MASTER

A method to enable ability-based resource allocation for runtime process management in manufacturing

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A Method to Enable Ability-based Resource Allocation for Runtime Process Management in Manufacturing

Master Thesis

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Abstract

Effective resource allocation is crucial for efficient management of business and manufacturing processes. Allocating the right resource to a task can lead to an increase in performance and significantly decrease the chance of errors. The current high-tech manufacturing environment and the corresponding focus on flexible production calls for more dynamic resource allocation. Here, allocating resources during runtime of a process as well as automatically allocating resources to tasks are considered important because they increase flexibility. Furthermore, this movement towards flexibility in manufacturing made personal characteristics arise as an important factor to base resource allocation decisions on because of their applicability to different contexts. The BPM domain offers various resource allocation methods that incorporate dynamic resource allocation. While personal characteristics are also deemed an important factor in these methods, no further specification or standardization of these characteristics is given.

While both manufacturing and BPM indicate that personal characteristics are an important factor to base resource allocation decisions on, there is no literature that attempts to provide a standardized way to define these personal characteristics. Consequently, the aim of this research is to develop a method to characterize tasks and operators based on personal characteristics such that automatic resource allocation is enabled. This is achieved by using a structured methodology to design a characterization method and verify whether this method enables automatic resource allocation.

The characterization methods designed in this research incorporates the Taxonomy of Human Abilities (Fleishman, 1975) to describe tasks and operators in terms of standardizes abilities. This characterization method is tested through a practical case study at Thomas Regout International (TRI). In collaboration with experts, a part of TRI’s process and corresponding operators are characterized in terms of abilities. This is followed by a verification of the method’s goal to enable automatic resource allocation. Using the process management platform Camunda, it is proven that the characterization data obtained from the designed method does enable automatic resource allocation. Furthermore, the TRI experts that participated in the case study were asked to evaluate the designed characterization method on the perceived ease of use, perceived usefulness and intention to use. The results of this evaluation were predominantly positive and it can be concluded that the characterization method is perceived as useful and usable. Finally, some interesting direction for future research are given regarding extension of the characterization method and its possible application to automated resources.

Keywords: resource allocation, human, characteristics, abilities, manufacturing, process management

Preface

And now it comes to a close. This master thesis marks the end of my dynamic career as a student. Originating in Groningen, one of the most vibrant student cities in the Netherlands, and ending in the smartest region of the world: Eindhoven, with many eye-opening experiences in between. This research can be considered the pinnacle of my work as a student, of which I am very proud. However, it would not have been possible without the support of others. Therefore, I would like to take this opportunity to thank some people.

First of all, I would like to thank my supervisors Irene Vanderfeesten, Jonnro Erasmus and Kostas Traganos for their guidance and support during the entire length of my project. The insightful discussions and positive, but critical, feedback sessions have helped me tremendously and motivated me to keep going. Our two-weekly sessions now come to an end, and I am definitely going to miss 'welcoming' you all to Irene her own office. So, one last time: "Hello and welcome!", and thanks for everything!

Secondly, I would like to thank TRI, and Ruud Keulen in particular, for providing me with the possibility to conduct a part of my project at their organization. Your extensive knowledge of manufacturing opened my eyes to the practical side of my research and helped me to make realistic expectations throughout the project. I really admire your flexibility and willingness to help students during their graduation project, even when they are not an intern at TRI. For that, I want to thank you!

Finally, I want to thank my roommates from our house 'Casa Romana' in Eindhoven and all of my other friends for their support. All being in the graduation phase of our master made it much more bearable. But most importantly, I am grateful for the awesome experiences and incredible adventures with you guys during my life as a student!

Xavier Jie-A-Looi
Eindhoven, October 2017

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1 Introduction

Resource management is an important topic within manufacturing and Business Process Management (BPM) because many business processes are not fully automated and require human interaction (Oberweis & Schuster, 2010). The proper selection and allocation of human resources improves performance and is therefore critical (Macris, Papadimitriou, & Vassilacopoulos, 2008). The current high-tech manufacturing environment moves toward a more flexible production environment. Here, smaller batch sizes and customized products are important targets. In reaching these targets, the manufacturing industry calls for more dynamic resource allocation. Automatically allocating resources to tasks and being able to do this *during* runtime of a process increases the flexibility of a manufacturing organization and are therefore desirable. Currently, resource allocation methods in manufacturing focus on allocation *before* runtime of the process where the allocation decisions are based on context specific characteristics (see e.g., Altuger & Chassapis, 2010; Koltai & Tatay, 2013). This limits the applicability of these methods to other contexts which is not desirable for a manufacturer that wants to move toward a more flexible production environment.

The BPM domain offers various resource allocation methods that incorporate dynamic resource allocation. These methods support automatic resource allocation (see e.g., Koltai & Tatay, 2013; Oberweis & Schuster, 2010) or focus on resource allocation *during* runtime of a process (see e.g., Cabanillas et al., 2013; Illibauer, Ziebermayr, & Geist, 2016). In these methods, the most commonly used factor to base allocation decisions on are personal characteristics (Arias, Munoz-Gama, & Sepúlveda, 2017). Personal characteristics are factors that are inherent to the resource and are commonly characterized as *competencies*, *skills* or *abilities*. Because these factors are inherent, their applicability is not limited to a single task but can be used in a range of tasks. While these personal characteristics are the most commonly used factors to base allocation decisions on, none of the resource allocation methods actually provide a detailed description of these characteristics. The methods only mention that personal characteristics like *competencies*, *skills* or *abilities* should be incorporated, but give no detailed specification or standardization for these factors (Jie-A-Looi, 2017). By not providing a detailed specification of these factors, the current resource allocation methods force the user to specify these themselves, leading to very context-specific factors and severely limiting the universal applicability of the method to other contexts.

The manufacturing industry's call for dynamic resource allocation and the lack of specified factors to base allocation decisions on in the BPM domain are the reasons why this research is conducted. By developing a method that enables automatic resource allocation based on detailed personal characteristics, this research aims to provide a universally applicable way to allocate human resources and support manufacturers on their way to a more flexible production environment. Consequently, the objective of this research is as follows:

The aim of this research is to develop a universally applicable method that enables automatic resource allocation of operators in a manufacturing environment based on personal characteristics.

1.1 Thesis Outline

The rest of this thesis is structured as follows. Section 2 describes the problem definition and the methodology of this research. This includes the scope, practical context, main and sub research questions as well. This is followed by Section 3, which provides background information regarding the topic of resource allocation. The decision on which factor is used in the characterization method is made in Section 4 by thoroughly analyzing several potential factors. Consequently, Section 5 describes the designed method to characterize task and operators in terms of human abilities. Through a step-by-step approach, characterization data can be obtained which enables resource allocation. This method is practically applied through a case study in Section 6. In this case study, part of an actual production process at a telescopic slide manufacturer is characterized in term of abilities. After the practical implementation, the method and the process of applying it is evaluated in Section 7. Finally, the conclusions of this research are provided in Section 8. This includes a discussion in which the contributions and limitations of this research are pointed out, and directions for further research are discussed.

2 Problem Definition & Methodology

This chapter describes the problem and context in more detail by elaborating on each section and describing the methodology used. As mentioned in the introduction, the research objective of this study is to enable automatic resource allocation of operators in a manufacturing environment based on personal characteristics. Resource allocation often consists of matching the required task characteristics with the possessed characteristics of potential operators (Jie-A-Looi, 2017). A visual representation of the resource allocation process is given in Figure 2-1.

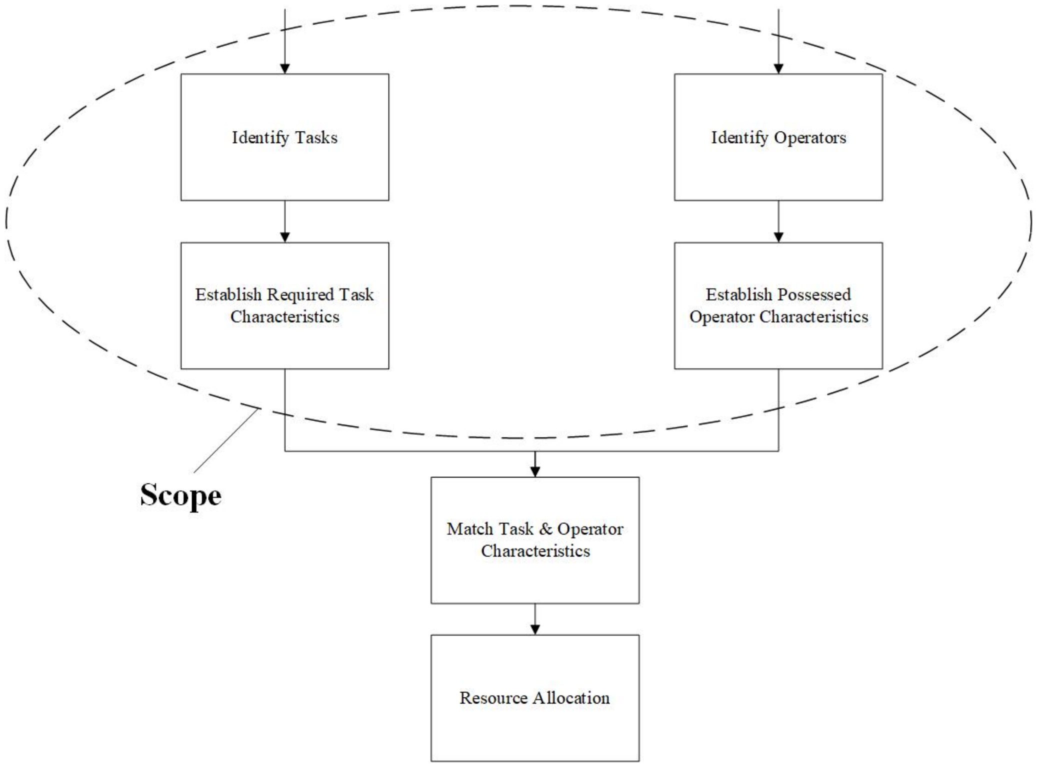

Figure 2-1: Resource allocation process of operators

As can be seen in Figure 2-1, the resource allocation procedure can start in parallel lanes where one lane focuses on the task and the other on the operators. At first, both the tasks and the potential operators for those tasks need to be identified. After the tasks to which operators need to be allocated are identified, the establishment of the required task characteristics and the operators' possessed characteristics needs to be performed. This is followed by the matching of these characteristics such that a match between task and operator is found. Consequently, this leads to the actual allocation of the operator to a certain task.

The focus of this research lies on the parallel part of the resource allocation process that involves the task and the operator. Establishing the required task and possessed operator characteristics is the main objective in this part of the process and is therefore the focus of the to-be developed method. This can be characterized as the scope of this research which is indicated by the dotted line in Figure 2-1 and will be further elaborated on in Section 2.4.

2.1 Problem Statement

Resource allocation in manufacturing currently is a topic of interest from both a practical and scientific perspective (see, e.g, Altuger & Chassapis, 2010; Campos Ciro, Dugardin, Yalaoui, & Kelly, 2016). Experts in manufacturing, however, point out that current practice shows that resource allocation of specific operators to tasks is often done in an ad hoc manner. This indicates that the resource allocation process is unstructured and relies on (predefined) knowledge of the operators' characteristics. This is in line with the findings of the literature study that preceded this research (Jie-A-Looi, 2017), where it is pointed out that resource allocation methods across different domains all rely on the user having knowledge of required/possessed characteristics beforehand (see, e.g., Altuger & Chassapis, 2010; Herfurth, Schuster, & Weiß, 2011; Koltai & Tatay, 2013; Koschmider, Yingbo, & Schuster, 2012). Furthermore, the factors that are used in resource allocation decisions are often only applicable in a certain situation (Jie-A-Looi, 2017). Literature indicates that this makes the process very context specific and not applicable to other situations (Oberweis & Schuster, 2010; Weiß, Schuster, & Weiß, 2010).These findings lead to the following problem statement:

Resource allocation of operators in manufacturing is currently done in an ad hoc manner and requires significant human effort. Furthermore, the factors on which the allocation decisions are based are very context specific and limit the applicability of the process in other situations.

2.2 Research Question

From the problem statement and the research objective, the following research question can be constructed:

How can personal characteristics be used to enable automatic resource allocation of operators in a manufacturing environment?

This research question covers the subject of this research to its full extent and aims to provide a solution to the problem statement. To increase understandability of the subject and elaborate on how each part of it will be addressed, the main research question in divided into sub questions. These sub questions are linked to the steps followed in the methodology and are therefore given in Section 2.5.

2.3 Practical Context

This research is done in the practical context of the HORSE Project[1]. The main objective of the HORSE project is to improve the collaboration between humans, robots, autonomous guided vehicles (AGV's) and machinery in small and medium manufacturing enterprises (SME's). The project has received funding from the European Union's Horizon 2020 research and innovation program, involves various (pilot) SME's and integrates research from numerous universities around Europe. Within the extensive

[1] http://www.horse-project.eu/

research area of the HORSE project, the Eindhoven University of Technology participates in analyzing the possibility of implementing Business Process Management (BPM) principles in the manufacturing industry. Combining this with (automated) resource allocation of humans in a manufacturing environment, one of the goals of the HORSE project, leads to the subject of this research.

One of the earlier mentioned SME's that is involved in the HORSE project is Thomas Regout International B.V.[2] (TRI). TRI is a telescopic slide manufacturer based in Maastricht, The Netherlands. Their involvement in the HORSE project can be characterized as extensive, allowing the testing of several pilot cases regarding subjects such as robotics, production line optimization and process modeling. For this research, TRI has provided their production process as a pilot case. This enables practical application of the method that will be constructed in this research to provide a more structured way of allocation operators. Further elaboration on the incorporation of TRI's process in this research is given in Chapter 6.

2.4 Scope

Resource allocation is a process that can incorporate various factors depending on the context it is conducted in. To be able to conduct structured research which leads to useful results, scoping of the subject is required. This section elaborates on the scoping decisions made, related to the stakeholders, when conducting this research.

Looking at current practice, the allocation of resources within manufacturing firms can be done by a variety of people. This is dependent on factors like: which resources need to be allocated and how detailed does this allocation need to be? For instance, a resource in manufacturing firms can be can be defined as a shift of operators, operator team, or specific operator. Each of them add value to the firm on a different hierarchical level and need to be allocated to tasks. When looking at a shift of operators, there often is no distinction between the operators, which means that they assigned as a group to the part of an order that covers their shift. In this situation, the *planner* often performs the resource allocation. A shift of operators consists of several operator teams which, in turn, have to perform parts of the production process. The teams are often allocated by *operation managers* because of their knowledge of the entire process and the required team characteristics for an order. Lastly, the allocation of specific operators to specific tasks is often done by *team leaders*. These leaders have knowledge of each operators' abilities and the requirements of specific tasks.

The method that is constructed in this research focuses on the allocation of specific operators to specific tasks. This is done through characterization and categorization of tasks and operators beforehand. Given that this requires extensive knowledge of both the process and the operators, the

[2] http://www.thomasregout-telescopicslides.com/

main stakeholders in the method will be *operations managers* and the *team leaders.* This leads to the decision to design the method in this research with these two stakeholders as main users.

2.5 Methodology

To be able to reach the research objective, a design science research as defined by Gregor & Hevner (2013) is performed. As stated in the research objective, the focus of this research is to develop a method to enable automatic resource allocation of operators in a manufacturing environment based on personal characteristics. This method is constructed using the regulative cycle from van Strien (1997) as a base methodology, adjusting it to fit the scope of this research. The regulative cycle of van Strien (1997), as depicted in Figure 2-2, is a cycle consisting of five steps. These steps are performed sequentially and the main focus of the cycle lies on the iterative process which should be followed, aiming to use an identified solution as input for new problem identification and starting a new cycle. For this research, the regulative cycle is adjusted to fit the specific requirements. A more detailed representation of the exact methodology used for this research is given in Figure 2-3. For the most part, the methodology used for this research is identical to the regulative cycle of van Strien (1997). Due to time constraints in which this research needs to be performed, only one iteration of the cycle will be conducted. Whereas five phases of this research's methodology are identical to the original cycle, and extra phase is added: *Verification.* After the design is implemented, the designed method's contribution to this research's goal is verified. The reason for including this extra phase is that the objective of this research is not reached by the designed method only. While the designed method will be the focus of this research, it's goal of enabling resource allocation must not be overlooked. Therefore, the extra verification phase is added to the original methodology to provide the reader with a more complete overview of the subject. An overview on each of the steps is given in the following sections elaborating on the performed actions and giving the research questions.

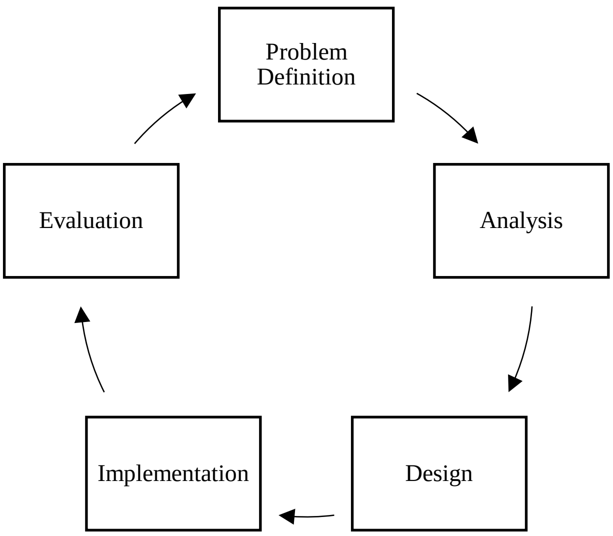

Figure 2-2: Original Regulative Cycle (van Strien, 1997)

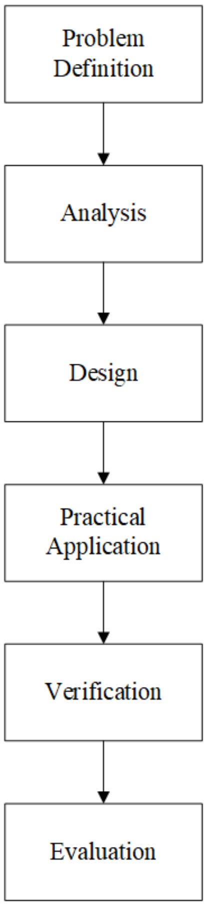

Figure 2-3: Adjusted methodology based on van Strien's Regulative Cycle

2.5.1 Problem Definition

In the first phase of the methodology, Problem Definition, the main problem is addressed. Through a preliminary literature study by Jie-A-Looi (2017), the current practice of resource allocation is analyzed and future research opportunities are defined. These findings, combined with extensive talks with experts throughout the various domains involved, lead to a problem statement, research questions and the definition of the methodology of the research. These deliverables are captured in Section 2 of the report.

