in understanding *Workforce Development* refers to activities related to understanding, hiring, and upskilling the people who will manufacture the novel technology.

In other words, MWP-Context (MWP-C) refers to understanding the technology, and MWP-Workforce Development (MWP-W) refers to understanding the workforce needed to manufacture that technology. Notably, MWP-C provides the background for MWP-W; as the context is understood, workforce development activities can begin. In a sense, then, MWP-C is the first step in MWP, and MWP-W is the second step. In Table 2, below, we provide the MWP steps next to the WRL stages.

Table 05: Manufacturing Workforce Preparation Process Overlay

Stage	WRL	MWP – Context	MWP – Workforce
1	Initial creator workforce	Key variables (materials, size, use) of novel technology identified	Research jobs, functions, competencies (JFC)
2	Specialized creator workforce	Parallel products and contributing (PC) technologies identified	Investigate JFC of PC technologies
3	Applied creator workforce	Study of the process and knowledge required to develop proof of concept	Identify the tasks, skills, and competencies that will be needed based on proof of concept
4	Transition creator/innovator workforce	Study of the process and knowledge required to produce in laboratory environment	Identify the tasks, skills and competencies that will be needed to transition from prototyping to laboratory
5	Generalist innovator workforce	Study of the process and knowledge required to produce components in production relevant environment	Identify the tasks, skills and competencies that will be needed to transition from laboratory to production
6	Specialist innovator workforce	Study of the process and knowledge required to produce prototype system in production relevant environment	Refine tasks, skills, and competencies. Identifying appropriate job roles based on tasks, skills, competencies, and JFC of the technology

Stage	WRL	MWP – Context	MWP – Workforce
7	Transition innovator/implementer workforce	Study of the process and knowledge required to produce fully in production relevant environment	Identify what tasks, skills, and competencies can be hired on and what must be trained
8	Initial implementer workforce		Develop training; Initial hiring
9	Scaled implementer workforce		Scale hiring; Training initial hires at low volume
10	Mature implementer workforce		Extend hiring, Implement widespread training

Below, we describe the activities that can occur at each MWP Process stage as part of preparation for the manufacturing technician workforce and provide key questions that will illuminate answers at that level. We will at times provide some detail and advice on how to investigate and answer these questions. More detailed best practices will be provided in Section 3.

MWP Level Descriptions

The descriptions of the MWP process follow alongside the development of both the novel technology and the manufacturing of that technology. The guidance that we provide below follows a step-by-step process that can begin at MRL-1 and TRL-1. That is, each MWP level can be conducted at the same time as its respective MRL, TRL, and WRL level.

While knowledge of the workforces required for manufacturing PC technologies can be leveraged beginning as early as MWP Level 1 to create strawman lists of JFC for manufacturing novel technology, technology and manufacturing maturation enables clarification and refinement of these initial lists. We note that in some cases,

assessments to prepare for manufacturing novel technology may not be initiated until later stages in the MRL and TRL processes. In these instances, parts of the assessment process below may not directly apply. However, the overall arc and intention of the process will continue to be relevant.

Next, we present a description of the information that can be gleaned at each MWP level. For each MWP level, we present a series of questions that address both context and workforce development as well as some high-level recommendations on how to gather information to answer those questions.

MWP Level 1: Initial Identification of the Characteristics of Novel Technology Product

As the creator workforce is in the early stages of identifying the basic principles of the novel technology, and likewise identifying the basic manufacturing principles, key variables related to the novel technology product can be identified (MWP-C Level 1). Specifically, variables that might relate to needed skills, tasks, and competencies during production should be the focus. This would include the size of the new product, potential component materials and technology, and the potential use of the product. Additionally, research can begin into potential JFC that might relate to those identified variables.

<u>MWP-Context Level 1</u>

- What materials may be needed to create this new product?
- How large may the novel product be?
- How might the product be used?
- Is there variability in materials, size, or use?
- What equipment is expected to be needed to create the product now, and at a larger scale?
- What field(s) and/or domain(s) does this product fall under or pull from (e.g., robotics, photonics, electronics, etc.)?

The workforce at WRL 1 is the initial creator workforce. Answering questions that inform the context (and therefore the workforce development exploration at MWP Level 1) will require interviewing experts and reviewing any written or pre-recorded materials on the novel technology product. Experts at this stage are predominantly academics and researchers with PhDs. They are generally expected to work in academic institutions.

The team conducting the MWP should first identify leading experts in the initial creator workforce and request interviews with these experts to learn about how they are thinking about the novel product, how it might be used, and what its properties might be. Additionally, these experts can provide insights into the anticipated PC technologies for the emerging technology product. Finally, experts can recommend readings, papers,

and other existing materials that will assist the team in learning more about the technology itself.

Where experts are beginning to build models or prototypes of the emerging product, the team may seek to conduct site observations to better understand both the thinking driving the product and some of the skills and competencies that may be required to put it together.

In addition to interviews with experts and observations of their work, the team can take steps to learn about the new product independently. Specifically, the team can conduct a literature review to identify key writings and thinking on the novel product.

The goal of an assessment at MWP-Context Level 1 is to understand the product itself as well as possible, with a particular emphasis on understanding PC technologies to guide preliminary workforce development explorations.

MWP-Workforce Level 1

- What skills, tasks, or competencies might be needed to work with the required materials? (consider: safety, skills, knowledge)
- What skills, tasks, or competencies might be needed to create a product of that size (consider: precision, physical requirements, skills)
- What skills, tasks, or competencies might be needed to work with the anticipated equipment used to create this product?
- What workforce implications might exist related to the different uses of the product? (consider: if product use will impact JFC)
- Might any variability in materials, size, or use impact the JFC for technician roles? If so, in what ways?

Based on the learnings at MWP-Context Level 1, the team should identify expected PC technologies. A more detailed explanation of how to do this is provided in Section 3. When identifying PC technologies, the team should focus initially on identifying 2-3 technologies whose manufacturing needs are likely to be most comparable to the manufacturing needs of the emerging technology. After identifying these technologies, the team should look at the JFC for technician roles driving manufacturing of the PC technologies. A review of available archival information enables the team to create an initial list of tasks, skills, and competencies that may be relevant for technicians manufacturing the novel product. This research should include a review of existing information and databases (such as O*NET and LightCast) and publicly available job postings. Additionally, the team should consult with industry groups to determine if they have any materials or insights that inform the PC technologies. Note that the initial exploration should focus on at most 2-3 technologies, as it is not likely at this stage of the MRL/TRL progress that the emerging technology product and its PC technologies are fully thought through. Additionally, the initial list of skills, tasks, and competencies

compiled at this stage will be essentially the list of skills, tasks, and competencies required by technicians manufacturing PC roles. Adaptations to these JFC to accommodate differences in manufacturing the novel product will be limited.

Interviews with experts in MWP-Context Level 1 can inform which of the existing skills, tasks, and competencies are most likely to be relevant amongst this list. Experts can provide insight into what distinguishes the new product, versus what is similar. Areas of similarity guide which JFC will carry over. Areas of difference guide which JFC might not be relevant, or which might be important to investigate and add.

MWP Level 2: Identifying Related Technologies and Workforce Needs

TRL and MRL Level 2 occur as the new product is formulated more clearly, enabling both technological and manufacturing concepts to be identified. At this stage, the study of the workforce can progress to identifying technologies related to the novel product. Specifically, it is rare that an entirely new product emerges. Instead, most novel products are innovations of, or derivations from, existing products. Additionally, most new technology products incorporate many existing technologies in their development. Research can continue into the workforce needs related to building PC technologies.

<u>MWP-Context Level 2</u>

- What technology/product is the new product most similar to? Is it derived from, or innovated from, any existing technology/product?
- What existing technologies or products are used in the assembly or development of the new product?
- What equipment is used to manufacture the PC technologies at scale?

At WRL 2, the specialized creator workforce emerges. Interviews and focus groups at this stage should refine an understanding of PC technology, and the distinctions that make the emerging technology product different from PC technology. Additionally, experts may be able to provide useful information regarding the types of equipment that might be needed to manufacture the new product at full scale. Finally, experts should be able to begin identifying challenges and barriers to full scale manufacturing.

The initial trailblazers who drive WRL 1 may provide recommendations of additional experts to speak to during MWP-Context Level 2. They may also have further insights as to PC technology. Site observations may again be useful at this level of the assessment.

The goal of an assessment at MWP-Context Level 2 is to understand the PC technologies as well as possible.

MWP-Workforce Level 2

- What JFC are required for middle-skilled technician roles to successfully manufacture the parallel products?
- What JFC are required for middle-skilled technician roles to successfully manufacture or leverage the contributing products or technologies?
- What gaps currently exist in workforce availability and training for PC technologies?

Based on the learnings at MWP-Context Level 2, the team should solidify their understanding of expected PC technologies. At this stage, the team should understand more clearly the 3-5 technologies whose manufacturing needs are likely to be most comparable to the manufacturing needs of the emerging technology product. Within each of these technologies, technician roles should be identified that are most likely to relate to the technician roles that may emerge when manufacturing the novel product. If it is not already developed, the team should develop the starting JFC list at this stage of the MWP process. As with MWP Level 1, adaptations to these JFC to accommodate differences in manufacturing the novel product will be limited.

MWP Level 3: Refining JFC Based on Proof of Concept

At the third level of TRL/MRL, the proof of concept for the product and for manufacturing the product is developed. At this stage, the initial workforce research conducted in MWP Levels 1 and 2 can be enhanced by any changes in the development of the product that emerged during proof of concept.

MWP-Context Level 3

- What changes to materials, size, and use occurred between TRL/MRL Level 1 and TRL/MRL Level 3?
- What changes in PC technologies occurred between TRL/MRL level 1 and TRL/MRL Level 3?
- What anticipated (updated) equipment is expected to be needed to create the product now, and at a larger scale?
- Where will manufacturing be done (domestic, international)?
- How will manufacturing be done (integrated, unintegrated)?

The applied creator workforce drives WRL Level 3. This workforce is focused on creating full proof of concept. The research team will continue interviews with experts, preferably identified experts leading teams that are developing specific applications of the novel technology product. The experts interviewed at this stage are again likely to work in academic spaces and research institutions. Lists of experts to contact will continue to snowball from prior stages, with experts from the assessments conducted at MWP Levels 1 and 2 providing suggestions on experts to speak to at MWP Level 3. If

the assessment is being conducted alongside the evolution of the novel product, it is also possible that the experts from MWP Levels 1 and 2 may become part of the applied creator workforce and may offer additional insights at WRL Level 3. Expert interviews at this stage can further inform the anticipated market for the novel technology, including critical challenges to scaling, cost, routinization, and size reduction, as applicable.

Interviews at this stage can reflect on the evolution of the product from idea to proof of concept. Experts from MWP Levels 1 and 2 who have become part of the applied creator workforce may offer particularly incisive ideas as they have watched the product evolve.

MWP-Workforce Level 3

- What are the JFC implications of any changes to materials, size, and use between TRL/MRL Level 1 and TRL/MRL Level 3?
- What are the JFC implications of any changes to PC technologies between TRL/MRL Level 1 and TRL/MRL Level 3?

At MWP Level 3, the assessment team should reflect on the JFC list developed based on the requirements for technician positions manufacturing PC technologies. At this stage, some evolution in the understanding of needed tasks, skills, and competencies is possible. Specifically, reflecting on changes in design from thought to proof of concept will provide a more nuanced insight into what on the JFC list may be relevant to manufacturing the novel product and what on the JFC list may need to be adapted. Initial adaptations may be possible, although they will be tentative.

MWP Level 4: Refining JFC Based on Production in a Laboratory Environment

At the fourth level of TRL/MRL, the technology is produced in a laboratory environment. At this stage, the initial workforce research conducted during MWP Levels 1 and 2 and refined in MWP Level 3 can be enhanced by any changes in the development of the technology that emerged during the transition to production in a laboratory environment.

MWP-Context Level 4

- What changes to materials, size, and use occurred between TRL/MRL Level 3 and TRL/MRL Level 4?
- What changes to the product development process occurred between TRL/MRL Level 3 and TRL/MRL Level 4?
- What anticipated (updated) equipment is expected to be needed to create the product now, and at a larger scale?

