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ASSESSMENT OF MOTIVATION AMONG WORKERS IN TECHNOLOGY ASSISTIVE PRODUCTION SCENARIOS

Examiners: Associate Professor, Lea Hannola
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ABSTRACT

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Digital tools and the rise of automation have made the shop floor knowledge intensive. Human beings still retain their importance on the production floor, but their role is being reimagined with more focus on creativity, innovation and problem-solving skills. Thus, technology is being developed in a way that augments the traditional workers capabilities by facilitating human-machine interaction. While this seems straightforward in theory, it is important to acknowledge the existence socio-technical barriers which need to be eradicated before such solutions can be successfully implemented on a large scale. Therefore, this thesis is aimed towards understanding the motivation of the workers and the perceived benefits of adopting high technology solutions on the shop floor. The study is part of a larger European project called Facts4Workers (F4W) which is dedicated towards development and evaluation of human centric smart tools for production workers. The data collection involves feedback from workers in six different production companies spread throughout the European Union. The data was then applied to Self Determination Theory (SDT) of motivation and then compared with a control group to find it's applicability based on high technology intervention. Results indicate that the F4W group demonstrated higher levels of competency, autonomy, relatedness and hence higher motivation when compared to the control group. The findings are of relevance both for companies and managers willing to adopt such technical solutions, and also for academicians interested in exploring motivation among workers.

Keywords: high technology solutions, smart factories, motivation for workers, SDT

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I feel lucky to have been a part of such an interdisciplinary project which required social, psychological and industrial engineering inputs and I hope the findings will be relevant for a better future where humans and automation work hand in hand. I would also like to acknowledge the fact that this opportunity has given me the necessary belief to pursue a career in academic research and take the next steps towards obtaining a doctorate.

I would like to apologize to my friends who I have disappointed a lot by locking myself in my room for days; Abhishek, Amila, Daniel, Rafa, Alejandro, Sohail, Sheraz, Tania, Olga, Saied I apologize for being not being social at times. I could not have survived this journey without you. My family has been a rock and has always supported me throughout this journey, especially when I needed them the most. Ayse, I am lost for words in trying to express your contribution to this thesis and my life. You have been more than a friend, a teacher and wonderful companion with whom I have spent my last year sharing my most intimate moments. Thank you for everything.

TABLE OF CONTENTS

List of Tables:

List of Figures:

Abbreviations Used

CG: Control Group

F4W: FACTS4WORKERS

SDT: Self Determination Theory

CET: Cognitive Evaluation Theory

TAM: Technology Acceptance Model

SCA: Schaeffler Group

HID: Hidria

ANOVA: Analysis of Variance

PLS: Partial Least Square

1. Introduction

Fueled by a rising population and an increase in consumer purchasing power, manufacturing has changed considerably over the years to respond to the changes in the demographic environment. Products have become diversified and to meet the demand for consumers preferences and customization, corporations have started looking for technologies that allow flexibility in manufacturing (Orio et al., 2015). To account for these advances in technology, the umbrella term, “industry 4.0” has become the lingua franca for automation and information technology that is rapidly reshaping manufacturing (Kagerman, Wahlster and Helbig, 2013). Bauer and Wee (2015) mention that the revolution is heralded by (i) rise in data volumes, computational power, and connectivity; (ii) emergence of analytics and business-intelligence capabilities; (iii) new forms of human-machine interaction; and (iv) improvements in transferring digital instructions to the physical world. In this context, it is important to understand the ramifications on human workers and operators who have the critical task of ensuring adherence to standards, specifications and machine maintenance (Boston Consulting group, 2015; Yew et al., 2016).

Hirsch Kreinsen (2016) lays out the possible alternative schemes, with one emphasizing on automation and deskilling while the other accentuates the importance of humans in decision making and creative role in manufacturing. Expanding on the latter, which seems more likely in terms of both technological possibilities and social acceptance, we see that Cyber Physical Systems (CPS) has the potential to augment production capabilities by enabling collaboration between information systems, machine accuracy and human intelligence.

Additionally, multiple studies predict that European demographics point towards an ageing population and it is becoming increasingly important to conceptualize workplaces that can motivate and sustain employees in the long term for industrial success along with societal flourishing (Richter et al., , 2014; Berlin et al., 2013; Fantini et. al, 2014). This implies that the industry needs to develop a holistic model of employee’s wellbeing involving constructs such as work-life balance and both physical and mental health (Taghavi et al., 2015).

1.1 Objective and Research Questions

Much of the literature has focused on new technological paradigms in manufacturing and human-machine augmented capabilities, while it remains to be seen how these affect the adopters of the technology and whether these developments are delivering their intended results.

To meet the objective of the thesis, the following research questions are put forward:

RQ1. How should the motivation of workers in the workplace be assessed?

RQ2. Do technologies that augment workers' capabilities have any effect on their motivation levels to work?

1.2 Research Scope and Delimitation

The purpose of this research is to evaluate the motivation levels of the workers in the F4W project after the introduction of the technological solutions in the workplace. A control group of regular employees in the company is selected as a reference for comparison to isolate the effect of the F4W solutions of the workers' psychological state. Within the scope of human centric solutions, the goal of the project is to increase the workers satisfaction and consequently their motivation to work. The effect of motivated workers on productivity and efficiency are delimited from the scope of this work owing to ethical considerations. Also long-term effects of these solutions on the workers are not a part of this study either.

1.3 Structure of Report

This thesis is divided into 8 chapters and a brief description of each is given as follows and Table 1 provides a visual schema of the report.

Chapter 1: An introduction to the industry 4.0, smart factories, cyber physical systems and augmented workers is introduced. The chapter also explorers, the scope of the study, research questions, gaps and objectives as well.

Chapter 2: This chapter delves into the literature to review already conducted studies in the field of technology introduction in manufacturing as well as theories of workers motivation.

Chapter 3: Using insights from the preceding section, the method for data collection as well as analysis is thoroughly described and justified in this chapter. A review of the techniques used is also accounted for in this section.