Furthermore, an elaboration on the topic of resource allocation is given in a separate section of this thesis. Here, the following research question will be answered:

Q1. Which type of resource allocation can be considered when designing a method to enable allocation of human operators in a manufacturing environment?

This first research question will focus on the topic of resource allocation specifically and elaborates on the type of resource allocation that is considered in this research. Partly covered in the preliminary literature review by Jie-A-Looi (2017), an overview of several types of resource allocation, including resource allocation methods, will be given which can lead to useful insights into what factors are considered in the design of this research's method. This background information is given in Section 3.

2.5.2 Analysis

In the Analysis phase, more knowledge and insights into the subjects related to this research is obtained. Whereas this is partly covered by the Problem Definition phase, the Analysis will provide more information regarding the personal characteristics on which the resource allocation in this research is based.

Q2. Which type of personal characteristics can enable resource allocation and how can they be incorporated in the process of allocating resources?

This research question addresses the concept of personal characteristics, which plays a vital role in this research. Through the analysis of literature on this subject, more insights into the incorporation of personal characteristics into resource allocation is obtained. Several interviews with experts in the Human Performance Management domain will also contribute to answering this research question. From this analysis, a decision about which human factor to include in the design is made. These deliverables are given in Section 4.

2.5.3 Design

After providing more in-depth background information regarding the subjects of this research the design for the method will be developed.

Q3. How can tasks and operators be described to enable resource allocation of operators in a manufacturing environment?

This phase focusses on creating an initial design of the method to enable resource allocation. Using the insights obtained from the Analysis phase, a step-by-step approach is created to identify task and operator characteristics in terms of personal characteristics. This is followed by a verification of the method's goal to enable resource allocation of operators in a manufacturing environment. Further elaboration on this phase is given in Section 5.

2.5.4 Practical Application

After the design phase, the method will be practically applied through a case study at TRI.

Q4. Can the designed method be used to characterize tasks and operators in a practical manufacturing environment?

Through interviews with several experts in operations and human resource management at TRI, a case study is conducted. This study will be performed on a part of the production process of TRI where the designed method will be tested on its practical applicability. An extensive elaboration on this case study is given in Section 6.

2.5.5 Verification

This added phase of the methodology focusses on verifying whether the designed method adheres to its goal of enabling resource allocation using the method's characterization data.

Q5. How can the characterization data obtained from the method be used such that it enables resource allocation of operators in a manufacturing environment?

Using Camunda, a business process management platform which can be used to model and manage workflows, both a conceptual manufacturing process and the TRI process used in the case study are created and executed. By doing this, the concept of automatically allocating resources as well as its practical applicability can be verified in line with the research objective. This is covered in the Sections 5.2 and 6.5 respectively.

2.5.6 Evaluation

In the concluding phase of the methodology, the method and its application procedure at TRI are evaluated.

Q6. Is the designed method useful/usable in characterizing tasks and operators in a manufacturing environment?

The method will be evaluated on its ease of use, usefulness and intention to use as described in the Method Evaluation Model by Moody (2003). Determining these factors is done in collaboration with potential users of this method to obtain a constructive review of the methods practical application. The evaluation is covered in Section 7.

3 Background information

In this section, more background information regarding the topic of resource allocation is given. Through scientific literature, resource allocation is defined and several types are elaborated on. Furthermore, examples of existing resource allocation methods are given to obtain insights in current practice and relevant factors. The aim of this section is to provide a better understanding of the concept of resource allocation and the scoping decisions made in this research.

3.1 Resource Allocation

Resource allocation can be characterized as the process of allocating an entity that is capable of doing work to a task. This entity is either classified as a *human* or *non-human*, whereas a human correspond to an actual person and a non-human to an entity such as a plant or a piece of equipment (Russell, van der Aalst, ter Hofstede, & Edmond, 2005). In this research, operators in a manufacturing environment are described as the resource. Since these operators are actual persons, the resource allocation in this research can be classified as *human* following the definition of Russell et al. (2005).

Next to the classification of the resource, the way in which tasks can be allocated for execution is essential to understand which type is used. Using an example presented by Russell, ter Hofstede, Edmond & van der Aalst (2005), different types of resource allocation are given. Figure 3-1 illustrates the lifecycle of a work item in the form of a state transition diagram from creation of the task until completion. The first part of the diagram is particularly interesting because it gives several options for allocating this task to a resource. Under the assumption that a task can be executed by a single resource, Russell et al. (2005) indicate that there are three options to allocate the created task. The task can be *offered to a single resource,* where only a single resource is notified about the availability of a task. This resource can consequently decide whether to accept the offered task depending on its availability and qualification. Secondly, the task can also be *offered to multiple resources*. This state is similar to the previous one whereas the only difference is that the task is made available to various resources of which one can decide to accept it. Lastly, the task be *allocated to a single resource*. This

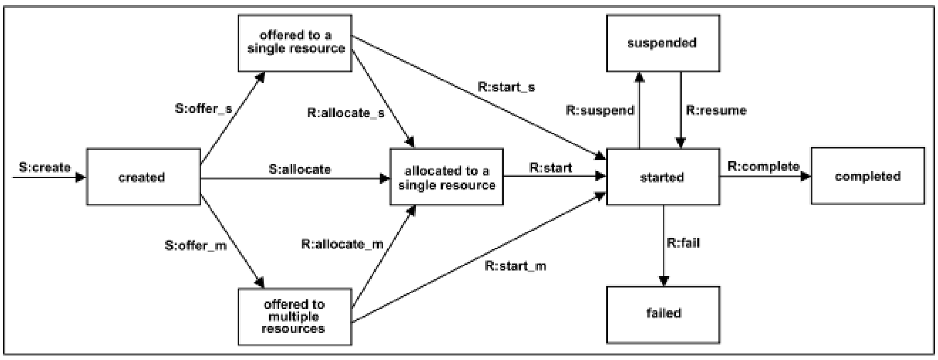

Figure 3-1: Work Item Lifecycle (Russell, ter Hofstede, et al., 2005)

implies that the task is directly allocated to a specific resource. It is assumed that the resource is always available or the option of choosing whether the resource wants to accept the task is not presented. This means that the resource to which the task is allocated starts the execution of this task. The type of resource allocation on which this research aims to enable can be classified as *allocated to a single resource.* The method designed in this research aims to provide the most optimal match between task and operator and therefor providing the person responsible for allocation with the best operator to allocate to the task. Even though other allocation options could be explored after applying the designed method, the goal is to provide the optimal allocation option to the user.

Several resource allocation methods using this type of resource allocation have been analyzed in a preliminary literature study by Jie-A-Looi (2017). In this study, an overview of methods from both the manufacturing domain as well as the BPM domain are given. A clear distinction is made between resource allocation methods that deal with allocation problems *before* and *during* the run time of a process. This indicates that the resource allocation can either be done beforehand, so that the resources are allocated to tasks before the process starts, or can occur while the process is running, in the case of replacements or breakdowns.

Examples of methods designed to deal with resource allocation *before* runtime are the Resource Modeling Language based meta models by Herfurth et al. (2011) and Koschmider et al. (2012), focusing on creating predefined competency profiles for tasks and operators to enable allocation through matching. These competency profiles can be used on different hierarchical levels such that individuals as well as function groups can be described. While the authors stress the importance and universal applicability of using competencies, no further explanation is given on determining them. In this context, the competencies are a type of human factor on which the resource allocation is based. Human factors, in the form of competencies, are also used by Oberweis & Schuster (2010) and Schuster & Weiß (2010). In their so-called resource, meta-model (RMM) they use a predefined competency framework called the European Framework for e-Skills and competencies (e-CF) to create competency profiles. This framework included competencies like *personnel development, needs identification* and *process improvement.* While on an organizational level and applicable to the information and communications sector, the authors show the potential of using a predefined framework for a structured, robust and universally applicable way of characterization.

This characterization of tasks and individuals also returns in the methods that deal with resource allocation problems *during* runtime of a process. Both Illibauer, Ziebermayr & Geist (2016) their Dynamic Resource Allocation based method and the prioritization method proposed by Cabanillas et al. (2013) are resource allocation methods based on predefined characterization of operators and tasks. While the first method focusses on re-allocating resources and the latter on prioritizing potential performers of a task, both require task and operators to be characterized such that through matching the right allocation decision can be made. While the authors do not specifically point out human factors as characteristics on which resource allocation can be based, they would still fit in as usable factors.

Recently, Arias, Munoz-Gama & Sepúlveda (2017) aimed to provide a more holistic overview of the criteria which can be used in human resource allocation. The criteria taxonomy created in this study is given in Figure 3-2 and contains a wide variety of factors such as *experience*, *expertise*, *previous performance* and *social context* among others. From these factors, the authors point out that *expertise* is one of the most frequently used criteria to base resource allocation decisions on. This is in line with the findings from the previously discussed specific resource allocation methods that mainly include competencies in their process. Arias et al. (2017) also include competencies in their definition of *expertise*, next to cognitive factors, skills and knowledge. Even though the definition of the factors used in the specific models and the overview are not completely aligned, it can be concluded that throughout the literature factors related to humans are deemed important and are frequently used in resource allocation. Interestingly, these factors are not properly defined and no further elaboration on how these factors can be incorporated in the resource allocation procedure is given. The analysis phase of this research therefore focusses on the selection of a specific appropriate human factor to include in the to-be designed characterization method. The consequent Section 4 will elaborate on this process.

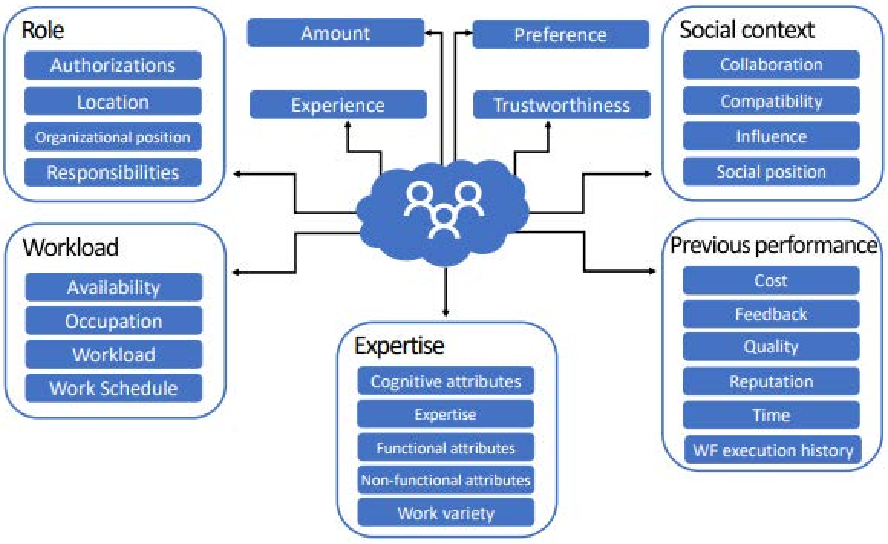

Figure 3-2: Taxonomy of allocation criteria (Arias et al., 2017)

4 Analysis

Looking at the title of this research, 'ability-based' resource allocation is addressed as the focus of this research. This implies that *abilities* are chosen as the factor on which the resource allocation decisions in this research are based. The decision to include *abilities* in this research is elaborated on in this section. Furthermore, the specific *abilities* that are used are more thoroughly explained using literature, providing the deliverables which function as input for the method design.

4.1 Personal Characteristics

As mentioned in Section 1 and 3 of this thesis, personal characteristics are the most commonly used factor to base resource allocation decisions on in the BPM domain (Arias et al., 2017). Looking at the literature, resource allocation methods characterize these personal characteristics in one of the three following factors: *skills*, *abilities* and *competencies.* Considering the aim of constructing a universally applicable method, *skills* are deemed too task-specific and *competencies* too operator-specific. Therefore, the decision is made to include *abilities* as the factor on which the resource allocation is based. A more detailed elaboration on why this decision has been made is given below.

While most factors are easily distinguishable from each other, the factors *skills*, *abilities*, and *competencies* often cause confusion regarding their definition. Each of these three personal characteristics factors can be used to describe jobs and resources, but there are some fundamental differences between them when looking at the level of generalization they provide. *Abilities* can be defined as relatively enduring attributes of an individual's capability for performing a range of different tasks (Carroll, 1993; Fleishman, 1982). They are regarded as traits in that they exhibit some degree of stability over relatively long periods of time. It is recognized, however, that abilities may develop over time and with exposure to multiple situations (Snow & Lohman, 1984). The fact that abilities are fairly stable over time and are generalized to be able to describe individuals with regards to a particular range of tasks makes this factor a suitable choice for this research. It enables the method to be universally applicable while maintaining enough specificity in describing operators and tasks to enable resource allocation.

Skills, on the other hand, can be characterized as specific situational traits that are largely dependent on learning and represent the product of training in particular tasks (Peterson, Borman, & Mumford, 1999). Combining this with the definition of *competencies*: underlying characteristics of an individual which are causally related to effective or superior performance in a wide range of jobs

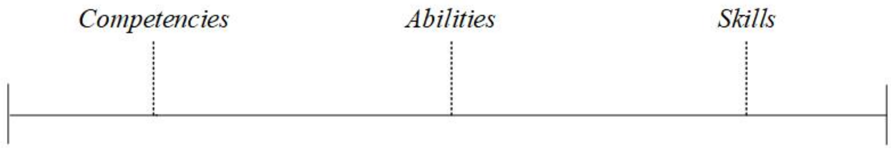

Figure 4-1: Factor generalization spectrum

(Boyatzis, 1983), a clear distinction in generalization can be seen Figure 4-1. *Skills* are situated on the far right-side of the spectrum, indicating that they are very context specific. Incorporating factors that are very context specific limits the universal applicability of the method, one of the main objectives of this research.

In comparison with skills, *competencies* are formulated very generally which enables usage in a multitude of situations. Cardy & Selvarajan (2006) for example, characterize competencies as the combination of an organization's resources and capabilities that are the source of strategic competitiveness. This clearly indicates that competencies are often used on organizational level. The focus of this research, however, is to still enable resource allocation of specific operators to specific tasks. *Competencies* are not suitable for such specific resource allocation targets and have therefore not been incorporated in this research.

This section concludes an important scoping decision of this research where the decision to include *abilities* as the personal characteristic in this research is made. Being the main factor included in the to-be designed characterization method, an extensive elaboration on its definition, the specific abilities and their assessment is given in the next section.

4.2 Human Abilities

As mentioned in the previous section, Human abilities can be defined as relatively enduring attributes of an individual's capability for performing a particular range of different tasks (Peterson et al., 1999). The words 'relatively enduring' and 'particular range' depict a specific focus on generalization in this definition. Generality is an important topic in determining how to describe the constructs used to describe differences in human abilities (Peterson et al., 1999). Constructs like "mental abilities", "problem solving abilities" and "agility" have turned out to be too broad and the tasks required by such broad categories are too diverse. On the other hand, constructs like "lift barbells of a given weight" or "solve quadratic equations of a given complexity" are specifically orientated on a situation and are therefore not very descriptive of an ability trait that extends to performance in a variety of task that require the same ability (Peterson et al., 1999). These examples illustrate that the proper definition of a construct is essential in capturing the right generalization.

It is clear that specifying abilities properly is essential in capturing the right characteristics in a specific situation. In the context of this research, the context in which abilities are used is that of resource allocation. Abilities function as the variables on which the resource allocation decisions are based. This is similar to the Capability-based allocation as described by Russell, ter Hofstede, et al. (2005). They describe this type of allocation as "The ability to offer or allocate instances of a task to resources based on specific capabilities that they possess". Russell, ter Hofstede, et al. (2005) suggest that for this type of allocation, a dictionary of capabilities should be defined in which individual capabilities have a distinct name and the type and potential range of values that each capability may take can also be specified. This approach will also be used in this research, where abilities will function as the capabilities on which the resource allocation is based. In using this type of allocation however, a common issue arises. Determining the proper resource to allocate to a task based on abilities can lead to an outcome where more than one resource is deemed capable of performing this task. As mentioned in Section 3.1, this research focusses on *allocating a task to a single resource*. As such, the aim of this research is to provide one optimal resource allocation decision. Russell, ter Hofstede, et al. (2005) propose a solution for the given issue by stating that through an extensive and detailed definition of the used capabilities the chances of finding an optimal solution significantly increase. In line with this reasoning, it has been decided to use an extensive taxonomy of human abilities in this research to characterize the operators and tasks. This taxonomy will be further elaborated on in Section 4.2.1.

4.2.1 Human Ability Taxonomy

Following Peterson et al. (1999) their description of how a construct to describe differences in human abilities should look like, various researchers have proposed theories and taxonomies describing humans in terms of abilities. Throughout the 20th century, a lot of focus has been put into describing abilities related to performance in the cognitive area of human performance (see e.g., Carroll, 1993a; Cattel & Horn, 1978; Guilford, 1956; Spearman, 1931; Thurstone, 1938). While cognitive abilities are described extensively, the issue that there are several other human ability categories that are relevant to performance arose. Edwin A. Fleishman took up this challenge to further research human abilities and to include other categories next to the present cognitive ones.