WRL 4 represents a key transition point between the creator and innovator workforces. In WRL 4, the workforce begins to move to private sector companies, in particular, start-ups and specialized laboratories in research and academic institutions. At this stage, both experts and organizational leadership should be interviewed. The team can continue to rely on a snowball sampling process wherein the experts they have spoken to previously offer further experts and organizational leadership they might speak to at this stage.

Interviews can focus on continued understanding of the evolution of materials, process, and equipment used to produce the emerging technology both at this point and in the future. Interviews at this stage provide enhanced understanding of market challenges including and extending beyond size of the product, cost, and so on. Interviews may explore the potential for market integration, as well as begin to explore the potential size of the market for the emerging technology.

MWP-Workforce Level 4

- What are the JFC implications of any changes to materials, size, and use between TRL/MRL Level 3 and TRL/MRL Level 4?
- What are the JFC implications of any changes to the product development process between TRL/MRL Level 3 and TRL/MRL Level 4?
- What training did you provide or may be necessary when transitioning to creating a viable prototype?

The assessment team at MWP Level 4 can continue gradually refining the JFC list giving further insights on the requirements for technician positions manufacturing PC technologies. At this stage, evolution in the understanding of needed tasks, skills, and competencies is possible. Specifically, reflecting on changes in design from proof of concept to developing a viable commercial product will provide a more nuanced insight into what on the JFC list may be relevant to manufacturing the novel technology product and what on the JFC list may need to be adapted. Initial adaptations may be possible, although the bulk of learning at this stage may be related to the market and barriers to production.

Finally, interviews at this stage can shed insight on the critical question of what skills and competencies may be needed at entry versus those which can and should be trained on the job. A preliminary attempt at distinguishing “needed at entry” skills and competencies can be made during this stage of the assessment.

MWP Level 5: Refining JFC Based on Production of Components

At the fifth level of TRL/MRL, components of the technology product are produced in a manufacturing environment. At this stage, the workforce research conducted through MWP Level 4 can be integrated and enhanced.

MWP-Context Level 5

- What is the process for developing components of the product in a manufacturing environment?
- How does this process differ from, or how is it similar to, the process for developing PC technology?
- Under what conditions (e.g., time of day, area, materials) do processes or work tasks for developing the components of this product vary?
- What anticipated (updated) equipment is expected to be needed to manufacture the product now?

At WRL 5, generalist innovators continue the production of the novel technology forward. This workforce includes experts and leaders with a variety of technical backgrounds, most of whom will hold PhDs or Master's degrees. Innovation and refining the process for developing the novel product are the dominant aim of this workforce. Members of this workforce tend to be skilled in a variety of jobs.

At this stage, interviews can continue with organizational leaders. Organizational leaders can provide high-level insights on the skills and competencies needed for success on the job and can continue to provide critical insights into the market.

Additionally, if possible, the assessment team should seek access to supervisors and incumbents in the roles related to creating the product. These individuals can provide more concrete information on the exact roles, tasks, and competencies essential for success in creating the product at this time. If possible, focus groups and/or surveys should be conducted on this population both on their current work and, for supervisors, on their expectations for the evolution of the workforce needs. The assessment team should also strive to conduct site observations to better understand exactly what this workforce needs to do on a day-to-day basis. This information would be critical in refining the JFC for manufacturing the emerging technology product in a more tangible and impactful way.

MWP-Workforce Level 5

- What do incumbents do when developing components of the product in a manufacturing environment? How is this similar or different from what incumbents do when developing PC technology?
- What competencies are required for incumbents to be successful in developing components of the product in a manufacturing environment? How is this similar or different from what incumbents need to be successful when developing PC technology?
- What work roles are needed to manufacture components of the product? How do they fit into the organizational structure?

MWP Level 5 assessments should ideally be informed by information gathering with two groups of stakeholders. First, interviews with experts and leaders can more fully inform the work roles that are needed to manufacture components of the product, and where they fit into the organizational structure. By the conclusion of MWP Level 5, a reasonably firm expectation for the responsibilities for the manufacturing technician work roles should emerge.

At Level 5, the tasks and skills for technician roles can also be meaningfully and substantially refined, given access to supervisors and incumbents. Interviews, focus groups, and site observations can be leveraged to obtain specific, concrete task, skill, and competency adaptations that will be necessary for manufacturing technicians. At the conclusion of MWP Level 5, if the team has access to supervisors and incumbents, a clean refined list of tasks and skills for manufacturing technicians for the emerging technology product can be created. If the team does not have access to supervisors and incumbents, they will need to rely on continued interviews with experts and leaders to inform the JFC list as effectively as possible.

MWP Level 6: Finalizing JFC and Roles

At level six of TRL/MRL, a prototype system or subsystem of the product is created in a manufacturing environment. With access to experts, leaders, supervisors, and incumbents, the team can have a firm understanding of the JFC for manufacturing the technology, including a reasonably robust competency model.

<u>MWP-Context Level 6</u>

- What is the process for developing a prototype system or subsystem of the product in a manufacturing environment?
- How does this process differ from, or how is it similar to, the process for developing components of the product?
- Under what conditions (e.g., time of day, area, materials) do processes or work tasks for developing the components of this product vary?
- What anticipated (updated) equipment is expected to be needed to manufacture the product?

Specialist innovators drive further technological advancement at WRL Level 6. Innovators at WRL Level 6 are beginning to fall into more differentiated roles, and are likely to hold Master's degrees or technical degrees. Members of this workforce work in more specialized jobs. The team at this stage should strive to focus, where possible, on supervisors and incumbents. Interviews, focus groups, and site observations should be conducted to understand any nuanced specifics of the JFC for the emerging, differentiated technician roles. Ideally, interviews with leaders and experts are no longer the primary source of information at this stage of the MWP. However, in instances

where it is not possible to access supervisors and incumbents, the research team may need to continue to rely on experts and leaders throughout the MWP process.

Information gathering at MWP Level 6 should focus on what makes creating a full prototype in a manufacturing environment, as compared to creating components of the novel product. Tasks and skills may be highlighted. Supervisors may provide additional insights on key differences in the skills and competencies necessary for success, as well as changes in tasks, skills, and competencies that they have observed over time as the process and equipment used to manufacture the novel product have emerged. Incumbents can provide particular information on their working conditions and the flow of their job, including the conditions under which they work tasks vary, and the equipment that they are currently using (and may use in the future) to manufacture the emerging technology product.

MWP-Workforce Level 6

- What do incumbents do when developing a prototype system or subsystem of the product in a manufacturing environment? How is this similar or different from what incumbents do when developing components of the system?
- What competencies are required for incumbents to be successful in developing the technology product or a subsystem of the product in a manufacturing environment? How is this similar or different from what incumbents need to be successful when developing components of the product? What additional competencies or skills are needed?
- What work roles are needed to manufacture the technology system? Are any additional work roles needed beyond the roles already required to produce components of the system?
- How many technicians might be needed to manufacture the novel technology product at scale?

Information gathered from interviews with incumbents and supervisors will inform any alterations to the existing JFC for the technician positions. The JFC should be relatively well developed by this time, however, as manufacturing continues to scale, tasks and skills may need to be adapted. Likewise, the job roles may also continue to develop and emerge. Changes and alterations should be made as job roles evolve. Where possible, the team should seek to provide insights on the number of technicians expected to manufacture the novel product at scale. Prior to MWP Level 6, this projection would be nearly impossible within any range of certainty. Even at MWP Level 6, this projection should be considered a very rough estimate.

At this stage, the team should also ensure the competency model is robustly developed. Drawing from interviews conducted to date, it is recommended that the team create a competency model for each job role by matching relevant competencies pulled from the

MOSAIC[1] model to the insights gathered in the assessment process. The MOSAIC, or the *Multipurpose Occupational Systems Analysis Inventory - Close-Ended*, competency model is developed and maintained by the Office of Personnel Management (OPM). It is a publicly available competency model created and leveraged by OPM in its work with the Federal workforce. The final competency model should initially be constructed by identifying relevant competencies from the MOSAIC framework. Where insights from stakeholders in the MWP process are not adequately reflected in the MOSAIC Competencies, additional competencies might be developed, defined, and documented as part of fully explicating the JWP for technicians.

MWP Level 7: Identifying What is Needed at Entry

At the seventh level of TRL/MRL, it is demonstrated that the product can be prototyped and produced in an operational and manufacturing environment. At this stage, workforce research must focus on ensuring clarity in what is needed for success at entry into manufacturing technician roles, and what will need to be trained.

MWP-Context Level 7

- What is unique about the process used to produce systems or subsystems in a production environment beyond what was captured in WRL 1 - WRL 7?
- What anticipated (updated) equipment is expected to be needed to manufacture the product?
- What changes as manufacturing progresses from small scale prototypes to production at scale?

WRL 7 represents another critical transition in the workforce creating novel products. At WRL 7, the workforce begins to transition from innovators to implementers as the technology moves into manufacturing. New equipment may be acquired and JFC may change as the work becomes more routinized, roles continue to differentiate, and technicians *do* more and *create* less.

The assessment team at this stage should focus interviews and focus groups on the continual fine tuning of the JFC. Changes in work roles, tasks, skills, and context should be reflected in the JFC with each successive level of development.

MWP-Workforce Level 7

- What JFC are critical for successfully producing the system in a production environment?
- What JFC are needed at entry as a manufacturing technician producing the system in a production relevant environment?

[1] https://www.opm.gov/policy-data-oversight/assessment-and-selection/competencies/

- What educational backgrounds or experiences are needed at entry as a manufacturing technician producing the system in a production relevant environment?
- What existing certifications and degrees are available to prepare technicians? What gaps need to be filled?

The research team at this stage should continue interviews and focus groups. The focus of these interviews and focus groups should be to speak to supervisors and incumbents on the JFC that are critical for successfully producing the new product, and which are needed at entry. As appropriate, the research team may design and implement short surveys during the interviews and focus groups to solicit more quantitative evaluations of JFC that are critical and needed at entry. Interviews should also address needed educational backgrounds and certifications.

The research team can also conduct a review of relevant available programs (with a focus on the region(s) most relevant to a particular manufacturing plant) that already provide the needed education. This review may include technical schools, community colleges, and possibly, four-year institutions. How many programs exist, what they cover, and how many potential students they may serve should all be noted. Where relevant programs do not exist, the research team can highlight the gaps in education that will need to be filled to create the necessary technician workforce to produce the emerging product at full scale. As appropriate, the research team may also reach out to community colleges and technical schools to learn more about how they are constructing training programs, and what needs they see for the emerging workforce.

MWP Level 8: Developing Hiring and Initial Training Guidance

Level 8 of TRL is attained when the whole new technology product is created and qualified through test and demonstration. Similarly, Level 8 MRL is attained when pilot line capability is demonstrated. At this stage, low-rate initial production can begin. MWP-C should be complete, with at most ongoing fine tuning required in understanding the JFC as manufacturing scales. MWP-Workforce Development must continue.

At WRL Level 8, manufacturers should be starting to hire technicians as the workforce shifts toward implementers. In parallel, training should begin to be developed. In house training will likely need to be developed initially. Ideally, community colleges and vocational schools will be able to begin developing training programs in parallel as well. Long-term, community colleges and vocational schools will be able to offer sufficient training to the background information that will be required to technician jobs that the only on-the-job training needed long term will pertain to specific equipment and safety protocols.

MWP-Workforce Level 8

- What are the final critical JFC that are also needed at entry for technician roles? What JFC are critical and should be trained on after entry?
- What JFC are needed at entry as a manufacturing technician producing the system in a production relevant environment?
- How many technicians are needed for effective low-rate production?
- From what organizations, schools, and lines of work are technicians for manufacturing the new technology hired?
- What systems and tools are used to recruit technicians for manufacturing the new technology?
- What process is used (e.g., assessment, interview) to screen candidates for hire for the JFC that are necessary and required at entry?
- Who will provide the training required to reskill technicians? What format will this training take (e.g., certifications, classes, internal, external, on the job, etc.)?

At this level of assessment, the team ideally can survey supervisors and incumbents. Surveys distributed to supervisors should focus on competencies and skills. Specifically, these surveys should provide a comprehensive list of identified competencies and skills and should request that supervisors reflect which are critical for success in each job role, and which are needed at entry (day 1) to the job. Surveys distributed to incumbents should focus on tasks. These surveys should provide a comprehensive list of tasks and should request that incumbents reflect which are critical for success on the job, and which are needed at entry in each job role. Finally, a separate set of surveys should be provided to a different set of stakeholders. Depending on who is likely to have the most accurate view of the linkage, either supervisors or incumbents (or both) should receive surveys that ask them to connect all critical tasks to identified skills and competencies in the JFC.