Chapter 4: This chapter describes the solutions used by the F4W consortium to assist workers in their production tasks. An overview of the technologies along with a brief justification forms the structural basis of the chapter.

Chapter 5: Descriptions of the industrial partners are provided to offer the reader with an understanding of the context of use of the solutions.

Chapter 6: Results are presented to compare the effect of technological solutions on the workers motivation both using descriptive and visual means. These are compiled on the basis of use case of the companies as well as a combined case to present a macro view of the project.

Chapter 7: The significance of the results is presented in this chapter. A critical analysis is also made that discusses the generalizability of the findings.

Chapter 8: This chapter reports the success of the findings in terms of the stated objectives. Insights into future research is also added as a recommendation to those interested in further inquiry.

Chapter 1. Introduction

- Background for thesis
- Research Questions and Objectives

Chapter 2. Literature Review

- Previous Works in the field of Motivation
- Technology in Manufacturing

Chapter 3. Methodology

- Establishment of research strategy
- Description of method used

Chapter 4. Facts4Workers Solutions

- Overview of solutions used for smart factory employees

Chapter 5. Use Cases

- Context and need specific description of solutions used in each company

Chapter 6. Results

- Computation of results for each company
- Combined results for macroscopic analysis

Chapter 7. Discussions and Limitations

- Key Findings and scope of results obtained

Chapter 8. Conclusion

- Implications for future research

Table 1. Structure of Report

2. Literature Review

Automation reduces the importance of workers as machines have proven themselves in reducing the chance for errors, accidents while contributing to higher productivity at the same time. However, the necessity for human intervention cannot be fully discredited and full automation devoid of human involvement is neither socially acceptable nor sustainable. The market now demands mass customizability and hence the need for human machine collaboration is growing stronger. The ultimate goal is to bridge the gap between the two dialectic paradigms of complete automation and manual work, towards a solution that reinvents humans as knowledge workers augmented with technology that assist in everyday work.

This section will be divided into two main themes, one dealing with the development of technology in manufacturing while the other will deal with the motivation for employees to work and prominent theories in this field.

2.1 Development of Production Technology

Industrial revolution completely changed the feudal agricultural societies harboring widespread changes in the way goods were produced and consumed, society and work is organized, and the way institutions supported and fostered the changes. Much of the western world was influenced by Adam Smith's idea of capitalism supported by protestant work ethics which promoted maximization of the self-interest of individuals through hard work and labor (Furnham, 1984). As agricultural work started being replaced with industrial work, there was a need for training the workers and also for organizing. and maximizing efficiency in the work place. Taylor developed his time and motion studies which paved the way for a new science of management (Kanigel, 2005). Fordism at the turn of the twentieth century revolutionized manufacturing by standardizing products, using assembly lines to increase efficiency and paying wages which effectively turned it workers into consumers that could ultimately afford the produced goods (Schoenberger, 1988). Thus, the Fordist era started being characterized by mass produced commodities, goods that were cheaper to produce and sell, and an unskilled workforce that could be employed to perform simple tasks in the factory floor. With time as the market became more diversified, the paradigm shifted towards post Fordism and neo-liberalism, a landscaped dominated by small production centers, highly specialized workforce, global sourcing and procurement and the rise of computer and information technology (Reynolds and Szerszynski, 2012). Fig 1. depicts the chronological development of manufacturing systems over the years.

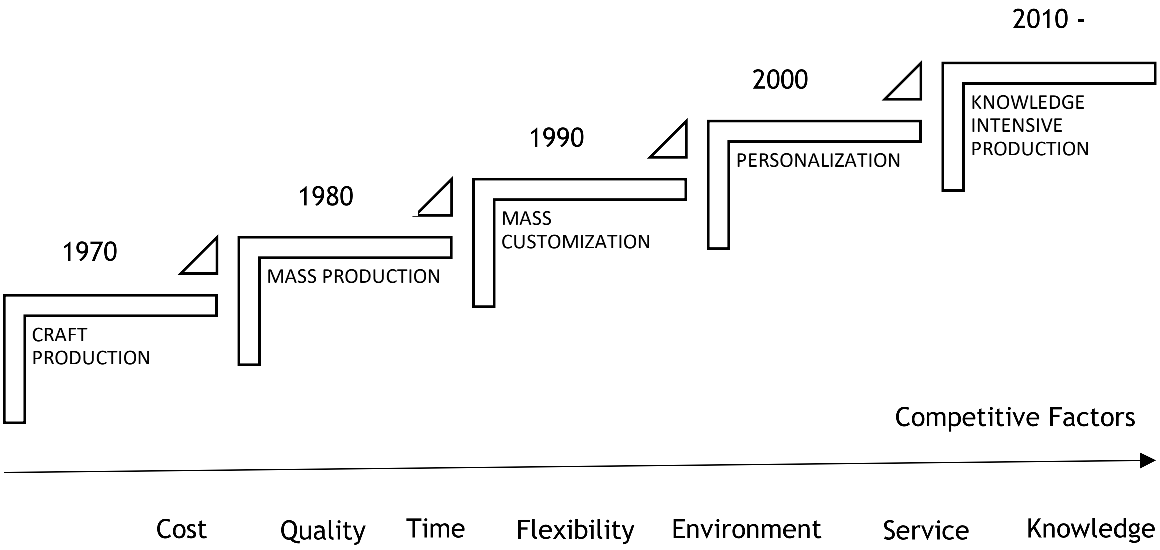

Figure 1. Chronological Development of Manufacturing Systems (adopted from Hannola et al, 2016)

The driver of development of production model has primarily been technology, product and market. Hannola et al. (2016), defines production models according to the needs of the industry and categorized them into:

1. Project Based: typically lower quantities and high customization
2. Job Based: specific orders tailored towards a customer
3. Batch Production: products manufactured over stages in a predefined quantity
4. Just in Time (JIT): efficient manufacturing aimed at reducing response times from customer and suppliers alike
5. Mass Production: high volume of product with less variation or customizability

Production after the 80's and 90's experienced a revolution with Toyota Production Systems and lean manufacturing focusing on creation of value through reduction of waste (Holweg, 2007). Six-sigma is a set of principles that aims to minimize variation in production and consequently achieve low defect rates in the order of less than 3.4 parts per million (Tennant, 2001).