The Taxonomy of Human Abilities (Fleishman, 1975) is the result of Fleishman’s extensive collaboration with various researchers. The taxonomy that has been developed enables job description based on abilities in a multitude of different jobs and sectors. It consists of 52 ability constructs, which are divided into four subcategories. Next to *cognitive* abilities, Fleishman has included *psychomotor*, *physical* and *sensory* abilities in the taxonomy as well. As the first category, *cognitive* abilities represent the general intellectual capacity of a person. Secondly, *psychomotor* abilities are abilties that combine cognitive and physical traits dealing with issues of coordination, dexterity and reaction time. *Physical* abilities such as strenght and stamina focus solely on the muscular traits of a person. Lastly, *sensory* abilities are the physical functions of vision, hearing , touch, taste, smell that are related to a persons senses (Landy & Conte, 2007). Figure 4-2 gives an overview of the taxonomy including the four subcategories. For each category, four abilities are listed to better visualize the content. The complete

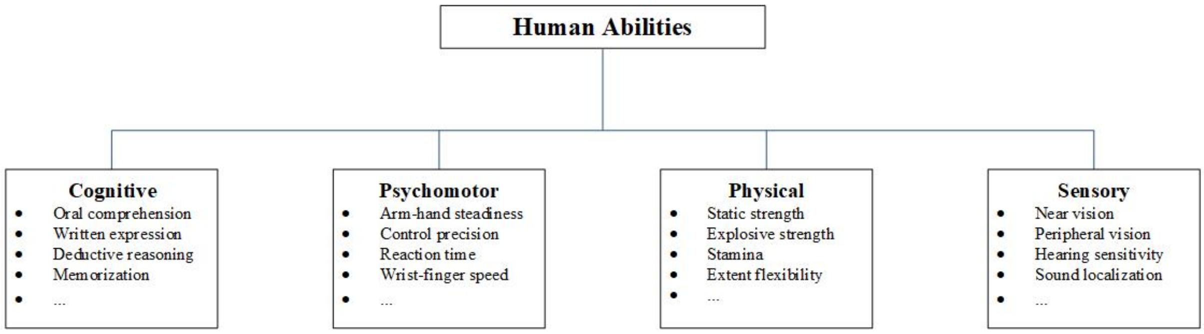

Figure 4-2: Taxonomy of Human Abilities (partially) based on Fleishman (1975)

Taxonomy of Human Abilities is given in Appendix I. There, each of the 52 abilities of the taxonomy are listed and described. This overview also includes a level rating with corresponding task examples to indicate when a person possesses the ability on a high or low level. The level rating is part of a measurement scale used to determine on which level a person possesses the ability or what level of a certain ability is required for a task. This measurement scale will be further discussed in the next section.

As is stated earlier in this chapter, the Taxonomy of Human Abilities is orginally designed to describe jobs in terms of human abilities. This type of characterization will also be applied in this research but in a different context, that of specific tasks and operators. The method that is designed in this research incorporates this taxonomy into the characterization process of both the tasks and operators. The main reason for doing this is that the Taxonomy of Human Abilities is a very comprehensive taxonomy that incorporates various types of abilities. In contrast to the previously mentioned taxonomies that mainly focus on *cognitive* abilities (Carroll, 1993a; Cattel & Horn, 1978; Guilford, 1956), the added *psychomotor*, *physicial* and *sensory* abilities are very relevent for the context of manufacturing as well. Furthermore, the Taxonomy of Human Abilities is widely used in human performance studies (see e.g., Kanfer & Ackerman, 1989; Stajkovic & Luthans, 1998) as well as being the foundation of a part of the United States' primary job description database O*NET[3] developed by Peterson, Borman & Mumford (1999). This confirms that the Taxonomy of Human Abilities is extensively used and has proven its value, both academically and practically. More information on how the taxonomy is incorporated in the designed method is given in Section 5.1.

4.2.2 Assessing Human Abilities

As mentioned in the previous section, the Taxonomy of Human Abilities presented in Appendix I includes a level rating that is part of a measurement system. As with the taxonomy, this measurement system has been developed to evaluate the ability requirements of various jobs to create job descriptions. Fleishman designed this measurement system, called the Fleishman Job Analysis Survey (F-JAS) (Fleishman & Reilly, 1992), such that experts can determine if an ability would be necessary for a job, how important this ability is for a certain job, and on what level the ability is required. This can be done for each of the 52 abilities present in the Taxonomy of Human Abilities.

[3] https://www.onetcenter.org/overview.html

Figure 4-3 shows the F-JAS for two arbitrary abilities; *written comprehension* and *static strength.* At the top of the F-JAS, the specific ability and its description is given. This is followed by two measurement scales; one to measure the *importance* of the ability (A) and one to measure the required *level* of an ability (B). The *importance* of an ability can be measure on a 5-point Likert scale and is particularly interesting when using job descriptions for recruitment or when creating vacancies. By comparing the possible applicants' abilities with the importance of a required ability, a recruiter can determine whether the applicant is suitable for the job. The goal of this research however, is not to use job/task description for recruitment purposes but rather for allocation of already employed operators. Therefore, the method designed in this research does not incorporate the *importance* in its characterization process and only focusses on the required *level* of an ability. The required *level* can be measured on a 7-point Likert scale, indicating to what extent a certain ability must be possessed by an individual. The F-JAS provides the user with three so-called *reference anchors* to assist in determining the required level. This measurement scale will be incorporated in the method designed in this research to help determine the required abilities for a certain task. Even though the focus of the F-JAS lies on describing jobs/tasks, the same measurement will be used to describe possessed operator abilities. While this is not the original application of the F-JAS, the abilities from the Taxonomy of Human Abilities are designed to describe a human in relation with a job. Furthermore, the *anchors* present in the F-JAS are also sufficiently applicable in measuring the ability level an operator possesses.

The complete F-JAS is included in this report in Appendix II and more detailed information on how the F-JAS is incorporated in the designed method is given in Section 5.1.

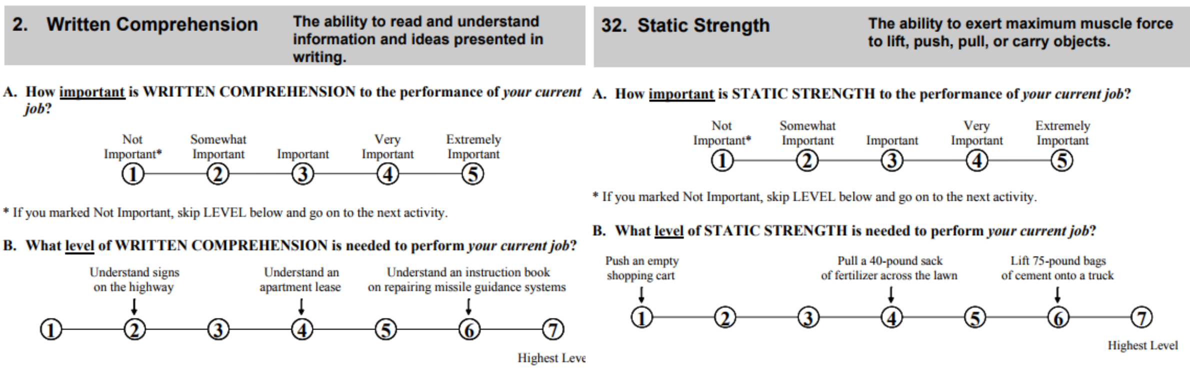

Figure 4-3: F-JAS for two arbitrary abilities

5 Characterization Method

This chapter elaborates on the initial design of the characterization method and is followed by a verification of the method's goal to enable automatic resource allocation. This provides an answer to the third research question: *How can tasks and operators be described to enable resource allocation of operators in a manufacturing environment?* Looking back at the objective of this research, the goal of the method is to enable automatic resource allocation of operators in a manufacturing environment based on personal characteristics. This is done by incorporating the Taxonomy of Human Abilities of Fleishman (1992), as described in Section 4.2.1, into the method. The characterization through this taxonomy is done for each task where dynamic resource allocation is desired and for each of the potential operators individually; leading to a detailed overview of the process and enabling the allocation of operators.

The remainder of this chapter is structured as follows, Section 5.1 describes the initial design of the method consisting of design decisions in Section 5.1.1 and a stepwise explanation of the method for both task and operator characterization in the Sections 5.1.2 and 5.1.3 respectively. Finally, the method's goal of enabling automatic resource allocation is verified in Section 5.2 using the process management tool Camunda.

5.1 Method Design

As Section 2 pointed out earlier, allocating operators to tasks can be done by matching required task characteristics with the operators' possessed characteristics. Before this can be done, task and operator characteristics must be determined. The method designed in this research enables the user to do this, and consequently make resource allocation based on this characterization possible. A visualization of this process is given in Figure 5-1, where the designed characterization method is represented by the two squares. This clearly indicates that the method consists of two separate procedures which are captured in Sections 5.1.2 and 5.1.3. The Taxonomy of Human Abilities and the F-JAS, discussed in Section 4.2, will form the foundation of both the task and operator characterization. This can be seen in both methods' steps related to determining the required/possessed abilities and their level. The F-JAS

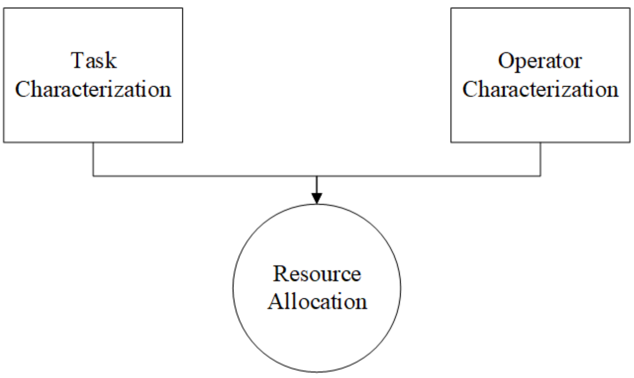

Figure 5-1: Characterization method

original design is coherent with this procedure, whereas only the context in which it is applied changes; resource allocation.

5.1.1 Design Decisions

This section describes the design decisions made regarding the characterization method. These decisions function as conceptual guidelines which the method follows and are given below:

- Universally applicable for different manufacturing processes
- Follow the ability assessment procedure of F-JAS
- Characterization based on abilities should be detailed enough to distinguish tasks
- The user should obtain the task/operator characteristics in a format which can be easily used for other purposes

These design decisions are determined such that the method adheres to the main research objective of developing a universally applicable method to enable automatic resource allocation of operators in a manufacturing environment based on personal characteristics. This includes the emphasis on a structured and scientific way of characterizing tasks and operators while keeping in the goal of allocating specific operators to tasks in mind. Finally, the application of the data obtained does not necessarily have to be limited to the goal of allocating resources. Therefore, the characterization data should be presented in a format that could possibly be reused for other purposes.

5.1.2 Task Characterization

The characterization of the tasks is done through a five-step method. In this process, a specific task is singled out and analyzed to enable characterization in terms of abilities. After the required task characteristics are determined, the data is stored for further use in the consequent resource allocation process. This process can be iterated to more than one task in the process. An overview of the method for task characterization is given in Figure 5-2.

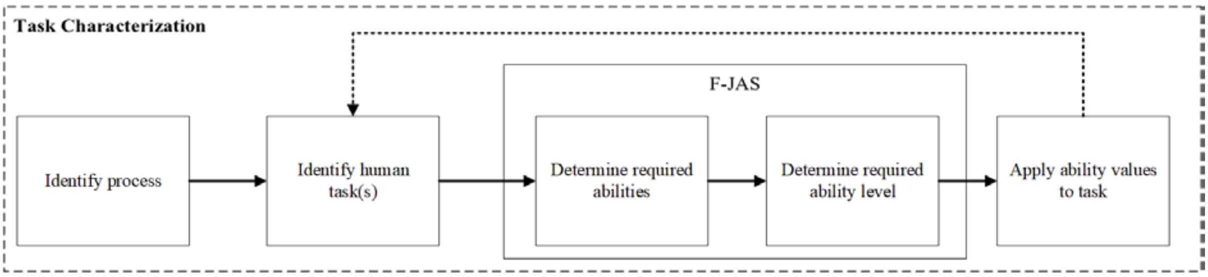

Figure 5-2: Stepwise overview of task characterization

Step 1: Identify Process

The first step of the method consists of identifying the process. While the aim of the method is to enable resource allocation to specific tasks, the tasks are often part of a bigger process. At this step, the user identifies and selects the process which contains the tasks to which resource allocation is needed. This selection forms the scope of the method execution and enables to user to perform the rest of the steps for each task individually.

There are some things to keep in mind when selecting the process for further analysis. The user needs to make sure the process is properly described or modeled to enable proper execution of the rest of the method. If not, the user should aim to make sure to this first before moving to specific task characterization. This includes proper scoping of the process, which is essential for proper execution of the method. For example, processes often consist of several different tasks of which are partly automated and do not need human resource allocated to them. These prerequisites are essential for the consequent steps and ultimately allocate specific operators to tasks for the entire process.

Figure 5-3 represents a process the user could identify during step 1. This process is called “Manufacturing Process X” and consists of 3 tasks. This process will act as an example to further illustrate each of the consequent steps.

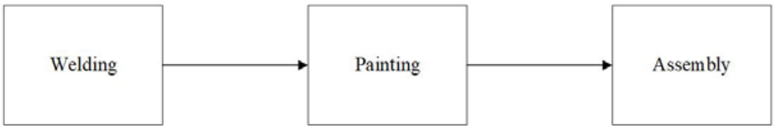

Figure 5-3: Manufacturing Process X

Step 2: Identify Task(s)

The second step of the method consists of identifying a specific task to which human resource allocation is required. After completing Step 1 and identifying the process, the user selects a specific task from this process. The rest of the method will solely focus on characterizing this specific task. Looking back at the example of “Manufacturing Process X”, the user can pick one of the three tasks. Let’s say that the “Welding” and “Painting” is done automatically and do not need an operator allocated to them. “Assembly” however, does need an operator assigned to it, so the user picks this task in Step 2.

Step 3: Determine Required Abilities

Arriving at the third step of the method, characterization of the task can commence. This process consists of Step 3 and 4 and results in a task being characterized in terms of the abilities included in the Taxonomy of Human Abilities by Fleishman (1975). As described in Section 4.2.1, the taxonomy consists of 52 abilities divided into four categories: cognitive abilities, psychomotor abilities, physical abilities and physical abilities. Tasks rarely require all 52 abilities and the user needs to determine which of these 52 abilities are required for a task. This requires an overview of the task, extensive knowledge of the task requirements and the ability to define these specific requirements in terms of the taxonomy’s abilities.

For instance, the “Assembly” task picked by the user in step 2 consists of assembling several parts of a product according to a graphical example on paper in a noisy manufacturing environment. This requires the *verbal* ability *written comprehension* but does not require *oral comprehension, oral* *expression* or *written expression*. Eliminating the unnecessary abilities provides the user with a list of abilities that are required for a specific task and reduces the complexity of the characterization. Returning to the assembly example, the list of required *cognitive* abilities for this task could look like this:

- *1. Written Comprehension*
- *7. Memorization*
- *10. Number Facility*
- *13. Information Ordering*
- *14. Category Flexibility*
- *17. Spatial Organization*
- *18. Visualization*
- *20. Selective Attention*

Once it is determined which abilities are required, the user can continue the characterization process through Step 4.

Step 4: Determine Required Ability Level

Since one of the design decisions is to make sure that tasks are distinguishable from each other when using the taxonomy of abilities, only determining whether an ability is required or not does not provide a comprehensive enough overview. To be able to enable resource allocation in the end, the level of the required abilities should be determined. This enables more detailed characterization which, in turn, will lead to more accurate allocation.

The user can determine the required level of an ability by using the Fleishman Job Analysis Survey (F-JAS) as described in Section 4.2.2. Previously, Step 3 provided the user with a list of the required abilities for the given task. For each of these abilities, a corresponding 7-point Likert scale exist in the F-JAS. The user should critically evaluate the minimum ability level required for the task where the anchors present on the scale act as reference. Applying this to the assembly example from the previous step, the result could look like this:

- *1. Written Comprehension* 3
- *7. Memorization* 2
- *10. Number Facility* 2
- *13. Information Ordering* 4
- *14. Category Flexibility* 2
- *17. Spatial Organization* 2
- *18. Visualization* 4
- *20. Selective Attention* 3

Once all the required abilities have been assigned a minimum value using the F-JAS, the user can move on to Step 5.

Step 5: Apply Ability Value to Task

This step concludes the task characterization method and brings the obtained data together indicating the minimum ability level requirements for a task. The user has determined what abilities are required for the task and what the minimum required level should be. Consequently, the user should store this data into software like Microsoft Acces or Microsoft Excel for further use. The data should be properly stored such that it is clear which tasks requires what abilities with a minimum ability level. This database will act as input for the allocation of operators by matching the required abilities for the task with the possessed abilities of potential operators. Applying this to the "Manufacturing Process X" example will result in an overview as presented in Table 5-1.

Process: Manufacturing Process X		**Task:** Assembly	
Ability Category: Cognitive Abilities			
Required Ability	**Level**	**Required Ability**	**Level**
1. Written Comprehension	3	*14. Category Flexibility*	2
7. Memorization	2	*17. Spatial Organization*	2
10. Number Facility	2	*18. Visualization*	4
13. Information Ordering	4	*20. Selective Attention*	3

Table 5-1: Overview of the required task characteristics of the task 'Assembly'

After the last step of the method, the user has the possibility to iterate the process by returning to step 2 and identify the next task in the process. This way, the user can assign the required task characteristics to all the tasks of a process such that resource allocation of the entire process is enabled.

5.1.3 Operator Characterization

As mentioned in Section 5.1, resource allocation requires both task characteristics and operator characteristics to be matched. This section explains the process of determination of operator characteristics. The same five step approach as the task characterization is used, which has been tailored to identify the operator characteristics. Globally, the method consists of identifying the potential operators, which is followed by the selection of a specific operator. Consequently, the operator's possessed abilities and their level are determined. Finally, this information is stored for further use in the resource allocation process. As with the characterization of tasks, this method should be iterated for all the potential operators of a task to ensure proper allocation of resources afterwards. An overview of the method to characterize operators is given in Figure 5-4.