Distributing this set of surveys will allow the team to create a working list of the JFC that are both critical and needed at entry. This list and continued interviews will begin to inform educational requirements at entry into the job, including both level of education and content provided in education.

Of note, the JFC that are seen as critical for success on the job but not needed at entry are important tasks, skills, and competencies for the manufacturing plant to focus on in formal training, onboarding, and on-the-job training.

Additionally, research at this stage can refine the team's understanding of the number of technicians who may be needed to manufacture the product at scale. Answering this question will require an understanding of the size of the market for the product, as well as the time required to create the product. Helpful information would also include the number of units that can be produced a day. Notably, since applications of the technology and the process to manufacture the product are likely to vary somewhat by

producer, the market size and number of technicians will also likely vary by producer. Sales teams and leadership may be helpful in determining market size. Supervisors and incumbents would be helpful in estimating how long it takes to produce a unit and how many can be produced a day.

The team can also begin to create and refine an intentional recruiting and hiring practice. Speaking to Human Resources (HR), operations, administrative professionals, and supervisors, the team can learn the organizations, schools, and lines of work from which technicians are recruited and hired. Using this list as a baseline, the team can do further research into other backgrounds that might be relevant for the successful manufacturing of the new technology and update the initial list of educational institutions from which to recruit developed in MWP Level 8.

HR, operations, administrative professionals and supervisors can also provide information on the systems, tools, and processes used to recruit technicians for manufacturing the new product. Based on the JFC that are critical and needed at entry and the more comprehensive list of recruiting sources, the team may be able to propose changes and refinements to the recruiting and hiring processes that will improve the manufacturer's ability to recruit, hire, and retain the best technicians.

Finally, supervisors and incumbents can provide more detailed information on the skilling and reskilling needed after entry, specifically, how technicians learn what they need to learn and who teaches them. More formal onboarding and training programs can begin being developed based on this information.

MWP Level 9: Scaling Hiring and Training

TRL/MRL level 9 marks the successful demonstration of the new system in mission operations and low-rate production. At this stage, facilities that will manufacture the new product will have capability in place to begin full rate production.

The implementer workforce at MWP Level 9 begins to scale. Technicians should predominantly hold Associate's degrees and technical certifications. Recruiting will still pull from manufacturers of related technology and some technical schools, and should be increasingly broad and proactive at this stage to satisfy a higher demand for technicians. Likewise, on-the-job training should be more formalized and implemented. Research for MWP will continue to focus on refining the JFC, needed at entry, and scaling understanding needed to continue to scale manufacturing operations.

<u>MWP-Workforce Level 9</u>

- How many (more) technicians are needed to transition from low rate to full rate production?

- What changes need to be made in recruiting and screening practices to enable scaled hiring for low rate production?
- What has been learned during TRL/MRL level 8 that informs the experiences and credentials required to be successful as a technician manufacturing the new product?
- What additional training is required to skill or reskill technicians? What format will this training take (e.g., certifications, classes, internal, external, on the job, etc.)? Are any new modes of training available since attaining WRL Level 8?

At MWP Level 9, the team will have well-developed lists of JFC, needed at entry lists, lists of educational institutions to recruit from, a more robust understanding of the number of technicians needed to manufacture the novel product, recommendations on recruiting and hiring, and initial insights on training required once on the job. Additional information gathered at this stage through interviews, focus groups, and where possible, HR data will serve to refine these already developed materials to reflect the evolving needs of manufacturing this technology to scale. At this stage, post-secondary institutions should be improving and developing curriculum related to the emerging product, which will support the increased hiring needs.

At this stage, the team should have a more nuanced understanding of the experiences needed to be a successful technician, as well as opportunities for career growth as a technician. This will make it possible to begin a qualitative and narrative analysis of potential career pathing for these roles, including mapping out: a) the educational path; b) prior experiences and job titles; and c) subsequent experiences and job titles. Databases such as O*NET may be leveraged in this process in addition to an internal study of career history and mobility within the producer.

MWP Level 10: Extending Hiring and Implementing Widespread Training

TRL concludes at Level 9. MRL Level 10 is attained when the whole new technology is produced at full rate. At this stage, MWP Level 10 is focused on scaling and creating a sustainable and structured workforce for manufacturing the new product. The mature implementer workforce is the dominant workforce at this stage in the product development. Education should be well-developed at this stage in providing the needed skills, knowledge, and task exposure that is genuinely needed at entry into these technician roles. On the job training should also be somewhat developed.

At this stage, the team will make final refinements to the lists of critical JFC, noting what is needed at entry. A list of educational institutions and credentials needed can be finalized. Any changes brought into the workforce by the transition to full scale manufacturing should be considered and reflected in the updated materials for the manufacturing jobs.

Two additional areas of work remain. First, a full training infrastructure should be developed on the JFC that are critical for success but not needed at entry to ensure the successful onboarding of new technicians. Second, career pathing can be completed at a higher level of rigor by employing a tool called network analysis. The team may choose to employ network analysis to track the flow of applicants through positions over time and create a more quantified map of how technicians move from position to position in their careers. HR data (such as positions held, years held those positions) are necessary to conduct these analyses.

Once the JFC are fully complete, it will be important for the team to conduct a formal job analysis every 3-5 years, or after major technological changes, to ensure that the JFC for each position are fully up to date and relevant to the current market. Note that O*NET draws information on existing job positions from the Department of Labor, Bureau of Labor Statistics (BLS). States update their information to BLS on their own schedules.

Below, we present a table that summarizes when key workforce development deliverables can be produced in draft and robust form. Note that “draft” denotes an early stage of a deliverable that is likely to change significantly before finalization. “Robust,” in contrast, denotes a later stage deliverable that is final or near-to-final. The initial Appendix A in this Deskbook integrates the first three tables to show the lifecycle of workforce readiness and development alongside the MRL/TRL frameworks.

Table 06: Key Deliverables

Stage	WRL	Deliverable
1	Initial creator workforce	2-3 PC Technologies (Draft)
2	Specialized creator workforce	3-5 PC Technologies (Robust) Job Roles (Draft)
3	Applied creator workforce	Market Insights (Draft) JFC (Draft, from PC technologies)
4	Transition creator/innovator workforce	Needed at entry (Draft) Equipment (Draft)
5	Generalist innovator workforce	Job roles (Robust) Skills and Tasks (Robust)
6	Specialist innovator workforce	Competency model (Robust) Number of technicians (Draft)

Stage	WRL	Deliverable
7	Transition innovator/implementer workforce	Needed at entry JFC (Draft) Education & Certifications needed and available (Draft)
8	Initial implementer workforce	Needed at entry JFC (Robust) Number of technicians (Robust) Recruiting and hiring guidance (Draft) Training and onboarding (Draft) Education & Certifications needed (Robust)
9	Scaled implementer workforce	Career path (Draft) Education & Certifications available (Robust)
10	Mature implementer workforce	Career path (Robust) Training and onboarding (Robust)

Section 3: Best Practices for Conducting Assessments of Workforce Readiness

Introduction

The assessment process outlined previously can be conducted either throughout the natural progression of a particular emerging technology product, beginning at WRL Level 1, or may be implemented as thoroughly as possible for an emerging technology product at any given WRL Level. Depending on the technology and on the availability of SMEs, the MWP may be more or less detailed and precise. For example, when an organization is funding a MWP specifically for their own workforce, it is likely that the assessment team will be able to provide detailed, accurate, and concrete deliverables. When the assessment team is working independently, unless an organization provides access to incumbents and supervisors, the precision and detail of their deliverables will be reduced.

Below, we present best practices in conducting a MWP, including how to begin the process and best practices in gathering information that will inform each step of the process.

Determine the Technology Product

The process we describe in this manual is designed to expedite workforce development for emerging technology products. It is therefore important to understand which products might be the focus of the study, and what about the technology product will impact the workforce assessment process. Below, we describe some of the features of a product that will influence whether a full workforce assessment process can be conducted, and if so, how.

Entirely New versus Adaptation

The first feature of a product that should be considered is whether the it is a true innovation - if it is entirely new - or if it is an adaptation of or amalgamation of existing technologies and products. Most novel products will not be in fact wholly new. Most will be adapted from, inspired by, or composed of existing technologies entirely. Rarely, a technology product or process will be wholly new, for example, 3D printing. The process for conducting a workforce assessment will vary for fully novel technologies as compared to innovations on existing technologies. Specifically, with innovations on existing products, it is possible to learn much about what the workforce needs will be by studying the workforces of the already produced existing technologies and modifying those requirements based on what is new or different about that adaptation of the technology. It is more challenging to understand the workforce needs for fully novel technology products, as there is less already existing to build off. However, it is likely

that there will still be somewhat similar or comparable technologies or workforces that can be used as a basis for fully novel products.

Level of Maturity in Development

The farther along on the TRL and MRL overlays a product is, the more information is available to conduct a workforce assessment. Plentiful information is available for technology products currently at TRL/MRL level 5 and above. New technology products at TRL/MRL Level 5 and above have progressed to production relevant environments. At the early TRL and MRL levels, those people working with the new products are the creator workforce. This workforce is highly specialized and is tasked with creating the product and - eventually - a blueprint for its production. At level 5 and above, those middle-skilled technicians will begin to become involved in the process of manufacturing these technologies. Therefore, preliminary work is already underway in identifying the required background and experiences for these technicians, as well as understanding what they need to be trained on to be successful.

Form MWP Assessment Team

The next step is to determine who will be on the MWP Assessment team. A core team of as few as three to four people could feasibly carry out a MWP. However, we recommend teams have a minimum of 5-6 people. Expediting the process would require more investigators on the team.

At minimum, your MWP Assessment team should include:

- One person familiar with the technology, or PC technologies, and the market
- One person (or a person representing an institution) who has access to academic and industry contacts in the industry, or the industries for PC technologies
- One industrial/organizational (I/O) psychologist (or a similar profession) with a background in job analysis and/or competency modeling
- One social science researcher with a background in qualitative (interview/focus group) and survey research methodology

You may be able to put together a team wherein multiple of the above requirements are fulfilled by the same person. For example, you may assemble a team where your industrial/organizational psychologist also has a background in qualitative methodology. In addition to assembling a team with the above qualifications, expertise, and experience, you will likely want at least one if not more junior I/O psychologists or researchers to support the efforts required to process archival and interview/focus group data.

Orient SMEs Being Assessed

Throughout the assessment process, you will interact with a number of SMEs, including experts, leadership, incumbents, supervisors, and other administrative and operational professionals. Every time you interact with a new SME, it will be important to orient them to the project, process, and outcomes. Your orientation should include:

- Personal introductions
- Introduction to the project
- Goals and output of the project
- What is being asked of them
- How their information is used and protected
- What, if any, benefits they may expect from participating

Also introduce the personnel involved in the assessment when contacting new SMEs and at the beginning of interviews and focus groups. Email introductions can include names and titles, and introductions in interviews and focus groups should include relevant background, experience and roles.

A short introduction to the project should be included both in any email outreach or introduction, and should be provided at the beginning of focus groups and interviews. The introduction to the project should include a description of what is being done, why it is being done, and the expected deliverables of the assessment. The team should also make what they are asking of each SME clear in email outreach, and in interviews/focus groups.

The team should inform SME's of the level of confidentiality with which their responses will be treated. If identities will be disclosed in any way, that information must be shared. SMEs should also be informed on the potential benefits to them, if there are any, for participating. Academic experts may appreciate research results, leaders may appreciate high level insights, and supervisors and incumbents may benefit from any improvements to hiring and training that come from this process.

Conducting the Assessment

As noted in Section 2, the assessment ideally leverages several forms of information gathering, including surveys, interviews, focus groups, and archival data. Below, we describe some best practices and considerations in identifying appropriate SMEs, in running interviews and focus groups, and in leveraging archival information. In Section 4, we describe in more detail the processes for constructing and informing each of the deliverables for the MWP.