In a bid to remain competitive, companies looked to focus towards high customization production strategies where products are increasingly being built in accordance with customer specifications (Orio et al., 2015; Forza et al., 2007). Engineered to Order (ETO), Assemble to Order (ATO), Manufacture to Order (MTO), Make to Stock (MTS) are just some of the popular strategies which involve customers in a highly customizable production process, each of which demands different set of skills and knowledge from the workers (Hannola et al., 2016)

Data and information are becoming more relevant today and has led to the widespread permeation of predictive manufacturing which allows for better decision making and optimization (Lee et al., 2013). Gao et al. (2011), remark that manufacturing is becoming highly specialized with focus on one Product Service System (PSS) and moving towards a paradigm of Service Oriented Manufacturing. Li et al. (2010), proposed Cloud Based Manufacturing (CMfg) using Industrial internet of Things (IIOT) and cloud-based technologies as a service paradigm that would enable true resolution of the problems faced by distributed and Networked Manufacturing (NM). Hessman (2013), states that the dominance of data and information in supporting manufacturing has predicated the concept of smart factories. Sustainable thinking has also made its way into manufacturing with production models focusing on all three pillars of environment, society and economics (Garetti & Taisch, 2012). Tao et al. (2015), also posit that service orientedness and green thinking have dominated the manufacturing landscape in the past decade.

The rapid developments in production models and technology demand reinvention of workers role where craft and knowledge of producing goods has been supplanted with skills and competencies requiring them to be decision makers in automated environments. Human intervention is expected to remain crucial as co-ordination will become a key responsibility for workers in self-controlling systems that are connected through IIOT (Brettel et al., 2014). Organizations have started introducing "knowledge work tools" and workers are now characterized as "knowledge workers" with competencies related to problem solving, innovation skills and decision making (Armbruster et al., 2007; Lampela et al., 2015).

Weyer et al. (2015) remarks that Smart Machines and Augmented Operators would be essential focal points in the transition to Industry 4.0 paradigm and factories of the future. Next generation assessment and evaluation of performance is expected to be human centric as suggested by Kaare and Otto (2015) using parameters from sensors integrated in the smart factory infrastructure. Hecklau et al. (2016), predict that in the future, manufacturing environment will require a new set of competencies from workers and identified 28 such qualifiers (Fig 2) that will be critical in Industry 4.0.

Category	**Competence**
Technological	State of the art knowledge Technical Skills Process Understanding Digital media Skills Programming Skills IT security
Methodological	Creativity Entrepreneurial Thinking Problem Solving Conflict Solving Decision Making Analytical Skills Research Skills Efficient Mindset
Social	Intercultural Skills Language Communication Networking Team Work Co-cooperativeness Leadership Knowledge Transfer
Personal	Flexibility Ambiguity Tolerance Motivation to Learn Work under Pressure Sustainable Mindset Compliance

Figure 2. List of Core Competencies for the Modern Worker (Hecklau et al., 2016)

2.2 Motivation of employees

As society started being characterized by work differentiation and employment, numerous studies have been put forward since the 1950's to explain motivation in workplaces. Among the pioneers were Hersberg, Mausner and Snyderman (1959) who proposed that human beings have inherent needs pertaining to maximization of comfort and growth of psychological state of mind. The researchers then interviewed 200 subjects consisting of engineers and accountants who were asked to recall instances when they remembered being exceptionally positive and negative about their work. From the study it was concluded that the subjects characterized enjoyable working condition and salary as lower order needs, while fulfilment, achievement, responsibility and meaningful work were attributed to higher order psychological needs. This led Hersberg and their colleagues to their hypothesis that "satisfiers", classifying higher order needs and "hygiene" which classifies lower order needs are factors that act independently on a person's motivation. A major hypothesis of their theory is that while satisfiers are positively corelated to the motivation and performance of an individual, dissatisfiers are negatively corelated to motivation. A classification of Hersberg's Satisfier and Hygiene factors, and ideal type combinations are given in Table 2 and Table 3 respectively.

Satisfiers	Hygiene
Challenging work	Security
Recognition	Salary
Opportunity for meaningful work	Work Condition
Involvement in decision making	Insurance
Sense of importance	Vacation
Achievement	Relationship with Peers
Personal growth	Company Policy
	Relationship with Boss

Table 2. Characterization of Motivation and Hygiene Factors (Hersberg, 1996)

High Motivation & High Hygiene	Low Motivation & High Hygiene	High Motivation & Low Hygiene	Low Motivation & Low Hygiene
Ideal	Low Complaints, work through the motions	Unhappy, unpredictable	Avoid

Table 3. Motivation & Hygiene Scenarios (Value Based Management, 2016)

Hersberg's theory was a pioneering study but was severely criticized by other researchers in the field. One of the criticisms is that Herzberg's studies failed to provide sufficient grounds for association between high satisfaction and implied higher productivity. Vroom (1964), noted that recollection of past incidents may elicit biased responses as people attribute positive scenarios with their personal achievements while negative situations are blamed on external environmental factors. Vroom's criticism was also directed towards the methodology employed by Hersberg's study. Burke (1966), Ewen (1964) and Dunnette, (1965) remark that the motivation and hygiene factors may overlap and there is little to suggest that they are mutually exclusive rather than being on a spectrum. Finally, Smith and Kendall (1963) raise questions about the subjective nature of the responses as some individuals may be satisfied with their work despite poor working condition and that the Two Factor Theory does not take individuality into account.

As a counter movement to organismic theories, hedonic theories were put forward to explain human behavior in work and motivation. Expectancy theory by Vroom explains that human motivation to choose to behave in a set way is contingent on the outcome of the particular behavior (August 1974). Therefore, the attractiveness of the outcome is a key determinant in the process of selection of behavior. As an implication of this theory, rewards should be designed in way that motivates employees to perform better. Three key terms are thus introduced in the context of this theory: expectancy of an action, instrumentality or means to an end, valence or the attractiveness of the outcome (Parijat and Bagga, 2014).