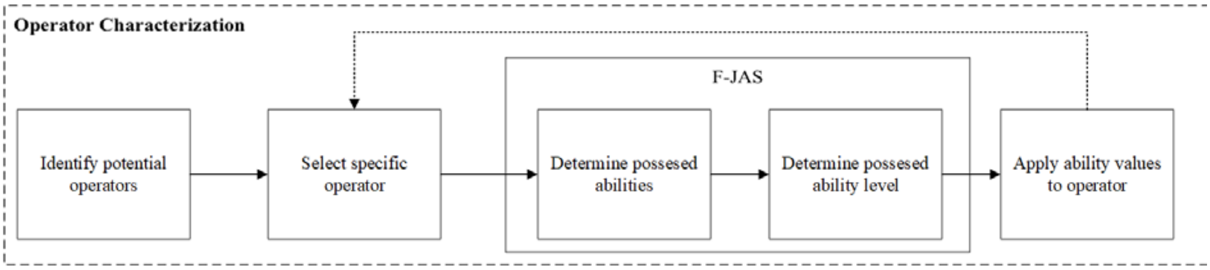

Figure 5-4: Stepwise overview of operator characterization

Step 1: Identify Potential Operators

The first step of the operator characterization method consists of identifying potential operators. The potential operators of a process are all the operators that are available and authorized to work at a certain process at a certain time. An example would be all the operators that are part of the department to which the process belongs, or the pool of operators that work during a certain time shift. The user should carefully create an overview of these potential operators to ultimately enable the matching of task and operator characteristics. As with the previous task characterization method, an example is provided to illustrate the output of each of the steps will look like. Looking back at the "Manufacturing Process X" example, a list of potential operators could look like Table 5-2.

Potential Operators **Process:** Manufacturing Process X	
• Mark	• John
• Eric	• Collin
• Isaac	• Tim
• Frank	• George

Table 5-2: Overview of potential operators for "Manufacturing Process X"

Keep in mind that this step only provides the operators that might be allocated to this process. This does not mean that each of the operators also has the required abilities to actually be allocated to a task within this process. The consequent steps will determine the actual abilities each operator possesses which ultimately determine whether an operator is allocated or not. This list will therefore function as input for the rest of the method.

Step 2: Select Specific Operator

In this second step, the user determines a specific operator to characterize. The previous step provides the user with a list of operators which need to be characterized. One of these operators is chosen from this list and the consequent steps 3, 4 and 5 will solely focus on this operator only. Looking at the examples, let's say the user pick the first operator 'Mark' to further analyze and characterize in terms of abilities.

Step 3: Determine Possessed Abilities

After the selection of a specific operator in Step 2, this step determines which abilities the operator possesses. As with the previous method of task characterization, the Taxonomy of Human Abilities by Fleishman (1992) contains the abilities used in the characterization. Through a thorough analysis of the operator, the user has to determine which of the 52 abilities present in the taxonomy are possessed by the operator. This step will require considerably more effort compared to its counterpart in task characterization because a person possesses a wide variety of abilities including the ones that might not be relevant for some tasks. Only the abilities that are not considered being working-proficient are excluded. Assistance by people that have extensive knowledge of a company's employee traits is therefore recommended.

Returning to the selected operator 'Mark', the user can consult his team leader and HR coordinator, for instance, to consult and describe Mark's possessed abilities. This results in an overview of abilities explicitly inherited to Mark. To illustrate the output of this step, an overview of Mark's *physical* abilities is created. Let's say that Mark has a physical disability which makes it unable for him to perform tasks that require repeated movement of a limb. This means that his *dynamic flexibility* is not at a working-proficient level and thus will be excluded. Similar to the determination of a task's required abilities, the overview of possessed abilities could look like this:

- *32. Static Strength*
- *33. Explosive Strength*
- *34. Dynamic Strength*
- *35. Trunk Strength*
- *39. Gross Body Flexibility*
- *36. Extent Flexibility*
- *38. Gross Body Coordination*
- *40. Stamina*

Once the possessed abilities of an operator are defined, the user can continue the characterization process through Step 4.

Step 4: Determine Possessed Ability Level

Step 4 of the operator characterization method determines the possessed level of each of the abilities determined in the previous step. As with the characterization of tasks, the determination of the possessed ability level in done through the F-JAS by Fleishman & Reilly (1992). Since the characterization of both the task and the operators is done using the same method, the user ultimately enables the possibility of matching tasks with potential operators to perform resource allocation.

Returning to the example of operator 'Mark', the user has to use the F-JAS to determine at what level Mark possesses a certain ability. To be able to do this, the user needs thorough knowledge of the operator under evaluation. If this is not the case, assistance of a team leader, operations/human resource manager or someone who does is strongly recommended. Again, the anchors in the F-JAS that represent a level of an ability can be used to properly characterize the possessed level. Applying this to the possessed *physical* abilities Mark has, the overview could look like this:

• *32. Static Strength*	2	• *39. Gross Body Flexibility*	2
• *33. Explosive Strength*	4	• *36. Extent Flexibility*	3
• *34. Dynamic Strength*	1	• *38. Gross Body Coordination*	4
• *35. Trunk Strength*	2	• *40. Stamina*	2

After assigning the proper value to each of the possessed abilities, the user can continue with Step 5 of the method.

Step 5: Apply Ability Value to Operator

In the last step of the method, the characterization of the specific operator finalizes and the data is brought together. In the previous steps, the user picked a specific operator, determined what abilities this operator possessed on a working-proficient level, and assigned values to each of those abilities. All this information needs to be properly categorized to be able to function as input for the consequent resource allocation. To do this, software can be used similar to the task characterization method. Applying this to the example of operator Mark, an overview as presented in Table 5-3 represents the maximum ability level that he possesses.

Operator: Mark **Ability Category:** Physical			
Possessed Ability	**Level**	**Possessed Ability**	**Level**
32. Static Strength	2	*39. Gross Body Flexibility*	2
33. Explosive Strength	4	*36. Extent Flexibility*	3
34. Dynamic Strength	1	*38. Gross Body Coordination*	4
35. Trunk Strength	2	*40. Stamina*	2

Table 5-3: Overview of an operator's possessed abilities

Since Step 1 of this method created a list of potential operators, this method can be iterated to characterize every operator separately. After Step 5 has been completed, the user can go back to Step 2 and select a different operator to characterize. Once all potential operators have been characterized, the required task characteristics can be compared to the possessed abilities of each operator to perform resource allocation based on the best match. This is part of verifying the method and the consequent usage of its result, which will be further elaborated on in the next section.

5.2 Method Verification

Since the goal of the designed method is to enable automatic resource allocation based on the obtained characteristics, this section verifies whether this goal is reached. Section 3.1 already pointed out that resource allocation can be performed *before* or *during* runtime of a process. As indicated, several methods that allocate resources *before* runtime of a process based on the matching of task and operator characteristics already exist. Therefore, this research aims to verify whether it is possible to allocate resource based on the matching of task and operator characteristics *during* runtime of a process. This is done using a process management platform called Camunda. Section 5.2.1 will give more information regarding Camunda and how it is used in this research. This is followed by Section 5.2.2, which describes the verification of the method's goal through the implementation and execution of a dummy manufacturing process in Camunda.

5.2.1 Camunda

Camunda[4] is an open source platform for workflow and business process management. It supports modeling and execution of various process modeling notations such as Business Process Model and Notation (BPMN) 2.0, Case Management Model and Notation (CMMN) 1.1 and Decision Modeling Notation (DMN) 1.1. After modeling a process, the user can execute the process causing it to behave as a physical process would. Camunda can perform various (automatic) tasks on such a process, related to decision making, notification, error handling and user allocation. For the resource allocation verification, BPMN and DMN models are used. The dummy manufacturing process will be modeled in BPMN. Once executed, Camunda can use DMN to compare the required task characteristics with possessed operator characteristics. From this comparison, Camunda can assign a suitable operator to a task. More in-depth information about how this procedure is applied to the dummy manufacturing process will be given in Section 5.2.2.

5.2.2 Dummy Process

To verify whether resource allocation *during* runtime using task/operator characteristics in terms of abilities is possible, a fictional manufacturing process is modeled and executed in Camunda. This process is given in Figure 5-5 and consists of 3 arbitrary tasks: *Cutting, Welding, Assembly*. To test whether resource allocation *during* runtime is possible, Camunda will ask the user to submit the required task characteristics when it arrives at a certain task. Once the user submits the required task characteristics, Camunda will match those characteristics with predefined operator characteristics. In practice, both these characteristics are determined at *design* time by using the designed characterization method. For this dummy process however, the required task characteristics and possessed operator

[4] https://camunda.org/

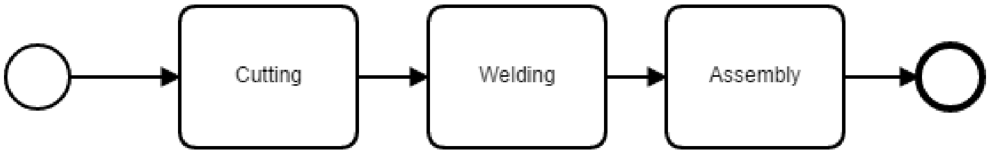

Figure 5-5: Dummy manufacturing process

characteristics are predefined and given in Table 5-4 and Table 5-5 respectively. If Camunda is able to find a match where an operator possesses the required task characteristics, it will automatically allocate that user to execute the task. Once the allocated operator completes the task, the process moves on to the next task where the same allocation process begins: user entering required task characteristics, Camunda matching these characteristics to possessed operator characteristics, and Camunda allocation the task to a suitable operator is possible. Because the goal of this dummy process is to verify whether the concept of resource allocation *during* runtime is possible, only three arbitrary abilities are used to characterize the tasks: *Originality, Memorization, Problem Sensitivity*. Furthermore, three potential operators exist for the dummy process.

Task	Originality	Memorization	Problem Sensitivity
Cutting	2	2	2
Welding	4	2	4
Assembly	6	6	3

Table 5-4: Required task characteristics Dummy Process

Operator	Originality	Memorization	Problem Sensitivity
John	2	4	5
Paul	4	2	6
Alan	7	6	3

Table 5-5: Required operator characteristics Dummy Process

The user interface of Camunda is given in Figure 5-6, this is what is presented to the user once a task starts. In the top left corner, the user is presented with the information about which task needs to be characterized, which in this case is the task *Cutting*. The center of the screen contains three fields in which the user can fill in the required level for each ability on the 7-point Likert scale from the F-JAS. If an ability is not required for a task, the user can fill in 0. Once the required task characteristics are filled in, the user completes the characterization by pressing the red 'Complete' button in the bottom right corner. This completes the characterization whereas Camunda will automatically match the filled in task characteristics with the predefined operator characteristics from Table 5-5. If an operator matches the requirements for a certain task, Camunda will start the assignment of this task and allocate that person to it.

For example, the task *Cutting* requires ability level 2 on *Originality*, *Memorization* and *Problem Sensitivity*. Matching these required ability levels with the operator characteristics, Camunda allocates 'Paul' to perform the *Cutting* task. The user is presented with the interface in Figure 5-7, which gives the specific task in the top left corner (Execute *Cutting*) and indicates the allocated operator in the top right corner (Paul). Once Paul completes this task, the process continues to the next task: *Welding*. Again, the user is presented with an interface in which the required ability levels for this task can be filled in. Continuing with the same example, let's say that the task *Welding* requires *Originality* level 4, *Memorization* level 2, and *Problem Sensitivity* level 4. Processing these required task characteristics, Camunda allocates the task to 'John' and provides the user with the interface given in Figure 5-8. Again, the specific task is given in the top left corner (Execute *Welding*) and the allocated operator in the top right (John). Moving to the last task of the process, *Assembly*, of which the required task characteristics are: *Originality* level 6, *Memorization* level 6, and *Problem Sensitivity* level 3. Camunda matches these levels with the possessed operator characteristics and allocates this task to 'Alan' as can be seen in Figure 5-9. This concludes the execution of the process and, with that, the allocation of resources *during* runtime.

As pointed out at the start of this section, the goal of executing this dummy process is to verify whether allocating resources using task characteristics in terms of abilities is possible *during* runtime of the process. Camunda is able to automatically allocate an operator to each task based on the ability levels provided. This confirms that it is possible to perform resource allocation based on characterization in terms of the abilities from the Taxonomy of Human Abilities by Fleishman (1975). However, some remarks must be made regarding this verification. Firstly, Camunda allocates the first operator who meets the level requirements to the task. This implies that there could be other allocation decision where, for example, operators possessing higher levels of certain abilities could also be allocated to that task whereas Camunda selects the first suitable operator is encounters. These possibilities are not taken into account since the purpose of this verification is only to verify if resource allocation is technically possible and not to verify whether Camunda prioritizes multiple suitable operators, should there be any. Secondly, Camunda is able to allocate an operator to each of the tasks. It could also be possible that a task requires a certain ability (level) that is not possessed by any operator. If this is the case, Camunda currently assigns no one to the task and the user has to manually allocate an operator. The reason that this situation is not considered is in line with the reasoning that the goal of this verification is only to test whether resource allocation is possible when the characteristics allow it, not to provide a solution when an exception occurs. While these remarks should definitely be taken into account when applying this to practice, it surpasses the goal of this verification and is therefore left out of scope.

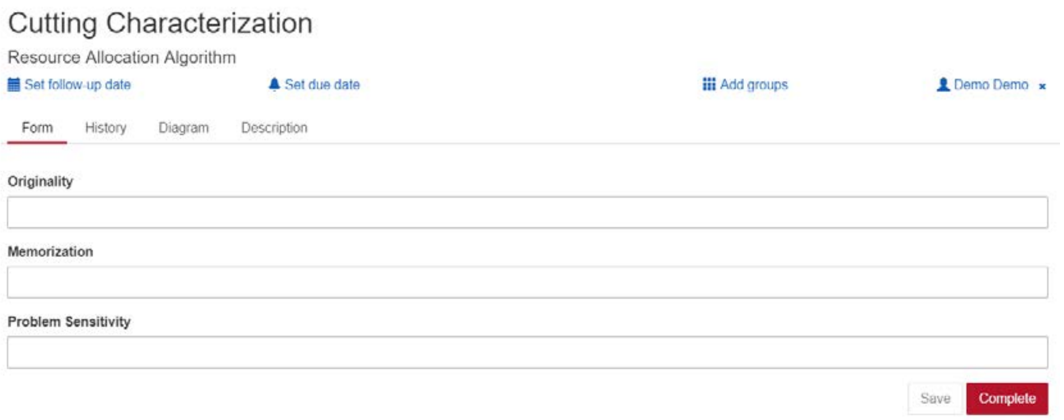

Figure 5-6: User interface task characterization dummy process

Figure 5-7: Allocated task: Cutting

Figure 5-8: Allocated task: Welding

Figure 5-9: Allocated task: Assembly

6 Case Study TRI

In this chapter, the method proposed in Section 5 is practically applied. This is done by conducting a case study at the telescopic slide manufacturer Thomas Regout International B.V.. In this case study, a part of their production process serves as the environment in which the method will be applied. Through interviews with two experts, the operations manager and the competence manager respectively, that have extensive knowledge of both the task and operator characteristics, a detailed description is created following the steps outlined in the designed method. Section 6.1 will give some more information about the production process of TRI and about the part that is used in the practical application in specific. Consequently, Sections 6.2 and 6.3 describe the characterization of the tasks and operators respectively. This is followed by a short reflection on the practical application and its results in Section 6.4 and the practical verification of the methods goal of enabling automatic resource allocation in Section 6.5.

6.1 TRI PL0 – Tool Assembly & Profistans Setup

As is explained in Section 2.3, TRI is a manufacturing company that produces telescopic slides and linear guides and is one of the SME’s that is extensively involved in the HORSE project. TRI’s end to end production process consists of four production areas (PL) and is included as a BPMN process model in Appendix III. The four distinctive production lines that are noticeable from this overview are PL0, PL1, PL2 and PL3. In general, PL0 assembles the die required for the punching machine and sets up this machine to starts production, PL1 covers the process of shaping raw material through punching, PL2 covers the chemical treatment of the parts and materials, and in PL3 the final product is assembled. It should be noted that the process model in Appendix III only provides a detailed overview of the PL0 process, the PL1, PL2 and PL3 processes are all collapsed to provide a clearer high-level overview and are not part of this practical application.

Figure 6-1 shows the PL0 process in more detail. This process is called Tool Assembly & Profistans Setup and is performed before the production of an order starts. To produce an order, the punching machine (*Profistans*) needs to be set up and the order specific die (*Wisselplaat*) used in this machine needs to be assembled. These preliminary activities are performed during in the PL0 process and can be seen in the figure below. The icons representing a human in the top left corner indicate that the task is performed by a user, which in this case is an operator, and the round icon in the top right corner of the last activity indicates that should the sample that is tested be incorrect, the process loops back and the previous activity needs to be performed again. Since all the tasks in this process are performed by human operators, PL0 is a suitable context to test the designed method.

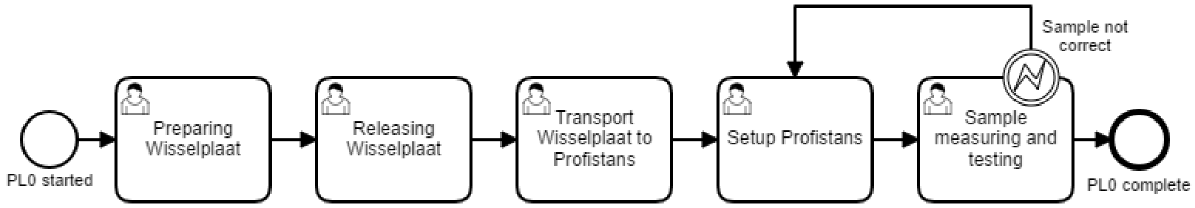

Figure 6-1: Process model of the PL0 process of TRI

6.2 Task Characterization PL0

The five tasks of the PL0 process are characterized in an interview with the operations manager of TRI. This person is experienced in managing operations at several organizations operating in different environments. The responsibility of the entire production process lies with the operations manager; he is therefore required to have extensive knowledge of each of the tasks. The interview is conducted using the Task Characterization method as presented in Section 5.1.2., following each of the steps closely.

The first step of the method consists of identifying the process. In this case this is the PL0 process as depicted in Figure 6-1. The decision to choose this process is made together with the operations manager which has two main reasons. Firstly, the entire process consists of tasks performed by human operators. Allocation of human operators is what this method aims to enable, which is applicable for this process. Secondly, the PL0 can be considered a diverse process, consisting of tasks which each require different abilities. This strengthens the practical verification of the method since a wide spectrum of required abilities has to be determined while using the method.

After identifying the PL0 process, the first task is selected to be characterized. This is the first task of the PL0 process: *Preparing Wisselplaat*. This task consists of several actions and together with the operations manager each of these are examined thoroughly. In doing this, all of the 52 abilities of the Taxonomy of Human Abilities are examined and it is determined which of these abilities are required for this task. This completes step 2 and 3 of the method where the abilities that are not required for performing this task are given the level rating of 0.