SMEs for the Assessment Process

Interviews and focus groups are an essential part of the MWP. A traditional job analysis will often be able to rely heavily on quantitative data, as incumbents and supervisors already exist for the jobs assessed in these analyses. When projecting what will be essential for jobs that do not yet exist, qualitative data from interviews and focus groups will be necessary in addition to surveys, observational data, and archival data. Specifically, the team should strive to assess SMEs in the below groups during the MWP process:

- Experts
- Top leadership of current manufacturers
- Administrative, sales, operations, or HR professionals
- Incumbents in technician roles for the emerging and PC technologies
- Supervisors of technicians for the emerging and PC technologies
- Industry groups

Interviews and focus groups will be an essential part of the workforce assessment process from the first step until the end of the process. Observation, archival data, and surveys will provide critical supplemental information where possible and appropriate. Each stakeholder group will provide slightly different necessary information for understanding the middle skilled workforce needs for manufacturing the emerging technology. Together, they structure the process of developing a full understanding of these needs. Table 4 below outlines when each group of stakeholder interviews are going to be most impactful by MWP level, and what information is generally sought at each stage, by each set of experts.

Table 07: SMEs Interviewed at Each Stage

Stage	Stakeholder group	Information sought	Information gathering process
1	Experts	Understanding the emerging technology product	Interviews, focus groups, literature review, site observations, archival
2	Experts	Identifying and understanding parallel products and contributing technologies, Job roles	Interviews, focus groups, site observations

Stage	Stakeholder group	Information sought	Information gathering process
3	Experts, Leadership, Administrative	Understanding broad workforce needs (categories of workforce needs that differentiate the emerging from existing technologies), Market insights	Interviews, focus groups
4	Experts, Leadership	Understanding broad workforce needs (categories of workforce needs that differentiate the emerging from existing technologies), needed at entry	Interviews, focus groups, surveys
5	Leadership, Incumbents, Supervisors, Industry Groups	Transitioning to understanding the technician role(s) for emerging and PC technologies; Refining understanding of skills and tasks	Interviews, focus groups, surveys, site observations
6	Incumbents, Supervisors, Administrative, Industry Groups	Understanding competencies for emerging and PC technologies; Number of technicians needed	Interviews, focus groups, surveys
7	Incumbents, Supervisors, Administrative, Industry Groups	Differentiating between what is needed at entry and what can be trained, Education/Certifications	Interviews, focus groups, surveys
8	Administrative, Leadership,	Number of technicians, JFC and education	Interviews, focus groups, surveys

Stage	Stakeholder group	Information sought	Information gathering process
	Incumbents, Supervisors, Industry Groups	needed at entry, recruiting, hiring, and onboarding practices	
9	Administrative, Industry groups	Education/ certifications; Career paths of technicians	Interviews, focus groups, archival
10	Administrative, Industry groups	Career paths; Training and onboarding	Interviews, focus groups, archival

As discussed above, different groups of stakeholders are useful for providing different information at different stages. Below, we summarize the stages at which each group of experts would be consulted, and what information would be sought from each group of experts. Note that additional sources of information include archival sources and a literature review. Later in this Deskbook, we will describe best practices for all information gathering techniques. In this next section, we focus on direct information gathering from SMEs only. Appendix B displays example interview and focus group questions for each of these groups of stakeholders.

Experts

Experts are the first available source of information for an MWP assessment. Experts include those highly trained specialists in the areas related to, and involved in the creation of, the new product. Experts are often going to be academics; professors working in universities. However, there may be times specialists working in practice are consulted for their expertise as well. Experts can also be helpful in developing lists of industry contacts for the team to reach out to while conducting the study, and in providing warm outreach introductions for the team.

Experts should be consulted to inform MWP-1, 2, 3, and 4. For MWP-1, experts provide a deeper understanding of the emerging technology product itself. They can explain, at a high level, what the new product does, why it was created, and how it works. They can also provide insight and advice on which companies and industry leaders may be able to inform the team's understanding of workforce needs. Experts may also be able to direct the team to resources for a literature review. When experts are beginning to build models, site observations may be helpful in providing information about the technology being developed. Addressing MWP-2, experts can provide context around the technologies that make up the novel technology product as well as the technologies from which the novel product was inspired. In other words, experts provide information regarding parallel products and contributing technologies. Site observations of experts may again prove useful in MWP-2. Informing both MWP-3 and MWP-4, experts can

provide some context and insight around the broad workforce needs they anticipate that will differentiate the merging technology from existing technologies. For example, they can explain the implications of differences between emerging and parallel products on the background and training required to be successful in manufacturing the novel technology, as well as where an existing workforce to upskill for manufacturing the new product might exist.

Top Leadership

Next, the team conducting the workforce assessment should talk to top leadership of current manufacturers of parallel products and contributing technologies, and, where possible, leadership of organizations beginning to manufacture the novel product. Leadership is not likely to be fully trained in the specialist area required to create the new technology product, so leadership cannot provide the same level of detail as experts on the specifics of the novel technology. Additionally, leadership should *not* be involved in the day-to-day work of manufacturing the product, so these subject matter experts will also not be able to provide rich detail on the skills, tasks, and competencies that are required to be successful in middle-skilled manufacturing jobs. However, leadership can provide insight about the general manufacturing and workforce challenges and opportunities posed in manufacturing the novel product, as well as some key insights around core tasks, skills, and competencies at a high level. Leadership and are essential for understanding the market that is emerging for the product. Finally, leadership can provide access to incumbents in technician roles and their supervisors.

Leadership should be consulted to inform MWP-3, 4, 5, and 8. At MWP 3, leadership can provide further insight on both parallel products and the technologies that are leveraged or included in the novel technology product. They provide a complementary view to the view provided by experts, as they have more direct experience with both the manufacturing demands of the novel product and the workforce. Leadership can then also provide information for both MWP levels 3 and 4, around noted workforce needs. That is, leadership will be able to provide insight on how the workforce needs for manufacturing the novel technology product have differed from manufacturing other technologies, in particular, any other product they make. If it is appropriate to do so, the team may implement short surveys as part of the interview process to begin to identify the JFC that are needed at entry versus those that can be learned on the job. At MWP level 5, leadership can provide a high-level view of any needs or challenges they noticed regarding middle skilled technician roles for emerging technology products as compared to the middle skilled technician roles for the associated PC technologies. Later in the evolution of the emerging technology, leadership can provide further insights into the market for the technology around MWP level 8.

Administrative, Sales, HR, and Operations Professionals

Administrative, Sales, Human Resources, and Operations professionals keep businesses running. They are not likely to have deep specialized backgrounds in the product being developed. Instead, they are likely to have expertise related to markets, economics, and personnel. These SMEs are able to provide critical insights that will inform sales volume, number of technicians needed, strategies in recruiting, hiring, and onboarding, and so on.

Administrative professionals can inform MWP levels 3, 6, 7, 8, 9, and 10. At MWP level 3, these professionals may provide broad market insights, including on integration of the expected future market. For MWP levels 6-10, administrative professionals provide context around the number of technicians needed, where current technicians received their education/certifications and what they concentrated in, and information on current personnel practices. Specifically, these SMEs can inform recruiting, hiring, onboarding, and training best practices. Ideally these SMEs are also able to provide both qualitative and quantitative career histories of the technicians they have hired. In addition to participating in interviews and focus groups, these SMEs may provide access to archival human resources data that inform recruiting, hiring, and career histories at MWP levels 9 and 10.

Incumbents

The next two groups of stakeholders provide an understanding of what is required to be successful in these positions. When conducting job analysis for middle-skilled technician roles in manufacturing PC technology, consulting incumbents is crucial for capturing detailed and accurate job information. Incumbents provide firsthand insights into their daily tasks, the conditions under which their work varies, and the specific skills and competencies required for effective performance (Morgeson, Brannick, & Levine, 2019). This approach ensures that job descriptions are comprehensive and relevant, addressing the variability and context of the job (Gatewood, Feild, & Barrick, 2015; Sanchez & Levine, 2012). Understanding these aspects is essential for workforce planning, especially in fields involving emerging technologies. Incumbents should be consulted at MWP levels 5, 6, 7, and 8. At level 5 and 6, technicians of PC technologies can provide insight into what they do. They can be asked about specific work tasks, when and how they do them, and under what conditions those work tasks vary. There may be occasions when the novel technology has reached early production, and the team is able to speak to technicians manufacturing the novel product. In these instances, if the technicians used to manufacture PC technologies, the team can also inquire about how their current tasks differ from those they used to perform when manufacturing PC technologies. At MWP level 5, it will also be helpful to do site observations of incumbents developing the product if possible. Short surveys can be implemented during incumbent interviews at MWP levels 5-7 to better determine JFC, particularly those needed at entry.

At MWP level 7, technicians can provide insight into what they need to be able to do at entry versus what they can be trained to do upon starting the job. Any technician manufacturing the novel product who used to manufacture PC technologies can provide direct feedback on what new skills they learned on the job.

Ideally, at MWP level 8, a comprehensive survey is developed to determine the JFC, including needed at entry, on a larger number of incumbents. This may not be possible unless an organization has sponsored the MWP for their own workforce.

Supervisors

Supervisors of middle skilled technicians provide the final critical pieces of information in understanding what it takes to be successful as a technician manufacturing the novel product. Specifically, while incumbents can describe their daily tasks, they often struggle to articulate the competencies and skills required for success. Supervisors, however, provide valuable insights into these aspects. Supervisors of middle-skilled technicians can inform the team about the competencies, skills, abilities, and other characteristics that distinguish high-performing technicians from lower-performing ones (Gatewood, Feild, & Barrick, 2015; Sanchez & Levine, 2012). Traditional job analysis literature emphasizes that incumbents offer detailed task-related information, whereas supervisors provide critical insights into performance standards and the attributes necessary for effective job performance (Brannick, Levine, & Morgeson, 2007; Morgeson, Brannick, & Levine, 2019).

Supervisors, like incumbents, should be consulted at MWP levels 5, 6, 7, and 8. At level 5 and 6, supervisors can begin to provide insights into what it takes to be successful as a technician manufacturing PC technology. As with the incumbent population, once the novel technology has reached early production, the team can speak to supervisors who have overseen manufacturing of the novel product itself. Further, some supervisors may have overseen technicians manufacturing both PC and the novel technologies.

These supervisors can therefore provide insight as to what unique competencies, knowledge, skills, and abilities are needed for the novel product that were not needed for manufacturing PC technologies. Site observations may be useful at this stage as well, and surveys may be included as part of interviews and focus groups to get more quantitative information on competencies.

Finally, at MWP level 7, supervisors can provide insight into what competencies, knowledge, skills, and abilities need to be present at entry versus what can be trained to do upon starting the job. Supervisors who oversee technicians manufacturing the novel technology can provide insight into anything they have had to train their technicians on.

Ideally, at MWP level 8, a comprehensive survey is developed to determine the JFC, including needed at entry, on a larger number of supervisors. This may not be possible unless an organization has sponsored the MWP for their own workforce.

Industry Groups

As a technology product emerges, industry groups will begin to form supporting those who work with and develop that product. Leaders and volunteers in these industry groups are likely to have additional information related to workforce requirements, including needed skills, competencies, job roles, and career paths.

Industry groups should therefore be consulted at MWP levels 5 through 10. At these stages of technology, manufacturing, and workforce development, industry groups can provide essential information about tasks, skills, competencies, education, and so on. Industry groups may also be able to recommend other subject matter experts. Generally speaking, the team is most likely to interview industry group leaders and experts, or request archival or written information from them throughout the process.

At MWP level 5, industry groups can provide a refined understanding of tasks and skills. Likewise, at MWP level 6, industry groups may provide insight into the competencies that are needed for these emerging roles. Some industry groups may track other workforce information and may have insights into how many technicians would be needed to manufacture the novel technology product.

Industry groups may also track existing education and certification programs and may be able to provide information on the programs that exist and are being built in MWP level 7. It is also possible, at MWP level 7, that industry groups could provide experts who can differentiate between what is needed at entry and what can be trained in technician roles. These experts may be willing and able to complete a survey indicating what is needed at entry at MWP levels 7 or 8.

At MWP level 8, industry groups may also be able to inform the number of technicians needed (if there are updates), and may have insights into what organizations are doing in terms of recruiting, hiring, and onboarding.

Finally, at MWP levels 9 and 10, industry group experts may have insights on the career paths of technicians, and may be able to provide updated information regarding available education/certifications and training and onboarding practices.

Next, we review best practices in conducting different forms of information gathering.