These terms are further defined in detail as:

- Expectancy: The idea that ines actions will lead to their defined performance level (Lee, 2007).
- Instrumentality: The faith that a certain reward is expected if performance goals are met (Lee, 2007)
- Valence: The value of the result itself people (Lee, 2007)

In the context of understanding motivation among employees, Porter and Lawler's (1968) concepts of Intrinsic and Extrinsic motivation form a major basis of understanding the Self Determination Theory (SDT). Intrinsic motivation refers to the natural pleasure one derives from a task or activity itself. Extrinsic Motivation on the other hand refers to an external benefit that an employee gains by completing a task. Porter and Lawler's (1968) model is based on designing a workplace that includes both aspects and leads to an increase in productivity and job satisfaction. Research by Deci (1971) found that these assumptions proved otherwise in the workplace where extrinsic and intrinsic motivation may sometimes have a negative effect on each other, specifically in the case of external rewards which was shown to subvert intrinsic motivation. This lead to further research where external aspects like competition, deadlines, surveillance and evaluation were found to be detrimental towards intrinsic motivation, creativity, cognitive flexibility, problem solving and hence autonomy in the personnel (Amabile, Dejong & Lepper, 1976; Smith 1975; Amabile, Goldfarb, & Brackfield, 1990; McGraw, 1978). Research conducted under the scope of Cognitive Evaluation Theory (CET) also suggested that a feeling of competence is central towards employee motivation. Deci, Koestner and Ryan (1999) corroborated these finding in a meta-analysis of 128 laboratory experiments where they were able to conclude that external rewards do indeed impede intrinsic motivation. Gagne and Deci (2005) however, note that CET had major shortcomings including; these studies were controlled experiments rather than real life observation in companies; some tasks in real work settings may not be inherently captivating and thus analysis from the point of view of intrinsic motivation is impractical and might need external rewards to fulfill the gap; CET establishes a dichotomy between external and internal motivation in a situation where decision makers have to focus on one or the either whereas in reality motivation exists across a spectrum.

Self Determination Theory (SDT) introduces the concept of choice and voluntariness to participate in a task (Gagne and Deci, 2005). A differentiation is thus evolved to autonomous motivation and controlled motivation. While autonomous motivation comes voluntarily from the excitement of participating in a task, there is a negative connotation associated with pressure and supervision in the controlled dimension. SDT also involves amotivation, a terminology associated with lack of interest and willingness to perform a task. At its core, SDT is an extension of the organismic view of individuals necessity for psychological growth that affects their motivation. These needs were categorized in the SDT theory as competence, autonomy and relatedness (Ryan and Deci, 2000). Explicating further to reveal the scope of these terms, the literature defines them as:

- Autonomy: The need to control and experience behaviors as voluntary (Niemiec & Ryan, 2009).
- Competence: The need to experience behaviors as successfully performed (Niemiec & Ryan, 2009).
- Relatedness: The need for purposeful connections and the desire to interact with people (Baumeister & Leary, 1995).

Table 4 shows SDT characterization of the factors on the degree of motivation and regulation.

Amotivation	Extrinsic Motivation				Intrinsic Motivation
	External Regulation	Introjected Regulation	Identified Regulation	Integrated Regulation	
Unwilling regulation	Possibility of reward and punishment measures	Self-worth based on performance	Significance of goals and Values	Relation and unity between goals, values and regulation	Appeal and fulfillment of task
Absence of motivation	Controlled motivation	Moderately controlled motivation	Moderately autonomous motivation	Autonomous motivation	Inherently autonomous motivation

Table 4. SDT Continuum with nature of Regulation and degree of Motivation (Gagne & Deci, 2005)

Illardi et al. (1993), made a comparative study using SDT to assess differences in perception of motivation between employees and their supervisors in a factory setting. Their findings confirmed that while all three factors of autonomy, competence and relatedness were associated positively with greater job satisfaction and well-being, autonomy was exceptionally significant in determining satisfaction of the employees. The authors also remark that their work is noteworthy in establishing the validity of SDT's hypothesis of psychological needs being as important or even more instrumental for satisfaction than wage and position in the frame of a factory setting.

Roca and Gagne (2007) studied the effect of introduction of Information Systems (IS) for continuous learning in workplaces. Their study employed a mix of TAM and SDT theory for assessing the motivation of employees, specifically in their intention to continue with the system. Their study compiled 164 responses from employees working in the International

Labor Organization, United Nations Educational, Scientific and Cultural Organization, United Nations Development Programme and Office of the United Nations High Commissioner for Human Rights, which showed that workers felt higher degrees of autonomy, competence and relatedness and was directly influencing their intrinsic and extrinsic motivation to continue using the e-learning platform.

As more and more companies continue to introduce high technology solutions in the workplace, a key challenge remains in making employees accept and adopt these solutions. Over the last few decades literature has exploded with Information System (IS) and Technology Acceptance Model (TAM) research. Theory of Reasoned Action (TRA) developed by Fishben and Ajzen (2011) states that an individual's behavior is closely linked to the outcome of the action and forms the theoretical basis for TAM model developed by Davis (1989). Technology Acceptance models generally include Extrinsic Motivation represented by constructs such as perceived usefulness and denotes a person's desire to act in a way for obtaining a particular reward (Vallerand 1997; Deci and Ryan 1987; Davis et al, 1992). Although TAM models do not include intrinsic motivation, a study by Zheng et al. (2008) showed that inclusion of intrinsic factors can explain motivation 71.3 % higher compared to traditional models.

A meta-analysis by King and He (2006), found 140 TAM research articles in leading journals with Information and Management journals sharing the bulk of the activity. Out of the 88 papers selected for the study, Perceived ease of use, perceived usefulness, Behavioral Intention and Attitude constructs were homogenously reported with the authors finding Behavioral Intention and Perceived Usefulness to be highly reliable for usage in multifaceted situations.