Now that the required abilities for the task are established, the minimum required level of these abilities are determined. Using the F-JAS, as can be seen in Appendix II, each of the required abilities are rated. The operations manager uses the provided *anchors* in the F-JAS to relate the ability description to the actions that need to be performed during this task. Consequently, a rating on the 7-point Likert scale of the F-JAS is given to each of the required abilities. The characterization data obtained is stored in a Microsoft Excel matrix to later enable resource allocation through the matching of task and operator characteristics. This finishes step 4 and 5 of the method and concludes the characterization of the task *Preparing Wisselplaat.*

As indicated in Section 5.1.2, the method can be iterated depending on the number of tasks the user wants to characterize. In the case of PL0, the operations manager iterates the process four more times to characterize the subsequent 4 tasks: *Releasing Wisselplaat, Transport Wisselplaat to Profistans*, *Setup Profistans* and *Sample measuring and testing.* The required abilities and the corresponding minimum level requirements are given in Table 6-1.

The task characteristics represented in Table 6-1 give some interesting insights on each of the tasks. The first two tasks, *preparing Wisselplaat* and *releasing Wisselplaat,* mainly require *Cognitive* abilities. During these tasks, the order specific die is assembled which requires the operator to process and follow instruction carefully because of the precision work that is required. *Transport Wisselplaat,* as the name implies, consists of physically transporting the die to the punching machine with the help of a transportation device. This implies a more physically oriented task which is resembled in the table by being the task with mainly *Physical* and *Psychomotor* abilities. *Sensory* abilities also play a vital role in this task because of safety requirements, transportation of a metal die weighing over 300kg requires various safety measures and procedures which must be met by the operator performing this task. During *Setup Profistans,* the operator must setup the punching machine which uses the assembled die to subsequently produce an order. This requires information input on a display and awareness of the surroundings of the punching machine because of safety requirements. Resembling these characteristics is the focus on *Cognitive* and *Sensory* abilities this task has. Arriving at the final task of the PL0 process, *Sample measuring & testing*, where the operator has to evaluate a test product to determine whether the punching machine has been set up correctly. This involves comparing the product to technical drawings and handling measuring tools to analyze whether the measurements are applied correctly. These detailed evaluation procedures are resembled in the required abilities for the task. High values at the *Cognitive* abilities represent the need for analytical thinking and reasoning to determine whether the product replies, while it also indicates that the operator must be able to come up with the correct improvements if the punching machine is not correctly set up. To be able to notice these discrepancies, the operator must have an eye for detail, hence the relatively high level of *Near Vision* required.

6.3 Operator Characterization PL0

The operators of the PL0 process are characterized in an interview with the competence manager at TRI. This person works at the human resource department of the company and knows the people that work at TRI well. The competence manager is especially knowledgeable about the operators that work in the factory because recently it is his job to evaluate the operators on their specific skills. The interview is conducted using the Operator Characterization method as presented in Section 5.1.3, following each of the steps listed.

Starting with the first step of the method, the potential operators for the process are determined. As with the task characterization, the PL0 process is taken as the scope and two arbitrary operators are identified as potential operators. Due to privacy regulations, the operators are called *Operator A* and *Operator B.* The reason for choosing two operators is that characterizing persons in terms of abilities requires significantly more effort compared to a task. Whereas tasks often only require a specific set of abilities depending on its nature, a person almost always possesses each of the abilities to some extent, even when they are not specifically needed for a task. This can clearly be seen in the characterization results in Table 6-1, where the tasks contain several zeroes and the operators possessing all the abilities to some extent.

Next, a specific operator is chosen to characterize in terms of abilities: *Operator A*. For this operator, the possessed abilities are determined in collaboration with the competence manager. While most people do possess every ability to some extent, it could be the case that someone does not possess an ability on a general working proficient level, in which case it could be excluded and given the rating of 0. Since *Operator A* does possess each of the 52 abilities on at least a working proficient level, this is not the case. With this process, step 2 and 3 of the method are completed.

Arriving at step 4 of the method, the possessed level of each of the abilities is determined for *Operator A.* As with the task characterization, the F-JAS is used to determine the possessed ability level *Operator A* has. Again, the *anchors* present in the F-JAS are used as reference to determine the right level. This process is less complicated as its task characterization counterpart because the anchors are designed to describe a person and relate to everyday tasks which are easily pictured for a human being which was less the case in characterizing the tasks. After the possessed level of each of the abilities is rated, the information is stored in the same Microsoft Excel sheet from Table 6-1, also completing step 5 of the method.

Because there are two potential operators to be characterized, the process is iterated at step 2 through 5 for *Operator B* of which the results are also included in Table 6-1. Looking at the possessed ability level of both operators and the required task characteristics, some interesting insights can be obtained. Firstly, it is immediately noticeable that the operators possess each of the 52 abilities even though they might not be required for any of the tasks characterized. This indicates that characterization of a person is much more diverse and requires more effort because of this. Secondly, when looking at the two operators' characteristics only, it can be seen that *Operator A* possesses a slightly higher level of *Cognitive* abilities compared to *Operator B*, while the level of *Psychomotor* and *Sensory* abilities are relatively the same. This could indicate that *Operator A* has more experience regarding the activities of the PL0 process and is thus able to cognitively process the activities in this context on a higher level. Another explanation for a difference in *Cognitive* ability levels could be the educational background of a person. Depending on the level of education, the way in which a person processes information and react accordingly to it can differ. Finally, a significant difference can be seen in *Physical* abilities between *Operator A* and *Operator B*. On average, *Operator A* scores 2 levels higher compared to *Operator B*. While this difference could be related to the physical differences that exist between men and women, it could also indicate that *Operator B* has a physical disability which refrains him or her from performing certain physical activities.

As can be seen, characterization of both tasks and operators in terms of abilities can provide useful insights into the context of a task and possible traits of a person. Even though the goal of the characterization method is to enable resource allocation by using this data, these insights could also be beneficial to an organization.

6.4 Reflection

This section briefly reflects on the application procedure at TRI and the obtained results to provide some insights in how the smoothly the application went and to highlight possible improvements that originate from this which can be incorporated in the future. At the start of the application, the interviewees seemed to instantly recognize the potential of the abilities from the taxonomy in describing tasks and operators. Immediately after introducing the abilities, both the operations manager and the competence manager gave examples of how these abilities were, or were not, required for one of the tasks or possessed by one of the operators. This indicates that the abilities incorporated in the method are defined in such a way that they are easily recognizable in different contexts.

While both interviewees could easily relate to the abilities' general definition, the rating of the required and possessed abilities using the F-JAS did not go untroubled initially. When characterizing the first task, the operations manager did find it hard to relate to the provided *anchors* form the F-JAS to give the appropriate required level of abilities to the task. This could be caused by the fact that he had no previously rated task on which he could compare the level rating with, or because the *anchors* give very basic examples of a certain level rating which are hard to relate to a specific manufacturing task. During the operators' characterization, the competence manager also encountered this problem, although to a lesser extent. This being less of a problem during the operator characterization can possibly be due to the taxonomy being originally designed to describe humans and not tasks. Interestingly, after characterization of the first task and operator the interviewees has less trouble using the *anchors* to characterize the consequent tasks and operators. This indicates that getting familiar with the procedure significantly increases the adaptability of the method. Therefore, providing a more suitable way to initially accommodate users in the application of the method is an interesting area to explore.

Looking at the results obtained from the practical application, it is noticeable that tasks are much more distinctive compared to operators when looking at the ability ratings. The results give a clear indication of what kind of work the operator is required to perform in terms of the type of ability; *cognitive, psychomotor, physical* or *sensory*. Looking at the description of the tasks given in Section 6.2, the resemblance between the actual actions which need to be performed and the ability rating that are given is clear. The results from the operator characterization however, are very similar to each other except for a couple of *physical* abilities as mentioned in Section 6.3. While the operators in the case study are actually similar because they are both authorized to perform all the tasks of the PL0 process, there cannot be said whether this will occur in a different manufacturing environment as well. Should this be the case, operators being characterized very similarly could pose a problem in the consequent resource allocation process as this might impair the choice of the best operator to perform the task.

Now that both tasks and operators are characterized, the data from Table 6-1 will be used to verify the methods goal of enabling automatic resource allocation in Section 6.5. Consequently, the process of characterizing the tasks and operators or TRI will be evaluated with the users in Section 7.

PL0 - Assembling Wisselplaat & Setup Profistans

Cognitive Abilities

	1 Oral Comprehension	2 Written Comprehension	3 Oral Expression	4 Written Expression	5 Fleuncy of Ideas	6 Originality	7 Memorization	8 Problem Sensitivity	9 Mathematical Reasoning	10 Number Facility	11 Deductive Reasoning	12 Inductive Reasoning	13 Information Ordering	14 Category Flexibility	15 Speed of Closure	16 Flexibility of Closure	17 Spatial Organization	18 Visualization	19 Perceptual Speed	20 Selective Attention	21 Time Sharing
Task Characteristics																					
PL0 - Preparing Wisselplaat	0	2	0	0	0	0	4	2	0	2	2	0	2	3	0	0	2	4	0	4	0
PL0 - Releasing Wisselplaat	0	2	0	0	0	0	4	2	0	2	4	2	2	3	0	0	2	2	0	4	3
PL0 - Transport Wisselplaat	0	0	0	0	0	0	5	4	0	0	4	2	2	0	0	0	3	4	0	5	3
PL0 - Setup Profistans	0	2	4	0	0	0	5	4	0	0	4	2	0	0	0	0	2	0	0	4	0
PL0 - Sample measuring & testing	0	4	4	1	0	0	4	4	1	2	4	4	2	0	3	4	2	3	0	4	4
Operator Characteristics																					
PL0 - Operator A	4	3	4	3	4	3	5	4	3	3	5	4	3	4	4	4	5	5	4	5	4
PL0 - Operator B	2	4	4	3	3	3	4	4	2	2	5	4	2	3	4	4	4	4	4	4	4

Psychomotor Abilities

	22 Control Precision	23 Multilimb Coordination	24 Response Orientation	25 Rate Control	26 Reaction Time	27 Arm-Hand Steadiness	28 Manual Dexterity	29 Finger Dexterity	30 Wrist-Finger Speed	31 Speed of Limb Movement
Task Characteristics										
PL0 - Preparing Wisselplaat	0	1	0	0	0	0	0	0	2	0
PL0 - Releasing Wisselplaat	5	3	0	0	0	1	0	4	2	0
PL0 - Transport Wisselplaat	4	0	4	1	6	0	0	0	0	0
PL0 - Setup Profistans	0	0	0	0	4	0	0	0	0	0
PL0 - Sample measuring & testing	5	3	0	0	0	3	0	0	0	0
Operator Characteristics										
PL0 - Operator A	5	5	5	4	6	4	5	4	4	5
PL0 - Operator B	5	5	4	4	6	4	4	4	3	4

Physical Abilities

	32 Static Strength	33 Explosive Strength	34 Dynamic Strength	35 Trunk Strength	36 Extent Flexibility	37 Dynamic Flexibility	38 Gross Body Coordination	39 Gross Body Equilibrium	40 Stamina
Task Characteristics									
PL0 - Preparing Wisselplaat	3	0	0	2	3	0	0	0	0
PL0 - Releasing Wisselplaat	1	0	0	3	1	0	0	0	0
PL0 - Transport Wisselplaat	0	0	0	2	2	1	3	0	1
PL0 - Setup Profistans	0	0	0	2	0	0	0	0	0
PL0 - Sample measuring & testing	0	0	0	1	0	0	0	0	0
Operator Characteristics									
PL0 - Operator A	5	5	5	5	5	5	5	5	5
PL0 - Operator B	3	3	2	2	3	1	3	4	3

Sensory Abilities

	41 Near Vision	42 Far Vision	43 Visual Color Discrimination	44 Night Vision	45 Peripheral Vision	46 Depth Perception	47 Glare Sensitivity	48 Hearing Sensitivity	49 Auditory Attention	50 Sound Localization	51 Speech Recognition	52 Speech Clarity
Task Characteristics												
PL0 - Preparing Wisselplaat	4	0	3	0	0	0	0	0	0	0	2	0
PL0 - Releasing Wisselplaat	5	0	2	0	0	0	0	0	0	0	2	0
PL0 - Transport Wisselplaat	0	2	0	0	4	2	0	2	2	2	2	2
PL0 - Setup Profistans	2	0	0	0	4	0	0	2	2	2	0	0
PL0 - Sample measuring & testing	5	0	0	0	0	0	0	0	0	0	0	0
Operator Characteristics												
PL0 - Operator A	5	5	2	2	5	3	5	4	6	6	6	3
PL0 - Operator B	5	5	5	4	5	3	5	4	6	6	6	4

Table 6-1: Characterization results PL0 process TRI

6.5 Automatic Resource Allocation PL0

To also verify the method's goal of enabling automatic resource allocation during runtime in a practical environment, the PL0 process of TRI is modeled and executed in Camunda. The simplified PL0 process used in this verification is given in Figure 6-2 and consists of 5 tasks: *Preparing Wisselplaat*, *Releasing Wisselplaat*, *Transport Wisselplaat to Profistans*, *Setup Profistans* and *Sample measuring and testing.* The execution of the process is performed similar to the dummy process from Section 5.2.2. At every task, the user is required to fill in the required task characteristics. Consequently, Camunda will match these required task characteristics with the possessed operator characteristics. Since the case study at TRI provided data on both, the characteristics from Table 6-1 will act as input for this verification.

Figure 6-2: TRI PL0 process as used in Camunda

Figure 6-3 represents the user interface of Camunda that is presented to the user at every task. Similar to the dummy process, the top left corner indicates for which task the required characteristics must be filled in (*Preparing Wisselplaat* in this case). As can be seen in the center of the user interface, a form is presented which enable the user to enter these characteristics. While the dummy process only incorporated three arbitrary abilities, this practical verification incorporated all 52 abilities form the Taxonomy of Human Abilities. After entering the required ability levels for the task, Camunda automatically tries to match a suitable operator possessing at least these ability levels. Entering the required ability levels for the *Preparing Wisselplaat* task from Table 6-1, Camunda presents the user with the instance of executing this task and allocates an operator to execute it. This instance is given in Figure 6-4, indicating that *Preparing Wisselplaat* is automatically allocated to 'Operator B' (top right corner). Once 'Operator B' executes this task, the process continues to the next task and the user is required to enter the required ability levels to enable automatic allocation again. This procedure is iterated until the PL0 process is completed. The allocation results for these iterations can be seen in Figure 6-5, Figure 6-6, Figure 6-7 and Figure 6-8 respectively. These figures show that *Releasing Wisselplaat, Transport Wisselplaat to Profistans* and *Setup Profistans* are allocated to 'Operator A' and the last task, *Sample measuring and testing,* should be executed by 'Operator B'.

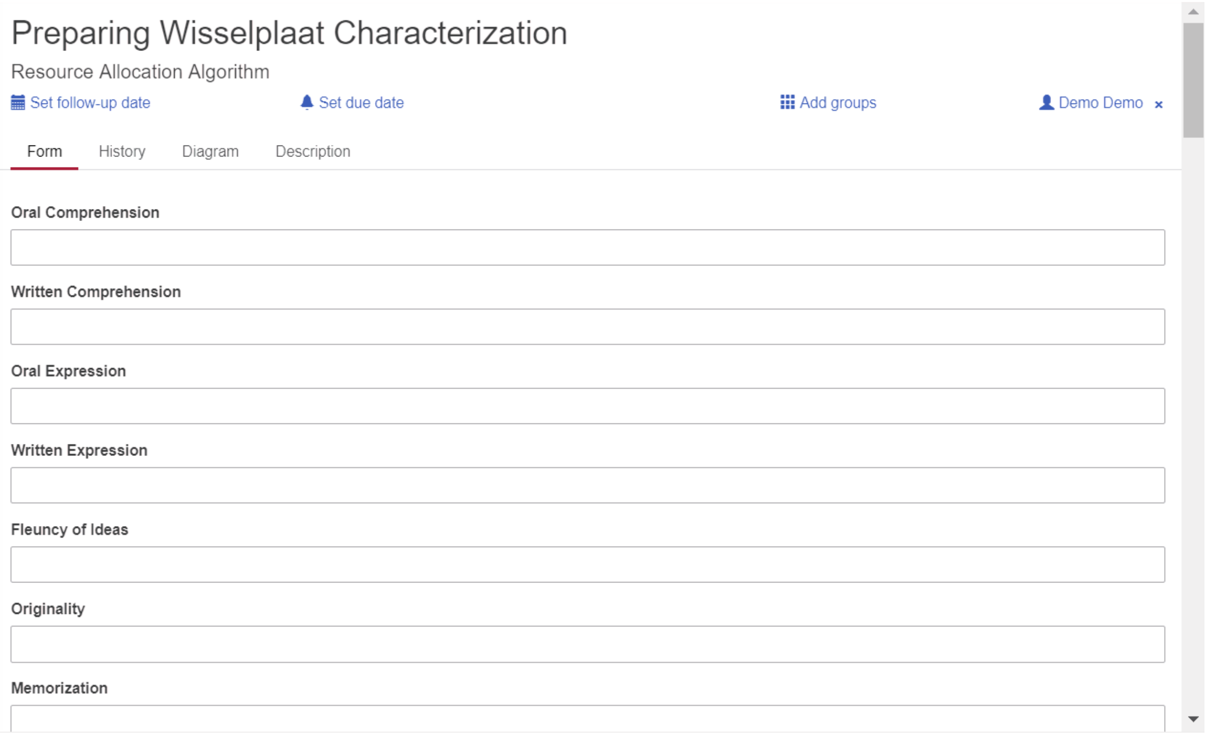

Figure 6-3: User interface task characterization TRI PL0 process

Figure 6-4: Allocated task: Preparing Wisselplaat

Figure 6-5: Allocated task: Releasing Wisselplaat

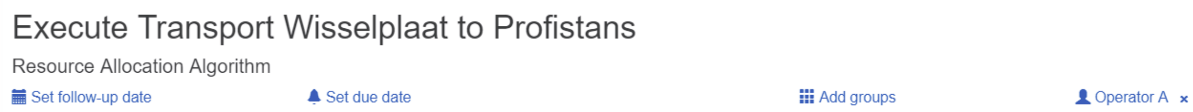

Figure 6-6: Allocated task: Transport Wisselplaat to Profistans

Figure 6-7: Allocated task: Setup Profistans

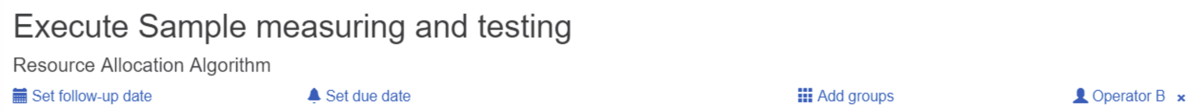

Figure 6-8: Allocated task: Sample measuring and testing

Comparing these results with the data obtained from the case study in Table 6-1, some interesting insights can be obtained. Section 6.3 already indicated that both operators are relatively comparable with regards to their possessed ability levels and only some minor differences in the *physical* ability category were noticeable. This has also causes the resource allocation decisions to be very close. While it turns out that either only 'Operator A' or "Operator B' is suitable for a task, and never both, it is due to minor differences where the other operator just falls short on a couple of abilities that not both are suitable. For example, 'Operator A' only falls short one level of *Visual Color Discrimination* at the first task *Preparing Wisselplaat* and 'Operator B' is not allocated to the third task *Transport Wisselplaat to Profistans* because of an insufficient level on *Memorization* and *Selective Attention.*

While this verification proves that automatic resource allocation in Camunda is also possible when using practical data, a couple of remarks similar to the dummy process can be made. First, TRI indicates that currently both operators are able to perform all the tasks of the PL0 process successfully. This is not the case when only looking at the characterization data, as the data implies that 'Operator A' is only suitable for the second, third and fourth task and 'Operator B' for the first and fifth. This difference supports the objective that both the method and the resource allocation suggestions originating from the method are aimed at supporting resource allocation decision making and should not be followed blindly. Secondly, in this verification all tasks can be assigned an operator. This does not always have to be the case because the resource allocation is based on 52 different abilities. In the case that no operator possessed the required ability levels, Camunda will currently assign no one to the task. While it is acknowledged that this is undesirable, this has been left out of scope and suggestions regarding this remark are given in Section 8.2. Finally, the effort to fill in the required ability levels for 52 abilities and every task is considerable. It requires the user to have the data accurately defined beforehand and present at runtime but also execute the repeated task of filling in this data. This is a time-consuming process and might not be as easy to realize in a practical environment. Better integration of data could be an important step in addressing this remark, which is also elaborated on in Section 8.2.