Best Practices in Indirect Data Collection

Workforce assessment for novel technologies will require active information gathering as well as a review of existing information. This process requires integration of data from a variety of sources. Below, we detail the process for gathering existing information to ensure that the workforce needs for the novel product are accurately anticipated and identified. Two forms of indirect data collection will be leveraged most frequently: literature reviews and archival data on jobs.

A workforce assessment should begin with a review of existing literature and information. Existing literature reviewed should address:

- Technical information on the technology itself
- Technical information on related technologies
- Workforce information on related technologies

Technical Information on the Technology

The team should ensure they have an introductory understanding of the novel product itself. While workforce analysis does not require that the workforce assessment team be experts in the novel technology product, they should know enough to understand what makes the novel product different from existing technologies, and enough to inform the kinds of questions they will ask when talking to the experts who create the product. Getting to this level of fluency may require auditing or reviewing course materials related to the technology as well as reading chapters and papers already published on the technology product.

A review of the novel technology product should include:

- Review of syllabi and course materials for courses related to the technology
- Auditing a course on the novel technology
- Review of papers and chapters written on the novel technology
- Review of any existing patents related to the technology

Technical Information on Related Technologies

Additionally, the team should have a high-level understanding of technologies related to the novel technology product. Once related technologies are identified, the team should develop an understanding of those technologies and what makes them distinct from the novel product. The team will need to know less about related technologies than they will need to know about the novel technology, but it is still critical to the formation of interview questions and the identification of workforce needs that the team understands these related technologies.

Getting to this level of fluency may require auditing or reviewing course materials related to the technology product as well as reading chapters and papers already published on the technology. However, since the existing technologies are already inherently well-developed, the review should focus on overview and summary chapters, courses, and papers only, not on minutia or the niche applications of that technology.

A review of related technologies may include:

- Review of syllabi and course materials for courses related to the technologies

- Auditing a course on the technologies
- Review of summary/overview papers and chapters written on the technologies

Workforce Information on Related Technologies

A large part of the information gathering process during the MWP will focus on collating skills, tasks, competencies, and other critical information about PC technician roles. It is critical at this stage to be comprehensive yet selective in the databases and information leveraged to ensure that the team is working efficiently and not missing any particularly important insights in the process.

Criteria for inclusion

A variety of potential resources exist that may provide critical information on the JFC of technicians needed to manufacture the emerging product. These resources include public access and paid databases. As there are so many different databases that can inform a workforce assessment, it is important to understand which databases are relevant, and for what information and purpose. Overall, your goal in understanding existing workforces is to understand:

- What are the middle-skilled job roles required to manufacture the existing technology?
- What are the core tasks and work behaviors required by these work roles?
- What are the knowledge, skills, abilities, and other characteristics (or competencies) required to perform these tasks and work behaviors effectively?
    - What is needed at entry? What is trained or learned on the job?
- About how many incumbents are needed to fill these job roles?
- What experience, credentials, education, and training is required to perform these job roles effectively?
- What skills gaps currently exist, according to industry experts?
- What facilities or organizations currently provide this training?

Databases that inform the above questions should be included in the team's review. It is unlikely that any one database will comprehensively cover all of the above pieces of information. Instead, the team will likely have to pull together information from a variety of sources. In assembling this information, the team should also make note of the questions that are not well answered by existing databases. When the team conducts interviews and focus groups, they should make sure to give particular focus to the questions in the list above that are not well-addressed by the existing databases.

Generally speaking, we strongly recommend always using O*NET, a publicly available database providing job information for a large number of positions. In addition to O*NET, you may leverage other databases, including Lightcast and

MOSAIC. Additionally, more specialized databases may be available for the specific technology of interest.

While any given database might not have all the needed information, it is possible that the team finds a database that covers much or all the information required. Regardless, the team should continue reviewing databases to enjoy that they have reached *saturation.* Saturation occurs when you are no longer getting novel answers to the questions you are asking. Specifically, if you are reviewing databases and continuing to find new information, keep reviewing databases. Once you begin encountering only the same information or answers, you can stop consulting databases. Make sure to document your search criteria for databases and in databases, the databases you consulted, and what information you obtained from each.

In addition to accessing databases, the team should review available job postings. Some paid services provide collated job postings. However, the team can also access job postings for technician roles for the emerging technology and/or PC technologies on publicly available websites such as LinkedIn, Indeed, and so on.

Locating and Accessing

Some of these databases, such as O*NET, are publicly available. These databases can be accessed by anyone, simply by visiting the website. Other databases require a fee. They can be accessed by purchasing a license or subscription. For these latter databases, weigh the cost of a subscription against the novel information available in that database. Only purchase access to a database if: a) funding is readily available for as comprehensive an exploration as possible, and b) that database will provide critical and novel information not contained in the existing public access databases. O*NET is relatively comprehensive, and in most cases, is likely to provide a strong starting point for identifying tasks, skills, and competencies needed to manufacture emerging technologies. Likewise, as noted, the team can access a number of job postings directly from public websites rather than needing to pay to access this information.

Best Practices in Interviews and Focus Groups

As stated previously, the process of conducting a job analysis for jobs that do not yet exist will need to rely heavily on qualitative data gathered in the form of interviews and focus groups simply because incumbents and supervisors do not yet exist for these roles. Interviews and focus groups are methods used to gather in-depth information from participants. Interviews are a method aimed at capturing a detailed view of the participant's perspective on the research topic. In this approach, the interviewee is regarded as the expert, and the interviewer as the learner (Milena et al., 2008). The researcher's interviewing techniques are driven by a desire to understand everything the participant can reveal about the topic. A focus group involves a group discussion aimed at identifying the perceptions, thoughts, and impressions of a selected group of individuals on a specific research topic (Milena et al., 2008). Below, we provide some suggestions

on how to determine whether to run interviews and focus groups, as well as how many the team may want to run.

Considerations for Which to Run

Interviews and focus groups are run for similar, but slightly different purposes. Interviews allow the interviewer to have more control over the conversation, allowing for a deeper understanding of each participant's responses and experiences (Gibbs, 1997). Interviews are beneficial when navigating personal or sensitive subjects, opinions, and experiences that one may be reluctant to share in a group setting (Milena et al., 2008). Interviews are also beneficial when the information provided by different participants is likely to have very little overlap.

The main objective of interviews is to focus on the individual; and learn as much as possible about their interpretations, decision-making processes, and associations with the research topic. Interviews are therefore essential in the beginning phase of conducting these assessments, particularly at the early stages of the MWP when very few experts are available, and when experts are likely to offer highly variable information. Interviews at these stages are necessary to get specific, one on one information regarding PC technologies, JFC, and the market. They allow the team to dive into the various skills needed for emerging technicians. Interviews should be primarily with experts, leadership, administrative and operations professions, and supervisors if available.

While interviews focus on a one-on-one dynamic, focus groups have the opportunity for participants to take control of the conversation. In focus groups, participants can "feed" off one another and often collectively identify things individuals alone may not. The interactions between the participants reveal information on the dynamic of the group including shared values, views, and perceptions (Kitzinger, 1994) allowing for an observation of real-world responses that build off of each other. Focus groups are also useful when exploring consensus or differences on a specific topic, shared language, and influences on behavior (Morgan & Kreuger, 1993).

Focus groups will be beneficial toward the middle of the MWP process. Once the team has a general idea of what it will be required of the emerging technician role(s), they can gather insights from diverse groups (e.g. incumbents in technician roles producing PC technologies, and management/ supervisors of these roles). Typically, however, focus groups will still be conducted by position. For example, the team may run focus groups of incumbents, and separately, focus groups of supervisors. Focus groups at these later stages of the MWP will help the team brainstorm, generate ideas, and explore new concepts about the roles. Later in the MWP process, focus groups also provide an opportunity to explore the team dynamics of incumbents and those who have worked in similar roles.

Considerations for Number to Run

As with reviewing existing information, interviews and focus groups should be conducted until saturation is reached. This practice should hold for each stakeholder group. Specifically, it is important to continue running interviews and focus groups until there is no new information from each stakeholder group.

Saturation plays a vital role in qualitative research by ensuring data sufficiency. Without saturation, there is a risk of overlooking important information, potentially leading to erroneous conclusions. Additionally, saturation is crucial for establishing credibility and trustworthiness in qualitative research. It represents the point where data redundancy is achieved, allowing the researcher to have confidence in the thoroughness of their understanding of the phenomenon under study.

Various data collection methods, such as interviews, focus groups, and observations, can contribute to achieving saturation. Researchers can employ different techniques, including theoretical sampling, data triangulation, and member checking, to ensure sufficiency in their study.

Analysis of Interview and Focus Group Results

Interviews and focus groups provide qualitative rather than quantitative data. Analyzing qualitative data requires distilling and summarizing themes. The goal in qualitative coding is to capture and reflect the core themes that are necessary and sufficient to summarize the main learnings across interviews. Often, qualitative coding processes code each line or sentence into one category. However, the qualitative data collection we encourage in the MWP process is multi-faceted. As a result, we anticipate that insights will be coded into multiple variables to best sort and describe the variety of insights that are expected to emerge.

First, interviews and focus groups should be recorded with consent, or should be documented with thorough notes that are as close to verbatim as possible. Notes and/or transcriptions should be separated into individual ideas. Each idea should receive a set of codes. The database created to code each idea should contain information linking the idea to a particular interviewer ID, including codes to indicate what kind of interview or focus group was conducted (for example, expert, supervisor, etc.).

The coding convention developed for interviews and focus groups will vary slightly depending on the technology investigated. However, it is possible that the team will code on:

Area: The specific technology referenced in the idea. For example, is the technology being discussed the technology under investigation, a PC technology, or an idea comparing two or more technologies?

Workforce: The workforce to which the idea refers. For example, creator, innovator, transition (between innovator and manufacturing, for example), manufacturing.

Job Type: Within each workforce, the job type referenced by the idea. When only one middle skilled role is expected to emerge, this part of the coding scheme may not be as critical. However, when multiple middle skilled roles are expected to emerge, this set of codes will help distinguish the JFC for different job roles.

Category: This coding variable should capture key categories of ideas, including whether they relate to core insights regarding: the market, skills, tasks, education, training, competencies, and so on.

Theme: This variable should capture the most granular information. For example, if the category is market, what theme does the idea relate to? Does it relate to *scaling* for example, or *vertical integration*? For a competency, what is the competency? And so on.

Ideally, multiple members of the team code and re-code the interviews and focus groups. This is expected to be an iterative process, with the codes evolving as interviews and focus groups progress. At the conclusion of the process, the findings should be summarized in a report and incorporated into the JFC lists, noting the frequency and importance of each theme.

Best Practices in Surveys

Surveys can and should be used both as part of the interview/focus group process and, ideally, as a separate part of the MWP study. For surveys to be employed to their maximal potential, the team will need to have access to a sufficiently large sample of both supervisors and incumbents.

Surveys are best employed to collect predominantly quantitative rather than predominantly qualitative data, although surveys can be designed to collect both forms of information. They are ideal for understanding the relevance of a predetermined set of JFC, for example.

Short surveys can be conducted in interviews and focus groups as a way of beginning to narrow the JFC. SMEs can be asked to reflect on shortened lists of JFC to determine which are expected to be both critical and needed as entry, or to modify or supplement the team's understanding of relevant JFC. The preparation for these surveys will involve distilling at most 10-12 JFC to review with a particular SME. For example, a SME might

reflect on 10-12 skills, or 10-12 tasks, or 10-12 competencies. Ideally, the SMEs being interviewed will provide a number to assign to the importance of the JFC, as well as an indication of whether or not it is needed at entry. In addition, the SMEs interviewed may correct the wording of a JFC or provide a nuanced understanding of how that JFC is expected to show up in a particular setting.

Longer surveys should be used for verifying which tasks, skills, and competencies are needed at entry. These are typically conducted using a survey platform online. For certain positions, where incumbents or supervisors may not have access to the internet or to online survey portals, paper surveys should be used. Demographic questions should be included in these surveys to ensure that the team can assess the representativeness of the responding sample. These surveys will be largely if not entirely quantitative in nature. Confidentiality or anonymity is necessary to ensure that all respondents are able to provide the most accurate, honest information possible.

Appendix C includes example items for supervisors and incumbents that can be used to collect JFC for the emerging technician roles.