TAM literature has focused on two main factors that affect employee engagement in high technology or novel solutions in the workplace; system design characteristics and individual's perception and experience with the system. Viswanath Venkatesh (2000), conducted three studies which included employees in financial service, retail and real estate sectors to explore attitude towards new information systems in the workplace. The study used a partial least square method to analyze the data regarding user reactions to new systems and the results indicate that despite increased interaction with the system over time, an individual's prior perception towards the system were more dominant in regulating perceived ease of use and ultimately technological acceptance. The author also calls for more emphasis on general system related training rather than focusing on system and design traits. Figure 3 shows the anchor and adjustment methods for TAM as proposed by Venkatesh (2000).

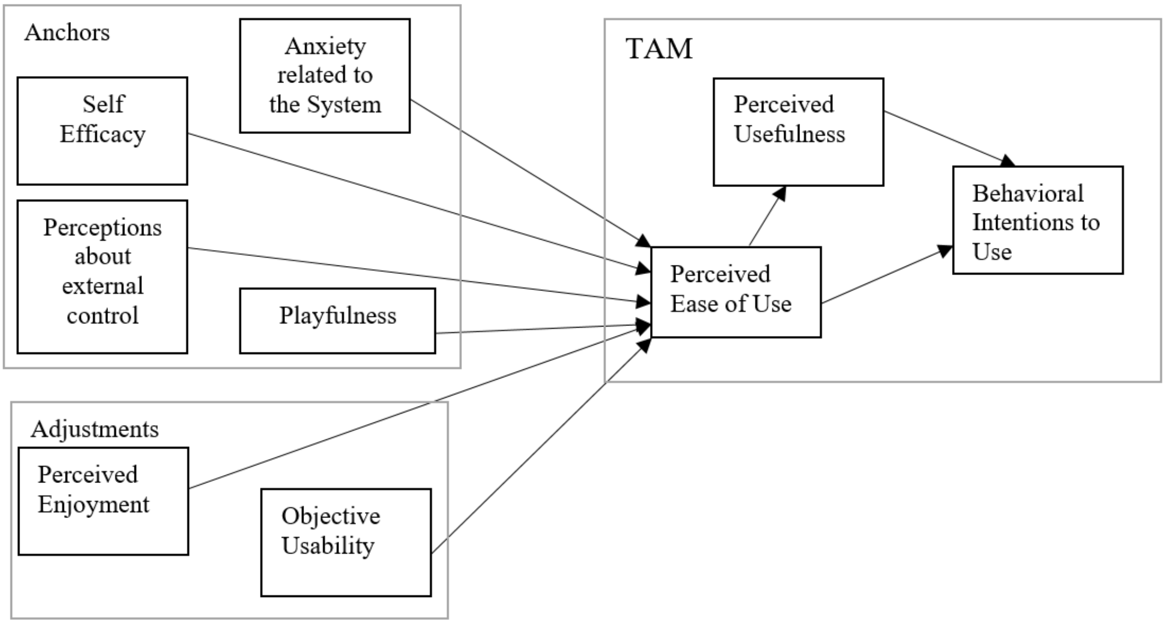

Figure 3. Technology Acceptance Model with Anchor and Adjustments (Adapted from Venkatesh, 2000)

Bagozzi (2007), however finds that TAM does not include group, cultural or social aspects in the model. The intention construct in TAM analyses "personal intentions" and overlooks a critical determinant in the form of group or collective intention and decision making which reflects the social normative influence on an individual as highlighted by Kelman (1974).

In conclusion, as the industry starts to demand different skillset from the workers it remains to be seen how competencies for smart factory and Industry 4.0 can be taught through education and training. Technology is augmenting workers capabilities in production environments however literature has mostly focused on adoption characteristics of

Information Systems among workers, implying that these studies are motivated towards pushing workers to use technologies that would increase productivity. No studies were found that establishes adoption of technology in smart factories to the psychological growth and motivation of the workers

3. Facts4Workers Solutions

The Facts4Workers (F4W) project consortium was focused on developing “worker-centric” solutions in a smart factory setting including aspects such as job satisfaction, innovation and problem-solving skills. The solutions were built using a modular approach to suit applicability in a wide range of industrial use cases. These Human Computer Interaction (HCI) or Human Machine Interaction (HMI) blocks were designed to assist workers in their daily tasks by supplying them the necessary knowledge in their production environment. Technological advancements in analytics, visual frameworks, semantics form the back-end of the smart factory infrastructure. Application Programming Interface (API’s) relay production information, maintenance information, production techniques and task specific content to the workers using the F4W building blocks (Facts4workers, 2018). Fig 5 depicts the F$W smart factory building blocks.