7 Method Evaluation

The practical implementation of the characterization method, as presented in Section 6, is evaluated with the operations manager and competence manager from TRI. This is done through a semi-structured interview and a survey based on the Technology Acceptance Model and Method Evaluation Model of Moody (2003). The survey enables evaluation of a designed method and provides insights in the following three aspects:

- *Perceived Ease of Use (PEOU)*: the extent to which someone believes that using the method is effortless
- *Perceived Usefulness (PU)*: the extent to which someone believes that using the method improves job performance
- *Intention to Use (ITU)*: the extent to which someone intends to use the method

Table 7-1 presents the questions and results of the survey conducted with both the operations and competence manager at TRI. While the questions on the original survey are shuffled, the table shows them categorized per category: PEOU, PU and ITU. The original survey also incorporates reverse reasoning in some question to eliminate factors such as biased answers based on previous answers given. In the results table, the results of these reverse reasoned questions are rearranged to provide a better overview of the results. Next to the quantifiable results obtained from filling in the survey, semi-structured interviews are conducted to obtain a better understanding of the reasoning behind the survey answers. In these interviews, the questions from the survey act as a foundation for discussion.

As mentioned earlier in this section, the evaluation of the characterization method is conducted with both the operations and competence manager of TRI. Since the operations manager used the method to characterize tasks and the competence manager to characterize operators, the evaluation survey focusses on these context for each of the users respectively. The semi-structured interviews are added to discuss the characterization method on a more holistic level to evaluate the three aspects; PEOU, PU and ITU. Since the evaluation is carried out by both the operations and competence mangers at TRI, the results will be discussed separately for each user. The results of these evaluations are given in Section 7.1 and 7.2. This is followed by a short reflection on the evaluation results in Section 7.3.

	#	Question	Type	(-)Disagree (+) Agree				(-) Agree (+) Disagree
PEOU	1	I found the procedure for applying the method complex and difficult to follow	-	C				O
	4	Overall, I found the method difficult to use	-	C				O
	6	I found the method easy to learn	+	C				O
	9	I found it difficult to apply the method to the practical process	-	O	C			
	11	I found the rules of the method clear and easy to understand	+	C		O		
	14	I am not confident that I am now competent to apply this method in practice	-	O C				
PU	2	I believe that this method would reduce the effort required to automatically allocate resources to tasks	+	O C				
	3	Resource allocation decisions, resulting from the use of this method, would be more difficult for users to understand	-	O	C			
	5	This method would make it easier for users to verify whether resource allocation decisions are correct	+	O C				
	7	Overall, I found the method to be useful	+	O C				
	8	Using this method would make it more difficult to automatically allocate resources	-	O C				
	12	Overall, I think this method does not provide an effective solution to the problem of automatically allocating resources to tasks	-	O	C			
	13	Using this method would make it easier to resource allocation decisions to end users	+	O C				
	15	Overall, I think this method is an improvement to the current way of allocating resources to tasks	+	O C				
ITU	10	I would definitely not use this method to automatically allocate resources to tasks	-	O C				
	16	I intend to use this method in preference to the current way of allocating resources if I have to perform resource allocation in the future	+	O C				

O = Operations Manager TRI

C = Competence Manager TRI

Table 7-1: User acceptance results

7.1 Operations Manager TRI

Based on the results of the survey, it can be concluded that the operations manager (qualified as "O" in the results table) is predominantly positive about the characterization method. 12 out of the 16 questions receive the highest score in a positive way. From the other four questions, question 1, 4 and 6 have a negative score and question 11 scores neutral. These four questions fall in the category PEOU, indicating that the operations manager has had a negative experience with the amount of effort that it requires to use the method.

This issue clearly emerged in the interview with the operations manager, where he indicated that initially applying the method was difficult. This difficulty lies in assigning the required ability level to a task using the F-JAS. When the tasks are characterized, the user can use the *anchors* present in the F-JAS for reference to determine the ability level required. The operations manager found it difficult to relate these generally formulated anchors to the context of the production tasks. He indicated that this severely limited the understandability of the concept at first, which is resembled in the questions 1, 4 and 6 scoring negatively. However, the operations manager also indicated that once he had characterized several tasks, it became easier to relate the *anchors* to the context of a task and his view on the method positively increased, which is indicated by the positive answer on question 14 in the PEOU category. Furthermore, the operations manager indicated that, beside from the *anchors*, the method is well structured and the definitions of each ability are clearly defined. This is the reason that question 11 scores neutral because of the method being clear, but difficult to understand at first.

In the category of PU, the operations manager indicated that he was extremely positive about the usefulness of the characterization methods and its function to enable resource allocation. He indicated that he saw a lot of potential in properly documenting task and operator characteristics in terms of universally applicable characteristics. He has worked in different companies and contexts where a lot of effort was required to understand each contexts' description of tasks. Furthermore, the operations manager addressed the issue of experienced operators currently allocating resource in an ad hoc manner and that when processes become more complex, the automatic allocation decisions that this characterization enables would be very useful to these persons. This is in line with the goal of the method to enable automatic resource allocation based on this characterization, which is strongly recommended by the operations manager in the form of implementing this data into a process management system which would automatically allocate suitable resources to tasks.

Regarding the application of this method in practice, the operations manager indicated that he feels competent in using this method independently. However, he added that this is because he now has used the method once and is thus able to make the translation of the generally formulated definitions and anchors to the context of a manufacturing company. This might me more difficult for users that do not have as much experience in the field of manufacturing.

7.2 Competence Manager TRI

Overall, the competence manager at TRI (indicated with “C” in the results table) is very positive about the characterization method. This is reflected in the results from Table 6-1, where 13 questions score very positive and 3 questions score somewhat positive. There does not seem to be a direct relation between a lower score and a specific category. The reasons however, do become clearer in the interview that follows the survey.

After initially applying the method, the competence manager was very enthusiastic about the structure and applicability. He indicated that the abilities were well defined and easily recognizable when describing a person. In contrast to the operations manager, the competence manager did not experience difficulties in using the *anchors* from the F-JAS to describe operators. The reason for this is that the F-JAS is originally designed to describe people, which obviously makes it harder to use describing tasks as this is a different context. Therefore, the competence manager indicated that he had no issues applying the method for the first time but could imagine that a person less experienced in human resource management could have. This is reflected in the score to question 9, in which the competence manager somewhat disagrees on the difficulty in applying the method. Furthermore, he indicated that a useful addition to the method would be to adjust the F-JAS such that it suited the manufacturing environment better. An example of this addition would be to incorporate *anchors* that describe a certain ability level through a manufacturing example. While he was aware that this hurts the applicability of the method to context other than manufacturing, he does think that it would improve the integration of the method into companies.

Acknowledging the fact that the current resource allocation process is unstructured and requires significant effort, the competence manager is predominantly positive about the usefulness of the method. He indicated that within an organization such as TRI, it is quite difficult to communicate general changes and decisions in the company to people. Using a structured and scientifically founded method enables easier communication of changes by being able to support these decision with clear and understandable data which people can relate to. This is in line with the argument the competence manager makes about the unstructured allocation of resources that is current practice, where he says that having the possibility of a process management system automatically allocates resources would make for robust decisions. Even though the competence manager indicates that he himself does not have the knowledge to implement this into a process management system, having this done would definitely improve his job performance.

The positive attitude of the competence manager towards the characterization method is also reflected in his intention to use it. While he had no problem applying the method to operators at TRI, he does have another suggestion for improvement. During the characterization of the operators, the competence manager indicates that he sometimes found it difficult to work with the 7-point Likert scale that is used in the F-JAS. He argues that, in some occasions, a 7-point is not detailed enough to describe a person. These were, for example, instances in which level 3 was to low but level 4 to high, but because the F-JAS requires the user to provide integers he was not entirely convinced by his rating. While he realized that this structure was inherit to the method, he is in favor of exploring possibilities to enable a more detailed description of ability levels.

7.3 Reflection

This section shortly reflects on the evaluation of both the operation manager and the competence manager. The remarks and suggestions they made are analyzed from which suggestions for improvement to the method and its application procedure originate.

The main remark both interviewees gave about the method is about the *anchors* present in the F-JAS. As was already perceived during the practical application in Section 6.4, the interviewees indicate that they perceived trouble initially relating to the *anchors* when characterizing both tasks and operators. Now that this issue is confirmed in the evaluation as well, possibilities to initially accommodate the user of the method in a way that is easier relatable most definitely need to be explored. The suggestion to provide *anchors* that relate to manufacturing might not be able to be realized, this is because the F-JAS is a scientifically founded method which is proved on its effectiveness based on its current design. Changing this design might cause the F-JAS to lose its credibility because it has not been proved with these changes included. This also relates to the suggestion the competence manager made with regards to providing more detailed characterization possibilities by adjusting the Likert scale used.

There might be some other approaches the method can take to resolve the issues indicated. Combining the characterization provided by the current method with other ways to describe or specify tasks and operators could be an option worthwhile to explore. The method's characterization of tasks for instance, could be accompanied by examples of previously described. Having examples of previously characterized tasks can cause the current user to be able to better relate to the *anchors* currently present in the F-JAS and thus enable the user to properly characterize the task without changing the F-JAS itself. The characterization of operators on the other hand, could incorporate other information describing a person to better determine their possessed ability level. This other information could be obtained through something like a personality test or by analyzing the person's education, certificates, diploma’s and other achievements or experiences. Combining multiple sources of information, next to this research’s method, in the characterization have the potential to provide the user with a way to more easily characterize tasks and operators while keeping the integrity of the used F-JAS intact.

8 Conclusion

The objective of this research was to enable resource allocation of operators in manufacturing based on personal characteristics. This has been done by developing a universally applicable characterization method that can be used to describe tasks and operators in terms of human abilities to enable resource allocation during runtime by matching these characteristics. The method is developed by using an adjusted methodology based on van Strien (1997). In this methodology, an extra verification phase is added which focusses on verifying the method's goal of enabling automatic resource allocation.

After application of the method in a practical case study, it is concluded that the method is able to describe tasks and operators in terms of abilities in a structured way. This is of value to both an operations manager as well as a human resource/competence manager. Both users acknowledge that the current practice in manufacturing consists of an ad hoc and very context specific way to characterize and allocate operators. While there are some remarks regarding the application of the generally formulated ability definitions to the manufacturing context, the concept and potential that the structured characterization of tasks and operators have are acknowledged and positively perceived overall. Furthermore, the goal of the method to enable automatic resource allocation is successfully verified by using the characterization data obtained from the practical case study. Through modeling and executing of a practical process, the characterization data enables a process management platform to automatically allocate appropriate operators to tasks. While there are some remarks to this verification with regards to other possible scenarios, the concept of enabling automatic resource allocation by using the characterization method is verified and is deemed useful and usable by the stakeholders.

8.1 Contributions

This design science research contributes to knowledge because it extends a new solution to a known problem (Gregor & Hevner, 2013) and therefore contributes to the existing literature in several ways. First, it has developed a method to characterize tasks and operators in terms of the human abilities from the Taxonomy of Human Abilities by Fleishman (1975). This enables a more structured and universally applicable way to establish task requirements and possessed operator characteristics using a taxonomy that originally was not designed for this context.

Secondly, this research established that human abilities are a suitable characteristic to describe tasks and operators. Through a thorough analysis on several similar factors, human abilities are deemed to have the right level of generalizability in being universally applicable while maintaining the possibility to characterize on a task and operator specific level.

Lastly, this characterization opens up the possibility to automatically allocate operators to tasks. The data obtained from the characterization method can be used as input for a process management system to automatically perform resource allocation. These allocation decisions can be final or can significantly reduce effort as they can be used as supportive suggestions to the person performing the allocation.

8.2 Limitations & Future Work

While this research contributes to the literature in multiple ways, there are some limitations and areas for future research present. The main recommendation for future work is to explore the possibilities of describing *automated* resources in a structured way such that automatic resource allocation can be enabled. As the focus of this research is the description of *human* resources, the factor used to describe tasks and resources is limited to human characteristics only. Development of a similar method applicable to *automated* resources could significantly reduce complexity in resource allocation decisions. This would open up the possibility to create a fully integrated resource allocation system that could determine whether a task should be performed by a robot or a human, and provide the user with a specific resource as well.

Another area for future research is to explore the possibility of adjusting the *anchors* in the F-JAS to better fit the manufacturing context. Currently, the *anchors* are generally defined to increase applicability in various contexts. The users of the method indicated that this limits the understandability and relatability to the context of manufacturing when they described tasks and operators. It is therefore suggested that the *anchors* should contain examples related to the manufacturing context to determine the ability levels more accurately, while keeping the definition of the abilities the same to maintain the universal applicability.

Furthermore, future research could analyze whether the 7-point Likert scale used in the F-JAS to determine the ability levels is detailed enough to distinguish tasks and operators. While this issue did not impair the resource allocation during the practical verification, the ability levels of the tasks and operators were similar. This could cause allocation issues if they were even more similar because of the process management platform being unable to allocate an appropriate resource. While it is unsure if adopting a higher-point Likert scale for more detail is a possible solution to this issue with regards to maintaining the proved effectiveness of the F-JAS, the option could be considered.

Looking at the process management platform used in this research, a smoother integration of the characterization data is an area for future research. Due to time constraints, this research could not directly integrate the characterization data into the process management platform for resource allocation. This means that a large part of the data used in the process management platform was hardcoded and static. Even though this did not impair the verification of the concept, the possibility to link and import the characterization data from Excel into the process management platform would be a positive addition.

Also, there are some events that occur on a daily basis in manufacturing firms that should therefore be considered regarding future research in the automatic allocation of resources. First, the situation were multiple processes are running at the same time is realistic in the manufacturing industry. If automatic resource allocation, as presented in this research, is applied to multiple processes at the same time, the case of one operator being assigned to multiple tasks is an issue that is realistic. Because of this, future research should focus on exploring possibilities to incorporate a sort of priority and back-up mechanic which prioritizes to which task the operator should be allocated and to provide another suitable operator for the unallocated task. Another issue that can occur very frequently in manufacturing is that an operator can be occupied when the process management platform allocates him to a task. In this case, exploration into a similar back-up mechanic as mentioned in the previous case is recommended.

Finally, Section 6.5 shortly addressed some exception handling procedures in the process management platform that can be considered areas for future research as well. The current configuration of the process management platform selects the first suitable operator found for a task and does not consider any other options after that. Therefore, it is recommended to explore the possibility of creating a prioritization function in the allocation procedure of the platform. This could enable the possibility of choosing the most suitable operator out in case multiple suitable operators are found. Another exception handling procedure considered an area for future research is the integration of a next-best function. This could enable the process management platform to find and allocate the next-best operator if no suitable operator is found. While these exceptions did not occur in the practical verification performed in this research, they are very real and there is a significant chance that they will occur in a different practical context.