Best Practices in Observation

Observation is helpful in an MWP, providing the team with detailed insights into JFC and work conditions. Effective observations begin with a thorough review of any available background information and prior research, ensuring a solid initial understanding of the job. This foundational knowledge is crucial for preparing the team for in-depth visits, which can follow two primary formats: direct observation and interviews. The observational format is suitable for entry-level or physically demanding jobs, allowing the team to see tasks performed firsthand. In contrast, interviews are better for higher-level or cognitively demanding jobs, focusing on mental processes. For manufacturing job positions, observations will typically be conducted through direct observation.

To ensure comprehensive data collection and validation, it is recommended that at least two team members participate in the observations. This collaboration enhances data accuracy. Detailed note-taking and, when appropriate, photographing key aspects of the job are vital practices for documenting and analyzing the data. Administrative preparation is also crucial, including selecting a diverse sample of SMEs, scheduling visits well in advance, and securing necessary approvals. Clear communication with SMEs about the purpose, duration, and expectations of the observations fosters cooperation. This ensures that high-quality data is collected to effectively inform the overall MWP process.

Prepare the Assessment Report

At the conclusion of the process, the team should ensure they prepare a detailed assessment report. The report should provide a summary of the steps they took during the MWP, the number and types of SMEs they spoke to, and their findings. The report should provide the tasks, skills, and competencies known to be critical, and should denote which are expected to be needed at entry. Additionally, the report should include other insights that will be relevant to understanding the emerging technology's market and manufacturing process.

In the next part of this manual, we go into detail about how the above information gathering process is leveraged to identify work roles, skills, requirements, skills gaps, training needs, and competencies. The MWP report should address, in some way, each of the below outlined deliverables.

Section 4: Preparing for the Deliverables

A final report from the MWP should include all relevant and available information to prepare an organization or industry for the JFC of emerging middle skilled technician roles that will be essential in the manufacturing process. Each of the below sections should be included. We provide some guidance on how each set of insights might be developed using the MWP tools (e.g., archival data, focus groups, surveys) previously discussed.

PC Technologies

The first step is to determine the relevant industry under which the emerging technology will fall, as well as related PC Technologies. PC Technologies will predominantly be determined through the interview and focus group process, in particular through interviews with experts and leadership. These groups of stakeholders will be able to provide concrete and concise guidance around the parallel products and contributing technologies for any given emerging technology. At least two PC technologies should be included and discussed in the report.

Determine Relevant Occupations and Job Roles

Later in the TRL/MRL development for the emerging technology, the industry of interest will begin hiring into technician-related roles. Therefore, it may be possible to identify more directly relevant and related job roles as the TRL/MRL develop. To identify these job roles, it is particularly helpful for the team to identify North American Industrial Classification System (NAICS) codes. A description of how to do this and how to link these codes to job positions is provided below.

Discern the Industry

1. Archetype Firms: The first step will be to identify 5-6 organizations/firms that are representative of the industry of interest based on suggestions from experts. These firms are called “archetypes.”
2. NAICS: First, identify the archetype firms using the North American Industrial Classification System (NAICS). If the discernment system is not NAICS, map the chosen system to NAICS.

Table 08: Example NAICS Industry Identification

Organization	North American Industrial Classification System (NAICS)

Boston Dynamics	333999 – All Other Miscellaneous General Purpose Machinery Manufacturing

5. Identify Other Codes: Using the list of archetype firm NAICS codes, enter these codes into a business list database (e.g., D&B Hoovers, NAICS Association, IBISWorld) database to identify a larger set of similar firms. For all similar firms, note the NAICS codes used to characterize those firms.
6. BLS Equivalent Code Mapping: Map the NAICS codes for your archetype firms and related firms to the BLS equivalent codes (three- or four-digit level NAICS codes). The truncated version of NAICS is required to use the occupation data available from BLS, such as the data on O*NET. An example of mapping to these BLS equivalent codes is shown below in Table 6:

Table 09: Example BLS Industry Identification

NAICS Code	NAICS Description	BLS Equivalent Code
333999	All Other Miscellaneous General-Purpose Machinery Manufacturing	3330A1

7. Identify Industry Cluster: Using these classification codes, the team can determine a cluster that describes the industry of interest for the emerging technology. For example, robotics maps to the following 3- or 4-digit NAICS codes: 334500, 3330A1, and 333500. The team can use this cluster of codes to identify PC occupations relevant to the emerging technology from which to draw tasks, skills, and competencies needed for success.

The BLS O*NET database provides extensive information regarding critical work tasks and skills for a wide variety of positions. The team can use the BLS equivalent NAICS codes derived from the PC technologies to determine a set of job roles that might be generalized to those needed by the emerging technology.

To accomplish this, the team should first download the most recent version of the National Employment Matrix and the O*NET database. The team should then search for occupation that:

1. Are associated with the industry of interest, as defined by the codes previously identified for PC technologies
2. Are technical jobs (these use standard Occupation Classification codes such as 15-0000, 17-0000, 19-0000, 49-0000, and 51-0000)
3. Are held predominantly by middle-skilled workers/technicians (the education level for the jobs is greater than a high school diploma and less than a bachelor's degree). To determine if a job is held predominantly my middle-skilled workers, look to see if the reported O*NET fraction for that job is greater than 30% middle skilled and less than 50% lower skilled.
4. Account for more than 0.1% of the workforce in the defined industry

For many technician roles, you may want to exclude roles that focus on computer programming and systems operations. Generally, manufacturing technicians will not be responsible for these tasks. However, depending on the technology being explored, it is possible that some may, especially if they need to leverage software to develop the novel product. Therefore, the decision to include or exclude these occupations should be made by the team based on the specific technology studied.

In addition to understanding possible roles from the classification codes, the team can use several other methods to triangulate and determine relevant roles. First, interviews and focus groups will provide insight into the evolving middle skilled technician roles that will be needed to manufacture the new technology. The team should also get insights from available job postings. Specifically, organizations that are developing the emerging technology will advertise for positions required to assemble that technology. The team should monitor job postings in the industry and by key organizations on publicly available websites such as LinkedIn and Indeed. These insights will be essential for determining what the job roles might be named as well.

Create Base Lists of Tasks and Skills

For each job role (occupation) identified, the team should identify and pull the tasks and skills included in O*NET for this occupation. Once you have curated the lists of tasks and skills, compile a shared set of tasks and skills that are most likely to form the foundation of the emerging technician role. As you compile the shared set of tasks and skills, consider:

1. Clusters of job roles. Reviewing the job roles and their associated tasks and skills, consider if there are sets of job roles that seem to be like each other, but different from other job roles. It is possible that several clusters of distinct job roles can be identified for middle skilled technicians manufacturing PC technology. These distinctions can form an early basis for understanding the likely job roles that will emerge with the novel technology product.

2. Overlap between PC technician roles. Within each cluster of similar job roles, begin identifying the base by focusing on the tasks and skills that are most frequently mentioned across the job roles. Tasks and skills that are represented across multiple job roles within an identified cluster are most likely to generalize to the technician roles for manufacturing the novel technology. Identify the most frequently mentioned 20-25 tasks and 20-25 skills for each identified cluster and use these as the basis for your JFC for each technician role for the emerging technology product.

3. Insights derived from interviews and focus groups. SMEs will provide clearer insight as to what will be needed to manufacture the novel product, including differentiators and most critical tasks and skills. Reflecting in an iterative way on the ongoing interviews and focus groups, the team can identify: a) among the most repeated tasks and skills, the most critical for the novel technology; b) modifications to the most repeated tasks and skills that are essential for the novel technology; c) less frequently repeated skills and tasks that might still be essential in manufacturing the emerging technology; and d) wholly new tasks and skills that should be added to the lists specifically for the novel technology.

The team can follow this overarching process to iteratively create and modify the JFC for manufacturing the novel technology, leveraging predominantly archival information and interviews and focus groups. In addition to leveraging information from O*NET, the team should look for other sources of tasks and skills. These may come from:

1. Job postings. A job posting represents a brief written description of the work—essentially a snapshot intended to communicate the essence of the job (Morgeson, Brannick, & Levine, 2019). Reviewing job postings, whether collated by a third-party like LightCast or accessed through job boards such as LinkedIn and Indeed, can offer specific guidance on the skills and tasks required for emerging technology roles.
2. Industry websites. As the industry emerges for the novel technology, groups and organizations will likewise emerge to support the members of that industry. These groups and organizations may offer collated lists of skills and/or tasks in their materials or on their websites that can be leveraged in developing the JFC for technician roles for the emerging technology.
3. Literature review. A thorough review of literature around the emerging technology product may provide additional insights around what skills and tasks are essential for manufacturing this technology.

When considering tasks and skills to include for the JFC, consider both technical skills and tasks and interpersonal or relational skills and tasks. Consider, for example, whether work is done predominantly independently or interdependently. If work is done

interdependently, consider whether the interdependence might be sequential (with individual job roles each having their unique tasks completed in order) or concurrent (with job roles working actively together throughout the process). Ensure that your final JFC includes both these technical and relational components, customized to the nature of the expected manufacturing process.

Market Insights

Interviews, focus groups, and reviewing industry group websites will provide essential information on the market as it evolves. Specifically, it will be important to understand market pressures and opportunities related to:

- Cost: Both the cost of raw materials and the cost of machines and technology required for manufacturing, including startup costs and ongoing should be considered
- Size: Consider the size of the novel product and contributing technologies
- Integration of the market: Will all components of the product be created and integrated on one site or will different organizations make and do different parts of the process?
- Demand for the product: Who will be the end users for the product and how much will they need?
- Variation in the product: Will the product be made the same way every time, for every purpose, or will it vary? How frequently will it vary, and how (size, composition, materials, etc.)?
- Automation: To what extent can the production of the emerging technology be automated, versus how much will need to be produced by hand/by an expert?
- Unit of development: At what unit can the product be created? Do technicians need to work on one unit at a time, or can multiple units of the product be created simultaneously?
- Time required: How long does it take to develop one unit of the product? This will be impacted by integration, variation, automation, and unit of development.
- Volume: At what volume can the product be manufactured? This will be impacted by the cost of the materials, integration, variation, automation, unit of development, and time required.
- Profitability: For how much will each unit sell? And, will the cost per unit at the expected level of demand offset the cost and time to produce?

In addition to providing critical insights on the extent to which the emerging technology can be produced and sold at scale – and what “at scale” might mean for that particular emerging product – market related insights can inform how technician roles will emerge. For example, technician roles in integrated low-volume markets may need to be involved in more parts of the assembly process, and therefore may have a wider variety

of skills, tasks, and competencies needed for success. Technicians in these roles may also require more education and training pre-hire. In contrast, technician roles in unintegrated and/or high-volume markets are likely to be involved in much more narrow parts of the assembly process and may have a lower variety of skills, tasks, and competencies needed for success. These technicians may therefore require less education and training pre-hire.

Competencies

Understanding the competencies needed for success requires first understanding both the tasks and skills needed for success, as well as what success actually looks like. Defining competencies for a given role will require first identifying that role, then identifying the tasks and skills needed to perform that role successfully, and finally, identifying what high performance looks like in that role.

Competencies can then be defined for the role by leveraging multiple sources of information. First, while O*NET does not specifically include competencies, it does provide knowledge, skills, and abilities, which may be leveraged as guidance for the competencies that might be needed. Industry websites and organizations may also provide guidance on core competencies needed for success. The team should also leverage interview and focus group insights to flesh out the competencies needed for success in the emerging technician roles.

Integrating all of this available information, the team should refer to the MOSAIC competency model offered by OPM. Specifically, the team should identify the existing competencies captured in MOSAIC that best describe the competencies, skills, abilities, and knowledge needed to be successful in the identified positions. Any remaining competencies necessary for success but not covered in this resource will supplement the existing MOSAIC competencies.

Competencies for success should cover both technical and relational components of the expected job, and can be refined through surveys, both independently distributed and distributed during interviews and focus groups. Finally, the competencies need to be linked to tasks and skills using linkage surveys or analyst judgment.

Equipment and Work Context

Interviews and archival information will be essential in determining the equipment that will be needed to manufacture the novel technology product, and in what environments/contexts the technicians may work. To begin with, the team can and should leverage what they know about PC technologies and related industries. O*NET provides information regarding equipment needs for the jobs in their database; the team can pull from this existing information to provide a baseline understanding of the

equipment that technicians might use and the context under which they get their work done.