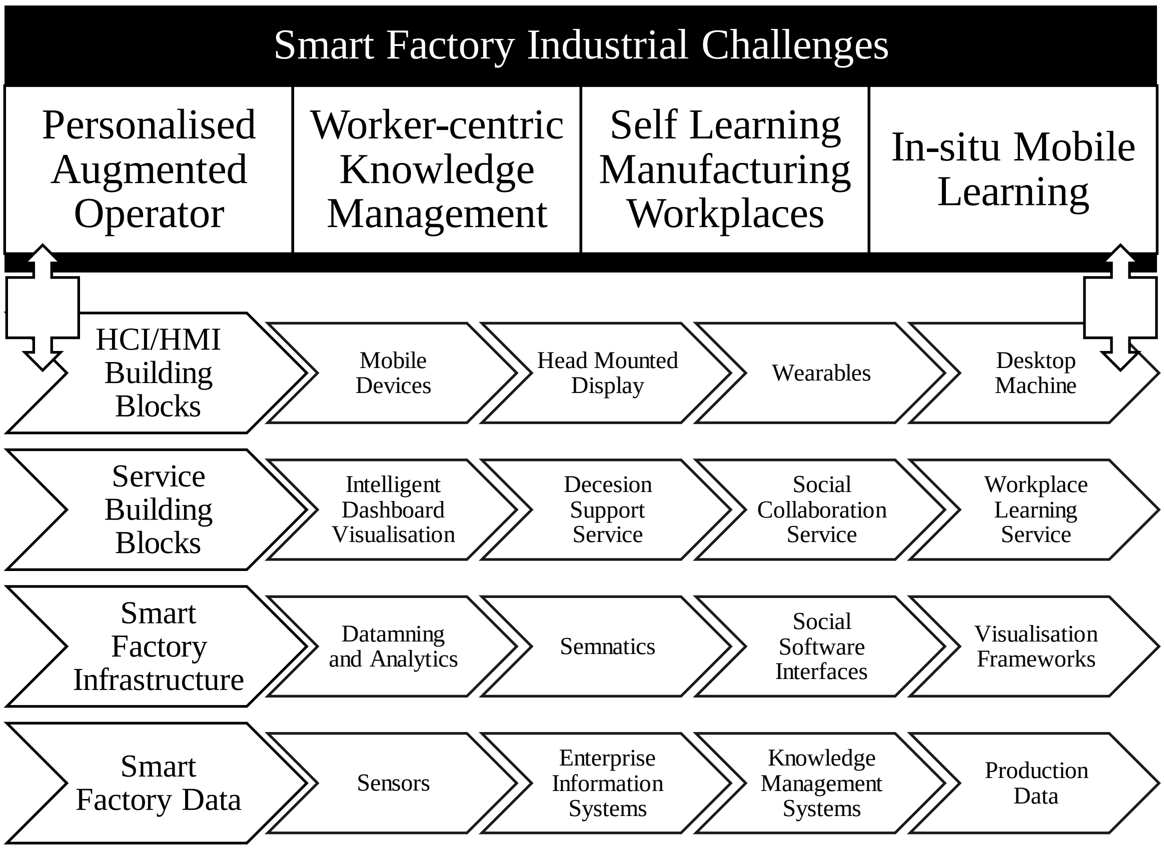

Figure 4. Overview of F4W Smart Factory Building Block (Facts4workers, 2018)

3.1 Software Architecture

A modular approach was taken so that the system architecture can be divided into parts capable of being built individually. Reverse proxy configuration was used to channelize data exchange between the Human Computer Interface and backend building blocks. was the choice markup language in conjunction with angular to deal with the frontend while backends were developed in accordance with the needs. Each module or Building Block (BB) used proxies as communication protocol. More complex and demanding tasks were dealt with Semantic Workflow Engine (SWE) on the backend (Facts4workers, 2018). Fig 5 shows the system architecture of the Facts4Workers solutions.

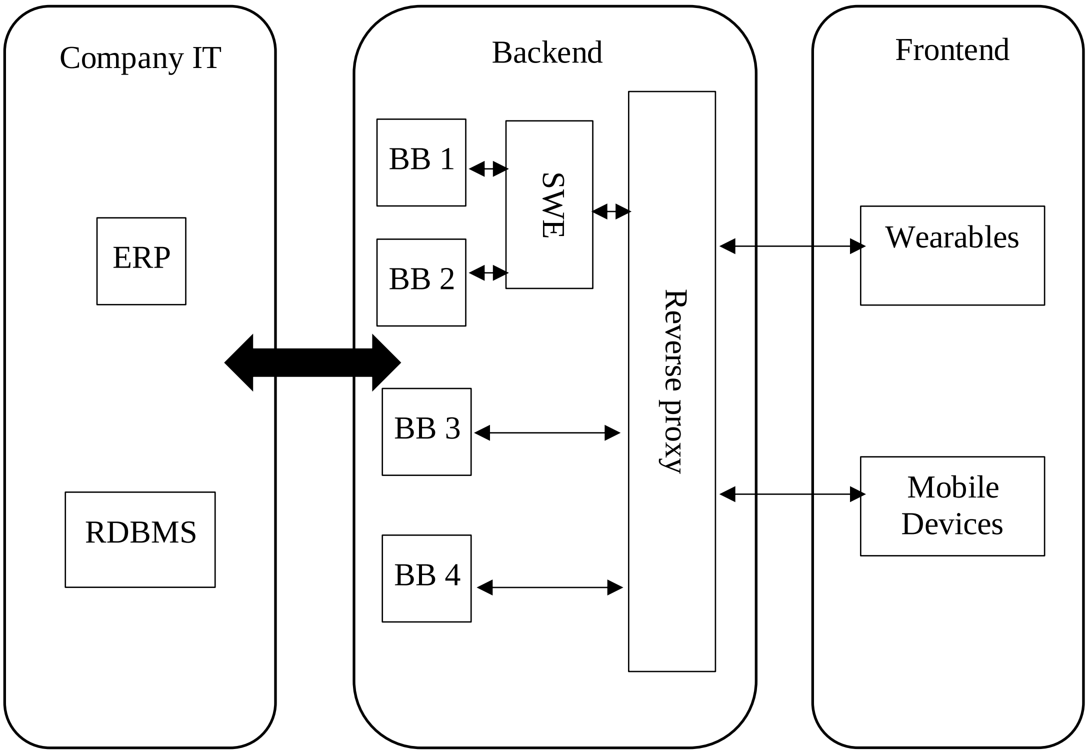

Figure 5. F4W architecture linking Frontend and Backend BB (Facts4Workers, 2018)

3.2 Semantic Workflow Engine

An adaptive algorithm was created that could assist the workers in the in their production and give solutions when critical situations arose. Human task performance was translated into machine language using the RESTdesc method. The SWE planned and proposed tasks that could be performed by the machine or required human intervention. It also follows a live approach where every preceding step and action is taken into account to determine the next course of action. Fig6 shows the F4W semantic workflow algorithm.