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10 Appendices

10.1 Appendix I – Taxonomy of Human Abilities (Fleishman, 1975)

Definitions of Abilities in the Taxonomy With Task Examples

Construct label	Operational definition	Level scale: Level rating	Level scale: Example
	Cognitive Abilities		
Verbal Abilities			
1. Oral Comprehension	The ability to listen to and understand information and ideas presented through spoken words and sentences.	High	Understanding a lecture on advanced physics.
		Low	Understanding a television commercial.
2. Written Comprehension	The ability to read and understand information and ideas presented in writing.	High	Understanding an instruction book on repairing a missile guidance system.
		Low	Understanding signs on the highway.
3. Oral Expression	The ability to communicate information and ideas in speaking so others will understand.	High	Explaining advanced principles of genetics to college freshmen.
		Low	Canceling newspaper delivery by phone.
4. Written Expression	The ability to communicate information and ideas in writing so others will understand.	High	Writing an advanced economics textbook.
		Low	Writing a note to remind someone to take something out of the freezer to thaw.
Idea Generation and Reasoning Abilities			
5. Fluency of Ideas	The ability to come up with a number of ideas about a given topic. It concerns the number of ideas produced and *not* the quality, correctness, or creativity of the ideas.	High	Naming all the possible strategies for a particular military battle.
		Low	Naming four different uses for a screwdriver.
6. Originality	The ability to come up with unusual or clever ideas about a given topic or situation, or to develop creative ways to solve a problem.	High	Inventing a new type of human-made fiber.
		Low	Using a credit card to open a locked door.
8. Problem Sensitivity	The ability to tell when something is wrong or is likely to go wrong. It does *not* involve solving the problem, only recognizing that there is a problem.	High	Recognizing an illness at an early stage of a disease when there are only a few symptoms.
		Low	Recognizing that an unplugged lamp does not work.
11. Deductive Reasoning	The ability to apply general rules to specific problems to come up with logical answers. It involves deciding if an answer makes sense.	High	Designing an aircraft wing using the principles of aerodynamics.
		Low	Knowing that, because of the law of gravity, a stalled car can coast down the hill.
12. Inductive Reasoning	The ability to combine separate pieces of information, or specific answers to problems, to form general rules or conclusions. It includes coming up with a logical explanation for why a series of seemingly unrelated events occur together.	High	Diagnosing a disease using the results of many different lab tests.
		Low	Determining clothing to wear on the basis of the weather report.
13. Information Ordering	The ability to correctly follow a given rule or set of rules in order to arrange things or actions in a certain order. The things or actions can include numbers, letters, words, pictures, procedures, sentences, and mathematical or logical operations.	High	Assembling a nuclear warhead.
		Low	Putting things in numerical order.
14. Category Flexibility	The ability to produce many rules so that each rule tells how to group (or combine) a set of things in a different way.	High	Classifying man-made fibers in terms of their strength, cost, flexibility, melting points, etc.
		Low	Sorting nails in a toolbox on the basis of length.
Quantitative Abilities			
9. Mathematical Reasoning	The ability to understand and organize a problem and then to select a mathematical method or formula to solve the problem.	High	Determining the mathematics required to simulate a space craft landing on the moon.
		Low	Determining how much 10 oranges will cost when they are priced at 2 for 29 cents.
10. Number Facility	The ability to add, subtract, multiply, or divide quickly and correctly.	High	Manually calculating the flight path of an aircraft, taking into account speed, fuel, wind, and altitude.
		Low	Adding 2 and 7.

Table 11-1 continues

Construct label	Operational definition	Level scale: Level rating	Level scale: Example
Memory			
7. Memorization	The ability to remember information such as words, numbers, pictures, and procedures.	High	Reciting the Gettysburg Address after studying it for 15 minutes.
		Low	Remembering the number on your bus to be sure you get back on the right one.
Perceptual Abilities			
15. Speed of Closure	The ability to quickly make sense of information that seems to be without meaning or organization. It involves quickly combining and organizing different pieces of information into a meaningful pattern.	High	Interpreting the patterns on a weather radarscope to decide if the weather is changing.
		Low	Recognizing a song after hearing only the first few notes.
16. Flexibility of Closure	The ability to identify or detect a known pattern (a figure, object, word, or sound) that is hidden in other distracting material.	High	Identifying camouflaged tanks while flying in a high speed airplane.
		Low	Tuning in a radio weather station in a noisy truck.
19. Perceptual Speed	The ability to quickly and accurately compare letters, numbers, objects, pictures, or patterns. The things to be compared may be presented at the same time or one after the other. This ability also includes comparing a presented object with a remembered object.	High	Inspecting electrical parts for defects as they flow by on a fast-moving assembly line.
		Low	Sorting mail according to zip codes with no time pressure.
Spatial Abilities			
17. Spatial Organization	The ability to know one's location in relation to the environment, or to know whether other objects are in relation to one's self.	High	Navigating an ocean voyage using only the positions of the sun and stars.
		Low	Using the floor plan to locate a store in a shopping mall.
18. Visualization	The ability to imagine how something will look after it is moved around or when its parts are moved or rearranged.	High	Anticipating opponent's as well as your own future moves in a chess game.
		Low	Imagining how to put paper in the typewriter so the letterhead comes out at the top.
Attentiveness			
20. Selective Attention	The ability to concentrate and not be distracted while performing a task over a period of time.	High	Studying a technical manual in a noisy boiler room.
		Low	Answering a business call with coworkers talking nearby.
21. Time Sharing	The ability to efficiently shift back and forth between two or more activities or sources of information (such as speech, sounds, touch, or other sources).	High	Monitoring radar and radio transmission to keep track of aircraft during periods of heavy traffic.
		Low	Listening to music while filing papers.
	Psychomotor Abilities		
Fine Manipulative Abilities			
27. Arm-Hand Steadiness	The ability to keep the hand and arm steady while making an arm movement or while holding the arm and hand in one position.	High	Cutting facets in diamonds.
		Low	Lighting a candle.
28. Manual Dexterity	The ability to quickly make coordinated movements of one hand, a hand together with the arm, or two hands to grasp, manipulate, or assemble objects.	High	Performing open-heart surgery using surgical instruments.
		Low	Screwing a light bulb into a lamp socket.
29. Finger Dexterity	The ability to make precisely coordinated movements of the fingers of one or both hands to grasp, manipulate, or assemble very small objects.	High	Putting together the inner workings of a small wrist watch.
		Low	Putting coins in a parking meter.
Control Movement Abilities			
22. Control Precision	The ability to quickly and repeatedly make precise adjustments in moving the controls of a machine or vehicle to exact positions.	High	Drilling a tooth.
		Low	Adjusting a room light with a dimmer switch.
23. Multilimb Coordination	The ability to coordinate movements of two or more limbs together (for example, two arms, two legs, or one leg and one arm) while sitting, standing, or lying down. It does not involve performing the activities while the body is in motion.	High	Playing the drum set in a jazz band.
		Low	Rowing a boat.

Table 11-1 continues

Construct label	Operational definition	Level rating	Level scale: Example
24. Response Orientation	The ability to choose quickly and correctly between two or more movements in response to two or more different signals (lights, sounds, pictures, etc.). It includes the speed with which the correct response is started with the hand, foot, or other body parts.	High	In a spacecraft that is out of control, reacting quickly to each malfunction with the correct control movements.
		Low	When the doorbell and telephone ring at the same time, quickly selecting which to answer first.
25. Rate Control	The ability to time the adjustments of a movement or equipment control in anticipation of changes in the speed and/or direction of a continuously moving object or scene.	High	Operating aircraft controls used to land a jet on an aircraft carrier in rough weather.
		Low	Riding a bicycle alongside a jogger.
Reaction Time and Speed Abilities			
26. Reaction Time	The ability to quickly respond (with the hand, finger, or foot) to one signal (sound, light, picture, etc.) when it appears.	High	Hitting the brake when a pedestrian steps in front of the car.
		Low	Starting to slow down the car when a traffic light turns yellow.
30. Wrist-Finger Speed	The ability to make fast, simple, repeated movements of the fingers, hands, and wrists.	High	Typing a document at the speed of 90 words per minute.
		Low	Using a manual pencil sharpener.
31. Speed of Limb Movement	The ability to quickly move the arms or legs.	High	Throwing punches in a boxing match.
		Low	Sawing through a thin piece of wood.
	Physical Abilities		
Physical Strength Abilities			
32. Static Strength	The ability to exert maximum muscle force to lift, push, pull, or carry objects.	High	Lifting 75-pound bags of cement onto a truck.
		Low	Pushing an empty shopping cart.
33. Explosive Strength	The ability to use short bursts of muscle force to propel oneself (as in jumping or sprinting), or to throw an object.	High	Propelling (throwing) a shot-put in a track meet.
		Low	Hitting a nail with a hammer.
34. Dynamic Strength	The ability to exert muscle force repeatedly or continuously over time. This involves muscular endurance and resistance to muscle fatigue.	High	Performing a gymnastics routine using the rings.
		Low	Using pruning shears to trim a bush.
35. Trunk Strength	The ability to use one's abdominal and lower back muscles to support part of the body repeatedly or continuously over time without "giving out" or fatiguing.	High	Doing 100 sit-ups.
		Low	Sitting up in an office chair.
Endurance			
40. Stamina	The ability to exert one's self physically over long periods of time without getting winded or out of breath.	High	Running a 10 mile race.
		Low	Walking a quarter of a mile to deliver a letter.
Flexibility, Balance, and Coordination			
36. Extent Flexibility	The ability to bend, stretch, twist, or reach out with the body, arms, and/or legs.	High	Working under a car dashboard to repair the heater.
		Low	Reaching for a microphone in a patrol car.
37. Dynamic Flexibility	The ability to quickly and repeatedly bend, stretch, twist, or reach out with the body, arms, and/or legs.	High	Maneuvering a kayak through swift rapids.
		Low	Hand picking a bushel of apples from a tree.
38. Gross Body Coordination	The ability to coordinate the movement of the arms, legs, and torso together in activities where the whole body is in motion.	High	Performing a ballet dance.
		Low	Getting in and out of a truck.
39. Gross Body Equilibrium	The ability to keep or regain one's body balance to stay upright when in an unstable position.	High	Walking on narrow beams in high-rise construction.
		Low	Standing on a ladder.
	Sensory Abilities		
Visual Abilities			
41. Near Vision	The ability to see details of objects at a close range (within a few feet of the observer).	High	Detecting minor defects in a diamond.
		Low	Reading dials on the car dashboard.

Table 11-1 continues

Construct label	Operational definition	Level rating	Level scale: Example
42. Far Vision	The ability to see details at a distance.	High	Detecting differences in ocean vessels on the horizon.
		Low	Reading a roadside billboard.
43. Visual Color Discrimination	The ability to match or detect differences between colors, including shades of color and brightness.	High	Painting a color portrait from a living subject.
		Low	Separating laundry into colors and whites.
44. Night Vision	The ability to see under low light conditions.	High	Finding one's way through the woods on a moonless night.
		Low	Reading street signs when driving at dusk (just after the sun sets).
45. Peripheral Vision	The ability to see objects or movement of objects to one's side when the eyes are focused forward.	High	When piloting a plane in air combat, distinguishing friendly and enemy aircraft.
		Low	Keeping in step while marching in a military formation.
46. Depth Perception	The ability to judge which of several objects is closer or farther away from the observer, or to judge the distance between an object and the observer.	High	Throwing a long pass to a teammate who is surrounded by opponents.
		Low	Merging a car into traffic on a city street.
47. Glare Sensitivity	The ability to see objects in the presence of glare or bright lighting.	High	Snow skiing in bright sunlight.
		Low	Driving on a familiar roadway on a cloudy day.
Auditory and Speech Abilities			
48. Hearing Sensitivity	The ability to detect or tell the difference between sounds that vary over broad ranges of pitch and loudness.	High	Tuning an orchestra.
		Low	Noticing when the hourly watch alarm goes off.
49. Auditory Attention	The ability to focus on a single source of auditory (hearing) information in the presence of other distracting sounds.	High	Listening to instructions from a coworker in a noisy saw mill.
		Low	Listening to a lecture while people are whispering nearby.
50. Sound Localization	The ability to tell the direction from which a sound originated.	High	Determining the direction of an emergency vehicle from the sound of its siren.
		Low	Listening to a stereo to determine which speaker is working.
51. Speech Recognition	The ability to identify and understand the speech of another person.	High	Understanding a speech presented by someone with a strong foreign accent.
		Low	Recognizing the voice of a coworker.
52. Speech Clarity	The ability to speak clearly so that it is understandable to a listener.	High	Giving a lecture to a large audience.
		Low	Calling the numbers in a bingo game.

Note. Adapted from Fleischman (1975a, 1992a) with permission of the publisher.

10.2 Appendix II – Fleishman Job Analysis Survey (F-JAS)[5]

Instructions for Making Abilities Ratings

These questions are about job-related activities. An *ability* is an enduring talent that can help a person do a job. You will be asked about a series of different abilities and how they relate to *your current job* – that is the job you hold now.

Each ability in this questionnaire is named and defined.

For example:

Arm-Hand Steadiness	**The ability to keep your hand and arm steady while moving your arm or while holding your arm and hand in one position.**

You are then asked to answer two questions about that ability:

A ***How important is the ability to your current job?***

For example:

How important is ARM-HAND STEADINESS to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	☒ (4)	⑤

*Mark your answer by putting an **X** through the number that represents your answer.*
Do not mark on the line between the numbers.

***If you rate the ability as Not Important to the performance of your job, mark the one [X] then skip over question B and proceed to the next ability.**

B ***What level of the ability is needed to perform your current job?***

To help you understand what we mean by **level**, we provide you with examples of job-related activities at different levels for each ability. For example:

What level of ARM-HAND STEADINESS is needed to perform *your current job*?

	Light a candle		Thread a needle		Cut facets in a diamond	
①	☒ (2)	③	④	⑤	⑥	⑦ Highest Level

*Mark your answer by putting an **X** through the number that represents your answer.*
Do not mark on the line between the numbers.

1 O*NET Abilities Questionnaire

[5] Retreived from: https://www.onetcenter.org/questionnaires.html

1. Oral Comprehension

The ability to listen to and understand information and ideas presented through spoken words and sentences.

A. How <u>important</u> is ORAL COMPREHENSION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
1	2	3	4	5

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of ORAL COMPREHENSION is needed to perform *your current job*?

1	2	3	4	5	6	7
	Understand a television commercial		Understand a coach's oral instructions for a sport		Understand a lecture on advanced physics	Highest Level

2. Written Comprehension

The ability to read and understand information and ideas presented in writing.

A. How <u>important</u> is WRITTEN COMPREHENSION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
1	2	3	4	5

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of WRITTEN COMPREHENSION is needed to perform *your current job*?

1	2	3	4	5	6	7
	Understand signs on the highway		Understand an apartment lease		Understand an instruction book on repairing missile guidance systems	Highest Level

3. Oral Expression	The ability to communicate information and ideas in speaking so others will understand.

A. How <u>important</u> is ORAL EXPRESSION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of ORAL EXPRESSION is needed to perform *your current job*?

①	②	③	④	⑤	⑥	⑦
	Cancel newspaper delivery by phone		Give instructions to a lost motorist		Explain advanced principles of genetics to college freshmen	Highest Level

4. Written Expression	The ability to communicate information and ideas in writing so others will understand.

A. How <u>important</u> is WRITTEN EXPRESSION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of WRITTEN EXPRESSION is needed to perform *your current job*?

①	②	③	④	⑤	⑥	⑦
Write a note to remind someone to take food out of the freezer			Write a job recommendation for a subordinate		Write an advanced economics texbook	Highest Level

5. Fluency of Ideas	The ability to come up with a number of ideas about a topic (the *number* of ideas is important not their quality, correctness, or creativity).

A. How important is FLUENCY OF IDEAS to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
1	2	3	4	5

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What level of FLUENCY OF IDEAS is needed to perform *your current job*?

1	2	3	4	5	6	7
	Name four different uses for a screwdriver		Think of as many ideas as possible for the name of a new company		Name all the possible strategies for a military battle	Highest Level

6. Originality	The ability to come up with unusual or clever ideas about a given topic or situation, or to develop creative ways to solve a problem.

A. How important is ORIGINALITY to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
1	2	3	4	5

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What level of ORIGINALITY is needed to perform *your current job*?

1	2	3	4	5	6	7
	Use a credit card to open a locked door		Redesign job tasks to be interesting for employees		Invent a new type of man-made fiber	Highest Level

7. Problem Sensitivity	The ability to tell when something is wrong or is likely to go wrong. It does not involve solving the problem, only recognizing that there is a problem.

A. How important is PROBLEM SENSITIVITY to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What level of PROBLEM SENSITIVITY is needed to perform *your current job*?

①	②	③	④	⑤	⑥	⑦
	Recognize that an unplugged lamp won't work		Recognize from the mood of prisoners that a prison riot is likely to occur		Recognize an illness at an early stage of a disease when there are only a few symptoms	Highest Level

8. Deductive Reasoning	The ability to apply general rules to specific problems to produce answers that make sense.

A. How important is DEDUCTIVE REASONING to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What level of DEDUCTIVE REASONING is needed to perform *your current job*?

①	②	③	④	⑤	⑥	⑦
	Know that a stalled car can coast downhill			Decide what factors to consider in selecting stocks	Design an aircraft wing using principles of aerodynamics	Highest Level

9. Inductive Reasoning	**The ability to combine pieces of information to form general rules or conclusions (includes finding a relationship among seemingly unrelated events).**

A. How <u>important</u> is INDUCTIVE REASONING to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of INDUCTIVE REASONING is needed to perform *your current job*?

	Decide what to wear based on the weather report ↓		Determine the prime suspect based on crime scene evidence ↓		Diagnose a disease using results of many different lab tests ↓	
①	②	③	④	⑤	⑥	⑦
						Highest Level

10. Information Ordering	**The ability to arrange things or actions in a certain order or pattern according to a specific rule or set of rules (e.g., patterns of numbers, letters, words, pictures, mathematical operations).**

A. How <u>important</u> is INFORMATION ORDERING to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of INFORMATION ORDERING is needed to perform *your current job*?

Put things in numerical order ↓	Follow the correct steps to make changes ↓				Assemble a nuclear warhead ↓	
①	②	③	④	⑤	⑥	⑦
						Highest Level

11. Category Flexibility	**The ability to generate or use different sets of rules for combining or grouping things in different ways.**

A. How important is CATEGORY FLEXIBILITY to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What level of CATEGORY FLEXIBILITY is needed to perform *your current job*?

	Sort nails in a toolbox on the basis of length ↓	Classify flowers according to size, color, and smell ↓			Classify man-made fibers in terms of their strength, cost, flexibility, melting points, etc. ↓	
①	②	③	④	⑤	⑥	⑦
						Highest Level

12. Mathematical Reasoning	**The ability to choose the right mathematical methods or formulas to solve a problem.**

A. How important is MATHEMATICAL REASONING to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What level of MATHEMATICAL REASONING is needed to perform *your current job*?

Determine how much 10 oranges will cost when they are priced at 2 for 20 cents ↓			Decide how to calculate profits to determine the amounts of yearly bonuses ↓		Determine the mathematics required to simulate a space craft landing on the moon ↓	
①	②	③	④	⑤	⑥	⑦
						Highest Level

13. Number Facility	The ability to add, subtract, multiply, or divide quickly and correctly.

A. How <u>important</u> is NUMBER FACILITY to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of NUMBER FACILITY is needed to perform *your current job*?