One of the challenges the team will face in accurately and precisely defining the equipment needed and work context is that the specific equipment appropriate for manufacturing a given emerging technology product is likely going to evolve as the technology itself evolves. Therefore, archival information such as the information provided in O*NET can provide a helpful baseline. However, conversations with SMEs later in the MRL/TRL process will be essential for more clearly narrowing down the exact machines and work context required to manufacture the novel product. Early interviews and focus groups will still provide some insight. When SMEs share information about the challenges associated with scaling production of a given technology, those challenges also underscore areas where equipment might expedite the process. For example, if SMEs discuss an aligning process that is time and labor intensive, and cannot be done incorrectly, it is likely that equipment will be produced to conduct that aligning process to a high degree of accuracy and automation.

Needed at Entry

Once the initial lists of JFC are created, the team will need to determine which are truly needed at entry (needed day one) and which can be learned and trained on the job. This step of the process will leverage archival data, focus group/interview data, and survey data.

When reviewing archival data, the team should consider both O*NET and other archival databases as well as job listings. O*NET and similar databases may provide initial indications of which JFC are needed at entry in job roles manufacturing PC technologies. Job listings, both for job roles for manufacturing PC technology and for emerging technician roles producing the new technology, will also list “required” qualifications. These required qualifications can likewise be taken as an initial indication of what JFC are truly needed at entry.

During the interview process, the team should obtain further information about what is needed at entry and what technicians can be trained on. The MWP team should solidify their understanding of the JFC that are needed at entry by, if at all possible, distributing a set of surveys to incumbents and supervisors of the technician role and technician roles producing PC technologies. This set of surveys should assist the team both in determining the final list of critical JFC as well as the final list of the JFC that are absolutely needed at entry. Appendix C displays sample questions that address these two pieces of information.

Number of Technicians

Determining the number of technicians that will be needed in the future manufacturing workforce will be an iterative, evolving effort. Even at MRL/TRL level 5, it is difficult to fully project the evolving market, the equipment needed, and what full scale manufacturing might look like. Therefore, early estimates on the number of technicians will likely need to be amended frequently as the MRL/TRL evolve in order to be responsive to the emerging manufacturing processes.

Estimates around the number of technicians needed can be adapted initially from workforce estimates of technicians needed for PC industries. These will need to be adapted to account for differences in the level of scale in production between the technologies as well as differences in the processes themselves (e.g., additional steps, additional precision, etc.). Interviews and focus groups with SMEs will enable the team to evolve and adapt the estimate of needed workforce size throughout the MWP process.

Education & Certifications Needed

Interviews and focus groups will provide initial information on the education or certifications needed to be successful in these technician positions. Experts and leadership can provide insight as to the expected types of education needed, whereas HR and administrative professionals can provide insight into the actual degrees and certifications held by those they hire. Likewise, incumbents can share information on the degrees they have.

Later in the MRL/TRL evolution, HR data can be used to summarize the degrees and certifications of incumbents in different technician roles. Additionally, a survey can be implemented that lists potentially useful educational backgrounds and/or certifications, and requests that experts identify which are necessary and/or helpful for success in the technician roles.

Education & Certifications Available

Once the needed education and certifications are determined, the team can conduct a thorough search of which are already available. When a particular organization is sponsoring the MWP, this search can provide insight specifically on the regional available education and certifications. Understanding gaps in the availability of education and certifications can help guide the creation of programs to prepare people for these technician roles.

In addition to finding relevant programs, the team can compare the *content* specified as helpful or essential with the content provided in the identified programs. This comparison can further guide educational development. Specifically, when content needed for success in technician roles is not currently offered through existing programs, those programs can enhance their offerings and coverage to better meet the needs of the evolving industry.

Recruiting and Hiring Guidance

The team can provide either general or specific recruiting and hiring guidance. When the MWP is funded by a third party, or by multiple parties, for the industry, recruiting and hiring advice will be more general. When the MWP is funded by a specific organization for their own internal purposes, the recruiting and hiring advice can be more specific. In this latter instance, it will be important for the MWP team to work closely with the internal personnel focused on recruiting and hiring.

The JFC that are denoted as needed at entry will form the foundation for both recruiting and hiring advice. Additionally, information on the education/credentials needed and available will be essential for recruiting. The team will be able to provide general information on both educational institutions and PC industries/job roles from which the emerging technicians will be recruiting, leveraging information gathered on education/certifications. When the MWP is funded by a specific organization, these recommendations can be targeted to the region or regions of interest rather than being specified more broadly. Additionally, organizational-level MWP's may result in detailed recruiting strategies the organization can implement immediately.

The JFC that are needed at entry can form the basis of a job description as well as a hiring process. Specifically, depending on what JFC are needed at entry, the team might recommend assessments, realistic job previews (RJPs), work samples, and/or specific interviews/interview questions that will most effectively identify candidates likely to have the necessary JFC to be successful on day one. When the MWP is funded by a specific organization, the team may develop and provide a fully functional hiring system, including the specific assessments, a fully developed interview and scoring system, and/or operational RJPs and work samples.

The team should draw both recruiting and hiring advice from the MWP outcomes as well as from evidence-based best practices according to the most recent research done in the field of I/O psychology and related fields. Hiring and recruiting advice may also reflect insights shared by SMEs during interviews and focus groups.

Training and Onboarding

In order to provide training and onboarding advice, the team first should focus on the JFC. Those JFC that are critical for success but not needed at entry will form the basis for any recommended onboarding and training plan.

Next, within a given workforce, the MWP team should conduct a gap analysis to identify any existing gaps between the JWP critical for success and the JWP held by the current workforce. This gap analysis can be conducted via semi-structured interviews with key industry stakeholders about the JFC for the role. The stakeholders would be asked to evaluate the competency level of a trained worker that has been in the role for a specified time (e.g., 2 years) versus the competency level for new hires coming in. The gap is therefore the difference between the competency level of a new hire and a trained worker. The results of the gap analysis will provide the priorities for that workforce's development.

When an MWP is funded by a third party or multiple organizations in a given emerging industry, the MWP team can provide general onboarding and training advice. Specifically, the MWP team may identify:

- The tasks, skills, and competencies that are critical but not needed at entry: The MWP team can provide a breakdown of what, within the JFC, is critical but not needed at entry and what is critical and needed at entry. The former of these lists will form the universe of core tasks, skills, and competencies that onboarding and training should ultimately be available for in each role.
- Gap analysis of tasks, skills, and competencies: The MWP team can provide a general, high-level review of the tasks, skills, and competencies that seem to currently be missing in the workforce that is most likely to enter the emerging technician roles. This list will highlight the top priorities that must be the initial focus during onboarding and training.
- Advice for onboarding: Drawing from best practices in I/O psychology and related fields, as well as from the prior two lists of JFC that might require training, the MWP team can provide general guidance on best practices in onboarding to the new technician positions. This guidance may include recommendations on onboarding format (e.g., apprenticing, simulations, formal training, etc.), length, and content.
- Advice for training: Drawing from best practices in I/O psychology and related fields, as well as from the two lists of JFC that might require training, the MWP team can provide general guidance on best practices in training for the new technician positions. The guidance may include recommendations on what to include in onboarding versus formal training; method, content, and frequency of

formal training; and JFC that may evolve and require ongoing training to stay on top of.

When an MWP is funded by a specific organization for their internal use, the MWP team can provide more specific onboarding and training advice. Specifically, the MWP team may identify:

- The tasks, skills, and competencies that are critical but not needed at entry: The MWP team can provide a breakdown of what, within the JFC, is critical but not needed at entry and what is critical and needed at entry. The former of these lists will form the universe of core tasks, skills, and competencies that onboarding and training should ultimately be available for in each role for that specific organization.
- Gap analysis of tasks, skills, and competencies: The MWP team can provide a general, high-level review of the tasks, skills, and competencies that seem to currently be missing in the workforce that is most likely to enter the emerging technician roles. This list will highlight the top priorities that must be the initial focus during onboarding and training for that specific organization.
- Advice for onboarding: Drawing from best practices in I/O psychology and related fields, as well as from the prior two lists of JFC that might require training, the MWP team can provide a specific, actionable onboarding plan for each of the anticipated emerging technician positions. This plan should provide length of onboarding, specific content to be included, and the different formats that should be used throughout (e.g., apprenticing, simulations, formal training, etc.). Parties responsible for successful onboarding and criteria to determine successful onboarding should also be included.
- Advice for training: Drawing from best practices in I/O psychology and related fields, as well as from the two lists of JFC that might require training, the MWP team can provide specific, actionable recommendations on training for the new technician positions. The guidance may include recommendations on what to include in onboarding versus formal training; method, content, and frequency of formal training; and JFC that may evolve and require ongoing training to stay on top of. The team should create and provide a training and onboarding plan that is aligned, immediately actionable, and logically progresses. In addition, the MWP team may offer resources or workshops on interpreting and applying the information provided in the onboarding and training plans.

Career Path

The MWP team can provide insights on technician career paths by leveraging interviews/focus groups, archival data, and, where appropriate, network analysis of existing archival data. In interviews and focus groups, the team can learn what

jobs technicians have had in the past, and which they might have in the future, from leadership, HR/administrative SMEs, supervisors, and incumbents. Leveraging this information, the team can provide a narrative summary of expected prior and future job roles for each identified emerging technician position.

In some circumstances, the team may have access to archival information that provides the exact job titles previously held by technicians. Similarly, the team may have access to actual promotional information for any incumbents who had at one time held the technician position. This information can be summarized by frequency of prior and future positions held, at minimum. When a larger volume of career path information is available, the team can conduct a network analysis to model the evolving career paths of technicians more precisely.

A precise career path analysis of the specific emerging technician positions will not be possible until later in the MRL/TRL/WRL process. However, modeling career paths for technicians manufacturing PC technologies can provide a foundational career path that can be modified based on insights obtained in interviews and focus groups.

Appendix A
TRL/MRL/WRL/MWP Full Lifecycle

Stage	TRL	MRL	WRL	MWP – Context	MWP – Workforce	Deliverable
1	Basic principles observed and reported	Basic manufacturing implications identified	Initial creator workforce	Key variables (materials, size, use) of novel technology identified	Research into the jobs, functions, competencies (JFC) begins	2-3 PC Technologies (Draft)
2	Technology concept and/or application formulated	Manufacturing concepts identified	Specialized creator workforce	Parallel products and contributing (PC) technologies identified	Investigation of JFC of PC technologies	3-5 PC Technologies (Robust) Job Roles (Draft)
3	Analytical and experimental critical function and/or characteristic proof-of concept	Manufacturing proof of concept developed	Applied creator workforce	Study of the process and knowledge required to develop proof of concept	Identifying the tasks, skills, and competencies that will be needed based on proof of concept	Market Insights (Draft) JFC (Draft, from PC technologies)

Stage	TRL	MRL	WRL	MWP – Context	MWP – Workforce	Deliverable
4	Component and/or breadboard validation in laboratory environment	Capability to produce the technology prototype in a laboratory environment	Transition creator/innovator workforce	Study of the process and knowledge required to produce in laboratory environment	Identifying the tasks, skills and competencies that will be needed to transition from prototyping to laboratory	Needed at entry (Draft) Equipment (Draft)
5	Component and/or breadboard validation in relevant environment	Capability to produce prototype components in a production relevant environment	Generalist innovator workforce	Study of the process and knowledge required to produce components in production relevant environment	Identifying the tasks, skills and competencies that will be needed to transition from laboratory to production	Job roles (Robust) Skills and Tasks (Robust)
6	System/subsystem model or prototype demonstration in a relevant environment	Capability to produce a prototype system or subsystem in a production relevant environment	Specialist innovator workforce	Study of the process and knowledge required to produce prototype system in production relevant environment	Final refinement of tasks, skills, and competencies. Identifying appropriate job roles based on tasks, skills, competencies,	Competency model (Robust) Number of technicians (Draft)

Stage	TRL	MRL	WRL	MWP – Context	MWP – Workforce	Deliverable
					and JFC of the technology	
7	System prototype demonstration in an operational environment.	Capability to produce systems, subsystems, or components in a production-representative environment	Transition innovator/implementer workforce	Study of the process and knowledge required to produce fully in production relevant environment	Identify what tasks, skills, and competencies can be hired on and what must be trained	Needed at entry JFC (Draft) Education & Certifications needed and available (Draft)
8	Actual system completed and qualified through test and demonstration.	Pilot line capability demonstrated; ready to begin low rate initial production	Initial implementer workforce		Development of training; Initial hiring	Needed at entry JFC (Robust) Number of technicians (Robust) Recruiting and hiring guidance (Draft)

Stage	TRL	MRL	WRL	MWP – Context	MWP – Workforce	Deliverable
						Training and onboarding (Draft) Education & Certifications needed (Robust)
9	Actual system proven through successful mission operations.	Low rate production demonstrated; capability in place to begin full rate production	Scaled implementer workforce		Scaled hiring; Training for initial hires at low volume	Career path (Draft) Education & Certifications available (Robust)
10		Full rate production demonstrated and lean production practices in-place	Mature implementer workforce		Extended hiring, implementation of widespread training	Career path (Robust) Training and onboarding (Robust)

Appendix B

Interview Guides

Academic Researchers:

Thank you for agreeing to speak with us today. I'm [name] with [organizational affiliation] and we are partnering with [relevant partners] to think about ways to address the difficulties of filling openings for middle skilled technicians manufacturing [name of emerging technology product].