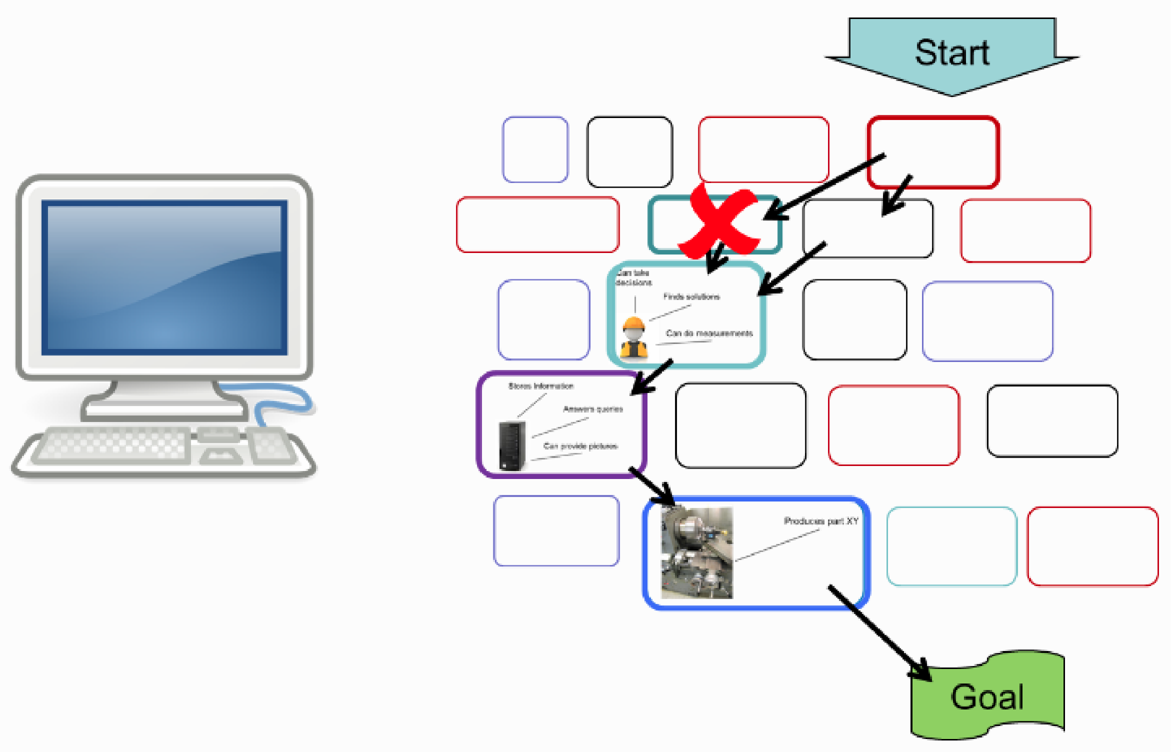

Figure 6. Semantic Workflow Algorithm (Facts4Workers, 2018)

3.3 Human Machine Interface

This section will focus on devices and interfaces that are used for implementing the F4W solutions. Three factors were deemed crucial for the choice and application of HMI and HCI to assist workers in their daily production activities (Facts4workers, 2018). These are:

1. Mobility and Availability
2. Experience and Usability
3. Knowledge transmission and visualization

To support workers with the necessary information in the shop floor, the devices need to be easy to carry and robust. The interaction needs to be designed in a way that is smooth and seamless as well. Third, the relay of information needs to be as simple and visual as possible so as to ensure maximum assistance and usability.

3.3.1 Mobile and Wearable Devices

One of the key features of Industry 4.0 is the permeation of already available sensors and technologies in the production floor. Much of what can be done is based on the context of use and presents tremendous potential for use in shop floors. Mobile and wearable devices use an array of location based and image-based sensors which can enable gathering of live manufacturing data and also give off alarms or notify operators in case of abnormalities of critical events.

3.3.1.1 Smart Glasses

Manufacturing presents a pressing challenge in the form of a demanding environment where a worker needs both hands to operate and is thus simultaneously unable to interact with screen-based interfaces. Peripheral information was achievable through deployment of smart glasses which not only freed the worker from the constraints of carrying an additional device but also provided information only on demand.

3.3.1.2 Tablets and Smart Phones

Portable screen-based interfaces are cheap, popular and widely available. The high level of commercial familiarity reduces the need for training as workers are able to work with them intuitively. F4W employed tablets and smartphones as a core solution, as touch screen capabilities coupled with large displays for presenting information, diagrams, schemas and instructions made it as a very convenient and practical alternative. For suitability in Industrial environments, the devices were designed in a manner that would be able withstand heavy usage, frequent drops and scratches.

3.3.1.3 Smart Watches

Smart watches were deemed ideal for alarms and notification and are most effective when a compromise is deemed necessary between a hands-free smart glass or a hands mobile phone interaction. Limitation wise, the reliance on a smartphone makes its usage cumbersome but with further developments, independent smart watches offer the promise of native standalone applications.

3.3.2 Novel Interaction Concepts

Hassle free interaction with the HCI/HMI is critical in ensuring the success of the solution. Poor or inefficient interaction would detract from the original goal of the project and instead contribute to low hygiene factor causing frustration and low levels of adoption.

3.3.2.1 Touch and Gestures

Interaction with screen-based interfaces can often prove challenging in production and manufacturing environments. To utilize touch technology, developmental focus needs to be allocated to touch friendly fabric for gloves and also screens that would eradicate any unwarranted effect of industrial chemicals or dust. Alternatively, gesture recognition eliminates the need for contact using already available technologies such as Kinect or Leap Motion sensors. An important concept here is the intuitiveness of the control mechanism, as familiarity with touch-based technologies far outweigh those of motion control or gesture-based technologies. Facts4Worker interaction solutions are developed in accordance with the principles of both intuitiveness and learned control.

3.3.2.2 Voice Control

As established already, industrial environments demand handsfree control mechanism within the HCI/ HMI. Voice control allows an excellent possibility to integrate solutions within existing mobile operating systems like that of google or apple. Some of the roadblocks for voice control lie in developing multilingual support, accent recognition as well as background noise cancellation in loud environments. Voice support was used in conjunction with other interaction mechanisms to augment the capabilities of the smart factory workers.

3.3.2.3 Augmented Reality

Unlike other concepts in HCI/HMI interaction, Augmented Reality (AR) is new to both commercial and industrial usage. At its core, AR offers the convenience of on demand information which is overlaid in the natural environment of the user. This especially useful considering hands-free approach with smart glasses and gesture control technologies. Facts4Workers project focused on developing AR in a way that would offer peripheral information that would not interfere with the line of sight of the worker. Information on machines and tasks along with models and instructions would be activated in real time three-dimensional space whenever the worker or the task at hand demands it.