Add 2 and 7		Balance a checkbook		Compute the interest payment that should be generated from an investment		
↓		↓		↓		
①	②	③	④	⑤	⑥	⑦
						Highest Level

14. Memorization	The ability to remember information such as words, numbers, pictures, and procedures.

A. How <u>important</u> is MEMORIZATION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of MEMORIZATION is needed to perform *your current job*?

Remember the number on your bus to to be sure you get back on the right one			Recite the first names of the five people you just met		Recite the Gettysburg Address after studying it for 15 minutes	
↓			↓		↓	
①	②	③	④	⑤	⑥	⑦
						Highest Level

15. Speed of Closure	The ability to quickly make sense of, combine, and organize information into meaningful patterns

A. How <u>important</u> is SPEED OF CLOSURE to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of SPEED OF CLOSURE is needed to perform *your current job*?

		Recognize a song after hearing only the first few notes ↓	Make sense out of strange handwriting ↓	Interpret patterns on weather radar to decide if the weather is changing ↓		
①	②	③	④	⑤	⑥	⑦
						Highest Level

16. Flexibility of Closure	The ability to identify or detect a known pattern (a figure, object, word, or sound) that is hidden in other distracting material.

A. How <u>important</u> is FLEXIBILITY OF CLOSURE to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of FLEXIBILITY OF CLOSURE is needed to perform *your current job*?

	Tune in a radio in a noisy truck ↓		Look for a golf ball in the rough ↓		Identify camouflaged tanks from a high-speed airplane ↓	
①	②	③	④	⑤	⑥	⑦
						Highest Level

17. Perceptual Speed	The ability to quickly and accurately compare similarities and differences among sets of letters, numbers, objects, pictures, or patterns. The things to be compared may be presented at the same time or one after the other. This ability also includes comparing a presented object with a remembered object.

A. How <u>important</u> is PERCEPTUAL SPEED to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of PERCEPTUAL SPEED is needed to perform *your current job*?

	Sort mail according to ZIP codes with no time pressure ↓		Read five temperature gauges in 10 seconds to make sure each temperature is within safe limits ↓		Inspect electrical parts for defects as they flow by on a fast-moving assembly line ↓	
①	②	③	④	⑤	⑥	⑦
						Highest Level

18. Spatial Orientation	The ability to know your location in relation to the environment or to know where other objects are in relation to you.

A. How <u>important</u> is SPATIAL ORIENTATION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of SPATIAL ORIENTATION is needed to perform *your current job*?

	Use the floor plan to locate a store In a mall ↓	Find your way through a dark room without hitting anything ↓			Navigate an ocean voyage using only the positions of the sun and stars ↓	
①	②	③	④	⑤	⑥	⑦
						Highest Level

19. Visualization	The ability to imagine how something will look after it is moved around or when its parts are moved or rearranged.

A. How <u>important</u> is VISUALIZATION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of VISUALIZATION is needed to perform *your current job*?

	Imagine how to put paper in a typewriter so that the letterhead comes out on top		Follow a diagram to assemble a metal storage cabinet		Anticipate opponent's as well as your own future moves in a chess game	
	↓		↓		↓	
①	②	③	④	⑤	⑥	⑦
						Highest Level

20. Selective Attention	The ability to concentrate on a task over a period of time without being distracted.

A. How <u>important</u> is SELECTIVE ATTENTION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of SELECTIVE ATTENTION is needed to perform *your current job*?

	Answer a business call with coworker talking nearby		Monitor security TV screens for intruders throughout the night shift		Study a technical manual in a noisy boiler room	
	↓		↓		↓	
①	②	③	④	⑤	⑥	⑦
						Highest Level

21. Time Sharing	**The ability to shift back and forth between two or more activities or sources of information (such as speech, sounds, touch, or other sources).**

A. How <u>important</u> is TIME SHARING to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of TIME SHARING is needed to perform *your current job*?

①	②	③	④	⑤	⑥	⑦
	Listen to music while filing papers	Watch street signs while driving at 30 miles an hour			Monitor radar and radio transmissions to keep track of aircraft during periods of heavy traffic	Highest Level

22. Arm-Hand Steadiness	**The ability to keep your hand and arm steady while moving your arm or while holding your arm and hand in one position.**

A. How <u>important</u> is ARM-HAND STEADINESS to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of ARM-HAND STEADINESS is needed to perform *your current job*?

①	②	③	④	⑤	⑥	⑦
	Light a candle		Thread a needle		Cut facets in a diamond	Highest Level

23. Manual Dexterity	The ability to quickly move your hand, your hand together with your arm, or your two hands to grasp, manipulate, or assemble objects.

A. How <u>important</u> is MANUAL DEXTERITY to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of MANUAL DEXTERITY is needed to perform *your current job*?

Screw a light bulb into a light socket			Pack oranges in crates as quickly as possible			Perform open heart surgery with surgical instruments
↓			↓			↓
①	②	③	④	⑤	⑥	⑦
						Highest Level

24. Finger Dexterity	The ability to make precisely coordinated movements of the fingers of one or both hands to grasp, manipulate, or assemble very small objects.

A. How <u>important</u> is FINGER DEXTERITY to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of FINGER DEXTERITY is needed to perform *your current job*?

	Put coins in a parking meter		Attach small knobs to stereo equipment on an assembly line		Put together the inner workings of a small wrist watch	
	↓		↓		↓	
①	②	③	④	⑤	⑥	⑦
						Highest Level

25. Control Precision	The ability to quickly and repeatedly adjust the controls of a machine or a vehicle to exact positions.

A. How <u>important</u> is CONTROL PRECISION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of CONTROL PRECISION is needed to perform *your current job*?

	Adjust a room light with a dimmer switch		Adjust farm tractor controls		Drill a tooth	
①	②	③	④	⑤	⑥	⑦
						Highest Level

26. Multilimb Coordination	The ability to coordinate two or more limbs (for example, two arms, two legs, or one leg and one arm) while sitting, standing, or lying down. It does <u>not</u> involve performing the activities while the whole body is in motion.

A. How <u>important</u> is MULTILIMB COORDINATION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of MULTILIMB COORDINATION is needed to perform *your current job*?

	Row a boat		Operate a forklift truck in a warehouse		Play the drum set in a jazz band	
①	②	③	④	⑤	⑥	⑦
						Highest Level

27. Response Orientation	The ability to choose quickly *between "two or more movements"* in response to *"two or more different signals"* (lights, sounds, pictures). It includes the speed with which the correct response is *started* with the hand, foot, or other body part.

A. How important is RESPONSE ORIENTATION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What level of RESPONSE ORIENTATION is needed to perform *your current job*?

①	②	③	④	⑤	⑥	⑦
	When the doorbell and telephone ring at the same time, quickly select which to answer first		Hit either the automobile break or gas pedal in a skid situation			In an out of control spacecraft, react quickly to restore control
						Highest Level

28. Rate Control	The ability to time your movements or the movement of a piece of equipment in anticipation of changes in the speed and/or direction of a moving object or scene.

A. How important is RATE CONTROL to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What level of RATE CONTROL is needed to perform *your current job*?

①	②	③	④	⑤	⑥	⑦
Ride a bicycle alongside a jogger			Keep up with a car that changes speed	Shoot a duck in flight		
						Highest Level

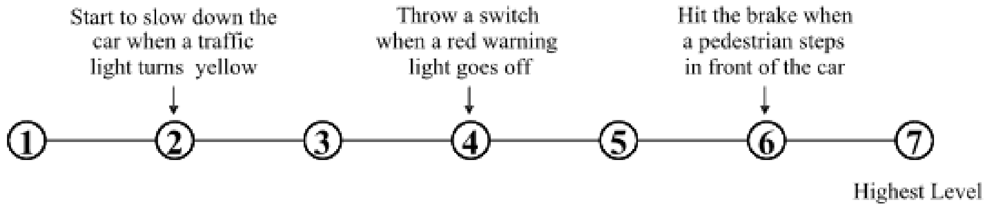
29. Reaction Time

The ability to quickly respond (with the hand, finger, or foot) to a signal (sound, light, picture) when it appears.

A. How <u>important</u> is REACTION TIME to the performance of *your current job*?

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of REACTION TIME is needed to perform *your current job*?



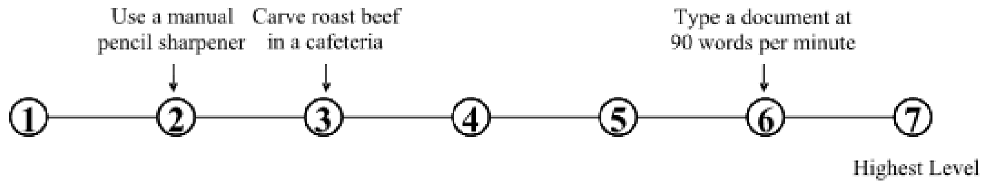
30. Wrist-Finger Speed

The ability to make *fast, simple,* repeated *movements* of the *fingers, hands, and wrists.*

A. How <u>important</u> is WRIST-FINGER SPEED to the performance of *your current job*?

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of WRIST-FINGER SPEED is needed to perform *your current job*?



31. Speed of Limb Movement	The ability to *quickly* move the arms and legs.

A. How important is SPEED OF LIMB MOVEMENT to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What level of SPEED OF LIMB MOVEMENT is needed to perform *your current job*?

	Saw through a thin piece of wood		Swat a fly with a fly swatter		Throw punches in a boxing match	
①	②	③	④	⑤	⑥	⑦
						Highest Level

32. Static Strength	The ability to exert maximum muscle force to lift, push, pull, or carry objects.

A. How important is STATIC STRENGTH to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What level of STATIC STRENGTH is needed to perform *your current job*?

Push an empty shopping cart			Pull a 40-pound sack of fertilizer across the lawn		Lift 75-pound bags of cement onto a truck	
①	②	③	④	⑤	⑥	⑦
						Highest Level

33. Explosive Strength	The ability to use short bursts of muscle force to propel oneself (as in jumping or sprinting) or to throw an object.

A. How <u>important</u> is EXPLOSIVE STRENGTH to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of EXPLOSIVE STRENGTH is needed to perform *your current job*?

1	2	3	4	5	6	7
	Hit a nail with a hammer		Jump onto a 3-foot high platform			Throw a shot-put in a track meet
①	②	③	④	⑤	⑥	⑦
						Highest Level

34. Dynamic Strength	The ability to exert muscle force repeatedly or continuously over time. This involves muscular endurance and resistance to muscle fatigue.

A. How <u>important</u> is DYNAMIC STRENGTH to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of DYNAMIC STRENGTH is needed to perform *your current job*?

1	2	3	4	5	6	7
	Use pruning shears to trim a bush			Climb a 48-foot long ladder	Perform a gymnastics routine using the rings	
①	②	③	④	⑤	⑥	⑦
						Highest Level

35. Trunk Strength	The ability to use your abdominal and lower back muscles to support part of the body repeatedly or continuously over time without "giving out" or fatiguing.

A. How important is TRUNK STRENGTH to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What level of TRUNK STRENGTH is needed to perform *your current job*?

	Sit up in an office chair		Shovel snow for half an hour		Do 100 sit-ups	
①	②	③	④	⑤	⑥	⑦
						Highest Level

36. Stamina	The ability to exert yourself physically over long periods of time without getting winded or out of breath.

A. How important is STAMINA to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What level of STAMINA is needed to perform *your current job*?

Walk ? mile			Climb 6 flights of stairs		Run 10 miles	
①	②	③	④	⑤	⑥	⑦
						Highest Level

37. Extent Flexibility

The ability to bend, stretch, twist, or reach with your body, arms, and/or legs.

A. How <u>important</u> is EXTENT FLEXIBILITY to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of EXTENT FLEXIBILITY is needed to perform *your current job*?

	Reach for a microphone in a patrol car ↓		Reach for a box on a high warehouse shelf ↓		Work under the dashboard of a car ↓	
①	②	③	④	⑤	⑥	⑦
						Highest Level

38. Dynamic Flexibility

The ability to quickly and repeatedly bend, stretch, twist, or reach out with your body, arms, and/or legs.

A. How <u>important</u> is DYNAMIC FLEXIBILITY to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of DYNAMIC FLEXIBILITY is needed to perform *your current job*?

	Hand pick a bushel of apples from a tree ↓			Perform a dance routine as part of a cheerleading squad ↓	Maneuver a kayak through swift rapids ↓	
①	②	③	④	⑤	⑥	⑦
						Highest Level

39. Gross Body Coordination	The ability to coordinate the *movement of your arms, legs, and torso together* when the whole body is in motion.

A. How <u>important</u> is GROSS BODY COORDINATION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of GROSS BODY COORDINATION is needed to perform *your current job*?

	Get in and out of a truck		Swim the length of a pool		Perform a ballet dance	
①	②	③	④	⑤	⑥	⑦
						Highest Level

40. Gross Body Equilibrium	The ability to keep or regain your body balance or stay upright when in an unstable position.

A. How <u>important</u> is GROSS BODY EQUILIBRIUM to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of GROSS BODY EQUILIBRIUM is needed to perform *your current job*?

	Stand on a ladder		Walk on ice across a pond		Walk on narrow beams in high-rise construction	
①	②	③	④	⑤	⑥	⑦
						Highest Level

41. Near Vision

The ability to see details at close range (within a few feet of the observer).

A. How <u>important</u> is NEAR VISION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
1	2	3	4	5

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of NEAR VISION is needed to perform *your current job*?

1	2	3	4	5	6	7
	Read dials on the dashboard of a car			Read the fine print of a legal document	Detect minor defects in a diamond	Highest Level

42. Far Vision

The ability to see details at a distance.

A. How <u>important</u> is FAR VISION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
1	2	3	4	5

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of FAR VISION is needed to perform *your current job*?

1	2	3	4	5	6	7
	Read a roadside billboard		Focus a slide projector			Detect differences in ships on the horizon; Highest Level

43. Visual Color Discrimination	The ability to match or detect differences between colors, including shades of color and brightness.

A. How <u>important</u> is VISUAL COLOR DISCRIMINATION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of VISUAL COLOR DISCRIMINATION is needed to perform *your current job*?

1	2	3	4	5	6	7
Separate laundry into colors and whites			Trace electrical circuits marked By various colored wires		Paint a color portrait Of a live person	Highest Level

44. Night Vision	The ability to see under low-light conditions.

A. How <u>important</u> is NIGHT VISION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of NIGHT VISION is needed to perform *your current job*?

1	2	3	4	5	6	7
	Read street signs at dusk (just before sunset)		Take notes during a slide presentation		Find your way through the woods on a moonless night	Highest Level

45. Peripheral Vision	The ability to see objects or movement of objects to one's side when the eyes are looking ahead.

A. How <u>important</u> is PERIPHERAL VISION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
1	2	3	4	5

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of PERIPHERAL VISION is needed to perform *your current job*?

1	2	3	4	5	6	7
	Keep in step while marching in a military formation		Be aware of the location of your teammates while dribbling a basketball		Distinguish friendly from enemy planes during air combat	Highest Level

46. Depth Perception	The ability to judge which of several objects is closer or farther away from you, or to judge the distance between you and an object.

A. How <u>important</u> is DEPTH PERCEPTION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
1	2	3	4	5

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of DEPTH PERCEPTION is needed to perform *your current job*?

1	2	3	4	5	6	7
	Merge a car into traffic on a city street		Operate a crane to move materials from a truck bed to the ground		Throw a long pass to a closely guarded teammate	Highest Level

47. Glare Sensitivity

The ability to see objects in the presence of a glare or bright lighting.

A. How <u>important</u> is GLARE SENSITIVITY to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of GLARE SENSITIVITY is needed to perform *your current job*?

①	②	③	④	⑤	⑥	⑦
	Drive on a familiar road on a cloudy day			See boats on the horizon when sailing	Snow ski in bright sunlight	Highest Level

48. Hearing Sensitivity

The ability to detect or tell the differences between sounds that vary in pitch and loudness.

A. How <u>important</u> is HEARING SENSITIVITY to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of HEARING SENSITIVITY is needed to perform *your current job*?

①	②	③	④	⑤	⑥	⑦
	Notice when a watch alarm goes off		Diagnose what's wrong with a car engine from its sound		Tune an orchestra	Highest Level

49. Auditory Attention	The ability to focus on a single source of sound in the presence of other distracting sounds.

A. How <u>important</u> is AUDITORY ATTENTION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of AUDITORY ATTENTION is needed to perform *your current job*?

	Listen to a lecture while people nearby are talking		Listen for your flight announcement at a busy airport		Listen to instructions from a coworker in a noisy saw mill	
①	②	③	④	⑤	⑥	⑦
						Highest Level

50. Sound Localization	The ability to tell the direction from which a sound originated.

A. How <u>important</u> is SOUND LOCALIZATION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of SOUND LOCALIZATION is needed to perform *your current job*?

	Listen to a stereo to determine which speaker is working		Find a ringing telephone in an unfamiliar apartment		Determine the direction of an emergency vehicle from the sound of the siren	
①	②	③	④	⑤	⑥	⑦
						Highest Level

51. Speech Recognition

The ability to identify and understand the speech of another person.

A. How <u>important</u> is SPEECH RECOGNITION to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of SPEECH RECOGNITION is needed to perform *your current job*?

	Recognize the voice of a coworker ↓		Identify a former customer's voice over the telephone ↓		Understand a speech presented by someone with a strange accent ↓	
①	②	③	④	⑤	⑥	⑦
						Highest Level

52. Speech Clarity

The ability to speak clearly so others can understand you.

A. How <u>important</u> is SPEECH CLARITY to the performance of *your current job*?

Not Important*	Somewhat Important	Important	Very Important	Extremely Important
①	②	③	④	⑤

* If you marked Not Important, skip LEVEL below and go on to the next activity.

B. What <u>level</u> of SPEECH CLARITY is needed to perform *your current job*?

Call numbers in a bingo game ↓			Make announcements over the loudspeaker at a sports event ↓		Give a lecture to a large audience ↓	
①	②	③	④	⑤	⑥	⑦
						Highest Level

10.3 Appendix III – End-to-end process TRI