I'll start off providing you a little more context for what the focus of this project is and then follow up with more specific questions for what I hope to learn from you given your experience/background.

Workforce availability typically lags technology and manufacturing readiness so steps to building a workforce need to begin earlier in the technology development process and manufacturing development process. We are therefore conducting an assessment to understand what the future manufacturing workforce needs are for creating [name of emerging technology product].

Questions to determine appropriate sub-technologies to focus on:

- Please describe your familiarity with [name of emerging technology product]. What goes into this [name of emerging technology product]? How is it made, so far?
- What are different types or applications of [name of emerging technology product]?
- How (in what ways) do they vary from one another?
- What stage of technology development is [name of emerging technology product] in? Where is [name of emerging technology product] more advanced, and where is it less advanced?
- What are the biggest challenges or opportunities for the application of [name of emerging technology product] right now?
- What are the biggest challenges or opportunities for the development of [name of emerging technology product] right now?
- What are some of the challenges and opportunities regarding the skills and knowledge needed to design this technology? What about manufacturing it?

Questions to determine parallel products and contributing technologies:

- What problems does [name of emerging technology product] solve? Why is this product being developed?
- What does it do that is similar to what other technologies or products already do?

    - What are some of those similar technologies or products (called, PC technologies in this guide)?
    - How (in what ways) are they similar?
- What is different?
    - Are there any industries or technologies that are relevant to the ways in which [name of emerging technology product] is different from the most closely related technologies? What are they?
    - How are they relevant?

CEOs of Manufacturing Facilities:

Thank you for agreeing to speak with us today. I'm [name] with [organizational affiliation] and we are partnering with [relevant partners] to think about ways to address the difficulties of filling openings for middle skilled technicians manufacturing [name of emerging technology product].

I'll start off providing you a little more context for what the focus of this project is and then follow up with more specific questions for what I hope to learn from you given your experience/background.

Workforce availability typically lags technology and manufacturing readiness so steps to building a workforce need to begin earlier in the technology development process and manufacturing development process. We are therefore conducting an assessment to understand what the future manufacturing workforce needs are for creating [name of emerging technology product].

1. What prompted you to begin manufacturing [name of emerging technology product]? What problem will [name of emerging technology product] solve?

2. What were some of the key manufacturing challenges you faced when beginning to produce [name of emerging technology product]? How did you overcome them?

3. What were some of the key workforce challenges you faced in staffing technician roles to manufacture [name of emerging technology product]? Where were you able to find the workforce for these roles? What did you have to do to prepare them after hire? Where are there still gaps, if anywhere?

4. What are some of the challenges or opportunities ahead of you in manufacturing [name of emerging technology product]?

5. Is there a production manager (or similar position) from your firm that could speak to us to learn more about what it takes to staff and train technicians that manufacture [name of emerging technology product]?

Management of Manufacturing Facilities:

Thank you for agreeing to speak with us today. I'm [name] with [organizational affiliation] and we are partnering with [relevant partners] to think about ways to address the difficulties of filling openings for middle skilled technicians manufacturing [name of emerging technology product].

I'll start off providing you a little more context for what the focus of this project is and then follow up with more specific questions for what I hope to learn from you given your experience/background.

Workforce availability typically lags technology and manufacturing readiness so steps to building a workforce need to begin earlier in the technology development process and manufacturing development process. We are therefore conducting an assessment to understand what the future manufacturing workforce needs are for creating [name of emerging technology product].

- What is the process by which [PC technologies] are manufactured?
- What materials, processes, and people are involved in manufacturing [PC technologies]?
- What job roles are involved in manufacturing [PC technologies]? What does each do, at a high level? (Probe why some roles are split, or combined)
- What workforce challenges have you faced, either in hiring or training, in manufacturing [PC technologies]?
- Are you considering manufacturing [name of emerging technology product] in the future? If so, what do you anticipate you might need to build or adapt to manufacture this technology?
- How they work together OR what these different roles relationships are. Do their careers tend to move in these different positions?

Incumbents in Technician Roles:

Thank you for agreeing to speak with us today. I'm [name] with [organizational affiliation] and we are partnering with [relevant partners] to think about ways to address the difficulties of filling openings for middle skilled technicians manufacturing [name of emerging technology product].

I'll start off providing you a little more context for what the focus of this project is and then follow up with more specific questions for what I hope to learn from you given your experience/background.

Workforce availability typically lags technology and manufacturing readiness so steps to building a workforce need to begin earlier in the technology development process and manufacturing development process. We are therefore conducting an assessment to understand what the future manufacturing workforce needs are for creating [name of emerging technology product].

- “Imagine you meet someone and tell them you’re a _____, and they say ‘that’s interesting, what exactly is that?’ How would you reply? How do you describe what you do to other people?”
- How does your job fit in with the organization?
    - Who do you report to?
    - Do you supervise any positions?
    - Who do you collaborate with? How?
- What do you do?
    - What is a typical day like?
    - What is the first thing you do when you arrive at work? What do you do next? How do you end the day?
    - What are the main tasks you do?
    - What decisions do you make without approval?
- Which tasks are the most critical?
- How did you learn to do these tasks?
- Thinking about yourself or other technicians, when have you seen T task done very well?
    - What made it so effective?
- Done not so well?
    - What made it so ineffective?
- Under what conditions do tasks vary? (e.g., time of day, area, etc.)
- How do you know what you are doing each day?
- What tools, equipment, or resources do you use to get your work done?
    - How do you know what to use and when?
- What do people in your role (or you) get praised for? Criticized for?
- What is the hardest part of the job to learn?
    - What kind of training do you get?

    - What didn’t you know how to do when you started this job? How did you learn it?
    - What did you absolutely need to know how to do when you started the job?
- What is surprising about your job? (Conditions, tasks, things that make people quit, etc.)
- Do you expect the job to change at any point? If so, how?
- Is there anything we need to know about your job that we haven’t talked about yet?

Supervisors of Technician Roles:

Thank you for agreeing to speak with us today. I'm [name] with [organizational affiliation] and we are partnering with [relevant partners] to think about ways to address the difficulties of filling openings for middle skilled technicians manufacturing [name of emerging technology product].

I'll start off providing you a little more context for what the focus of this project is and then follow up with more specific questions for what I hope to learn from you given your experience/background.

Workforce availability typically lags technology and manufacturing readiness so steps to building a workforce need to begin earlier in the technology development process and manufacturing development process. We are therefore conducting an assessment to understand what the future manufacturing workforce needs are for creating [name of emerging technology product].

- Imagine you meet someone, and in telling them what you do, you mention that you supervise [technician]. They say 'that's interesting – what exactly is that?' How would you reply? How do you describe the job of [technician] to other people?
- What are the characteristics of effective technicians? What do they do differently and how do they do it differently?
- Think of someone you know who is better than anyone else at [task]
    - What is the reason they do it so well?
    - Can you tell me about a specific time someone did this well? What happened?
- Think of someone you know who struggles at [task]
    - What is the reason they struggle?
    - Can you tell me about a specific time someone did not do this well? What happened?
- What do technicians for [PC technology] need to do that is unique to [PC technology] (or that technicians manufacturing other technologies do not need to do)? What about [PC technology] requires this specific skill or characteristic?
- If you were going to have a new technician join your team, what would you need them to be able to do right off the bat?
- What would you expect them to learn in training that would make them more effective?
- What are the most challenging things to train technicians to do? What is the most difficult part of the job for new people to learn?
    - Are there prior experiences or training that the best technicians have?

- Where are the biggest issues in terms of technician performance generally? What do you wish technicians would do that they don't do consistently?
- What do you find yourself focusing on when you evaluate technicians? Where are the issues typically?
- What things are surprising to new technicians? Are there conditions or tasks they might not expect as part of the job?
- Is there anything we need to know about the job of [technician] that we haven't talked about yet?

Appendix C

Example Supervisor and Incumbent Items

Supervisors

Below are a list of competencies and skills that may be relevant to the position of ***Technician.*** Please indicate how important each competency and skill are for successful performance in this position and whether that competency or skill is needed at entry to this position using the scales below, and considering the behaviors associated with that competency or skill as relevant.

Importance: How important is this competency or skill for successfully performing the job of ***technician***? Consider the importance of each competency or skill for successful overall job performance, and its impact on ensuring that an employee in the ***technician*** position is able to perform the important and critical job tasks.

0 = Not important. This competency/skill is not important to successful performance.
1 = Minor importance. This competency/skill is of minor importance to successful job performance.
2 = Important. This competency/skill is important for successful performance.
3 = Critical. This competency/skill is essential to the job and is critically important to successful performance.

Needed at Entry: Is this competency/skill needed upon entry into this job? In other words, must an individual be competent in a particular area before entering the job, or is an individual expected to gain competence through training or experience on the job? Likewise, must an individual have this skill before entering the job, or are they expected to gain the skills through training or experience on the job?

0 = No. Successful job performance does not require proficiency in this area prior to entry. Competence in this area/this skill must be developed over time through training or experience on the job.

1 = Yes. Successful job performance requires this competency or skill prior to entry. Competence in this area/this skill is difficult to acquire and job demands require this competency soon after hire (for example, in the first week or so).

Competency Importance and Needed at Entry Evaluations

Competency	Importance (0 to 3)	Needed at Entry (0 to 1)
Competency 1		
Competency 2		
Competency 3		

Skill Importance and Needed at Entry Evaluations

Skill	Importance (0 to 3)	Needed at Entry (0 to 1)
Skill 1		
Skill 2		
Skill 3		

Incumbent
Below is a list of tasks that may be relevant to the position of ***Technician.*** Please indicate how important each task is for successful performance in this position and whether that task is needed at entry to this position using the scales below.

Importance: How important is this task for successfully performing the job of ***technician***? Consider the importance of the task for successful overall job performance.

0 = Not important. This task is not important to successful performance.
1 = Minor importance. This task is of minor importance to successful job performance.
2 = Important. This task is important for successful performance.
3 = Critical. This task is essential to the job and is critically important to successful performance.

Needed at Entry: Is this task needed upon entry into this job? In other words, must an individual be able to complete this task before entering the job, or is an individual expected to learn how to complete this task through training or experience on the job?

0 = No. Successful job performance does not require proficiency in this task prior to entry. Competence in this task must be developed over time through training or experience on the job.

1 = Yes. Successful job performance requires being able to complete this task prior to entry. Competence in this area is difficult to acquire and job demands require this task soon after hire (for example, in the first week or so).

Task Importance and Needed at Entry Evaluations

Task	Importance (0 to 3)	Needed at Entry (0 to 1)
Task 1		
Task 2		
Task 3		

Linkage Questions

Purpose: Our goal today is to learn more about the skills/competencies that are most important for accomplishing the critical tasks of this job. We will ask you to rate how useful skills/competencies are for performing sets of important tasks.

Below, we provide a description of each skill/competency and a list of the most critical tasks. Read through the competencies and rate how useful each skill/competency is for effective performance on each task.

Please use the following rating scale:

0 – Not Useful This skill/competency is not useful for effective performance of this task. Task performance is UNRELATED to this skill/competency.

1 – Of Little Use This skill/competency is of little use for effective performance of this task. Task performance is LIKELY to be effective even without this skill/competency.

2 – Useful This skill/competency is useful for effective performance of this task. Task performance is UNLIKELY to be effective without this skill/competency.

3 – Essential This skill/competency is essential for effective performance of this task. The task CANNOT be performed without this skill/competency.

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