4. Use Cases

This section describes the case companies used in the project and gives an overview of the needs and F4W solutions implemented in their workplaces.

4.1 Thermolympic

Thermolympic is a family owned business established in Zaragoza, Spain and specializes in thermoplastic injection moulding. Their customers range from OEM manufacturers in the car making industry to suppliers of end consumer products for supermarkets. One of the challenges that the F4W project decided to focus on was the issue of paper documents being transferred back and forth in the organization leading to loss of information and inaccuracy because it was difficult to determine the current version of these documents. Since work piece related instructions and part specific knowledge was handed over by peers and paper-based documents, information reported in them were hard to manage and lacked specificity. Moreover, the delay in communication from operators to management over traditional channels meant that decision and planning regarding manufacturing were based on outdated data.

The use case Paperless information management system provided an opportunity to share real-time information and support the in situ mobile learning paradigm as suggested in the F4W solutions. ICT tools would be able to monitor and standardize reporting of production data. This would not only improve production quality and decision making, it would also provide employees with more opportunities to access context specific knowledge and trainings in order to have growth in their career (Dener et al., 2015).

4.2 Schaeffler (SCA)

Two of Schaeffler's factories in Schweinfurt and Ingolstadt were involved in the project. Schaeffler is a considerably large organisation with over 87000 employees in 50 countries.

In the first use case, the factory under consideration (SCA1) experienced a change in their production from series production to value stream production. Quality Assurance (QA) staff and production employees needed to be in constant synergy with each other while working on documentation and selection of production process. This presented an opportunity to eliminate paper documents by providing a platform for centralized exchange of information including critical processes and shift handover (Dener et al., 2015). Contingency measures could also be avoided as assistance requests would reduce, and employees can be supported with assistance for problem solving skills, which in turn would increase production quality and reduce strain in the workplace.

The second context-of-use (SCA 2) is meant to make handover of shift more efficient. (Dener et al., 2015). The factory was suffering from a variety of personnel involved in the production of chain spanners writing or verbally exchanging information for the proceeding shift. This process is not only inefficient but is also prone to errors and delay. ICT capabilities would largely be able to avoid such situations by employing centralized information systems that could be displayed on handheld screen interfaces along with the necessary rights to the right personnel. The entire workplace would benefit from this solution with operators becoming more self-sufficient and competent.

4.3 EMO

EMO Orodjarna d.o.o. (EMO) serves car making and aviation industries through the production of in-house metal stamping tools. The company manufactures progressive and transfer tools that are assembled into the required products for its customers. Close ties are maintained with end users and customers, involving them throughout the production process from design to quality control and shipment. Within this company two use cases have been raised which are discussed as follows.

Personalized augmented operators

This use case deals with missing information which causes delay in work during assembly. Each operator dealing with a specific machine becomes aware of the problems or deviations only after starting their shift. Tool switching also suffers from the lack of information about the progress of other jobs at hand. F4W workers are supported with Augmented Reality Tools which provide them with the necessary information required for their production activities (Lacueva et al., 2018).

Worked-centric rich-media knowledge sharing/management.

Similar to previously mentioned challenges, the EMO workplace also suffers from a lack of efficient means to share and collaborate on production related problems. F4W project combines expertise in ICT, workflow and information management for supporting the workers with the necessary technological solutions. Touch and gesture based rugged devices were provided to solve the challenge at hand (Lacueva et al., 2018).

4.4 Thyssenkrup Steel Europe (TKSE)

ThyssenKrupp Steel Europe AG (TKSE) Works with over 19500 employees supplying carbon flat steel products for highly challenging applications in a wide range of industries. Skilled workers are deemed crucial in their high-quality production and brings in a lot of complexity as employees have to be trained for constant development of competencies.

The use case presents maintenance and repair employees that handle TKSE's of Heating, Ventilation and Air-Conditioning (HVAC) unit in Duisberg, Germany. Fault reporting measures include telephone or paper documents lacking specific details about the nature of the problem, spare part requirement or location. Naturally inexperienced employees suffer not only from an awareness of the environment but also lack competencies that would allow them to troubleshoot independently without requiring assistance from more experienced employees. Additionally, more than one employee may be engaged in the same work without awareness of the other's involvement (Dener et al., 2015).

F4W solutions would be effective in eradicating these problems by providing information specific to the context of the problem through a mobile knowledge management platform. Communication and collaboration capabilities would improve between the workers providing better information exchange thereby eliminating redundancies in work.

4.5 Hidria Dieseltec and Rotomatika (HID)

Hidria Dieseltec and Rotomatika are Slovenian companies engaged in the production of Engineered to Order (ETO) assembly lines for Hidria technology Center and mass production of rotors for electric motors in the automotive industry respectively. Hidria Dieseltec was suffering from frequent machine breakdowns and recurring faults in their production line. Hidria Rotomatika on the other hand requires very high levels of precession in their CNC process and suffers from configuration and part setting delay.

At the core of Dieseltec's problem was event driven maintenance which presented an opportunity for the implementation of predictive maintenance built. F4W solutions would be based on production data to predict and prevent breakdowns by employing an active rather than reactive approach. An online repository of manuals, quality control sheets, and process knowledge would provide workers with context specific knowledge and assist in better decision making (Lacueva et al., 2018). The solution also has the potential to increase autonomy by making workers more confident and self-reliant. A ratings system provided by the response of the workers to a particular solution would also contribute to less time wastage and continuously evolving solutions in the workplace. Also, trend analysis from logging production data parameters would connect workers to machines and increase awareness in the factory.

For Hidria Rotomatika, the F4W solution gives access to a database of solutions for frequently occurring issues. The architecture is connected to the programmable logic connector (PLC) of the production line for real time updates to problems and optimal solutions (Lacueva et al., 2018). A similar bottom-up approach to the Dieseltec solution was employed with employee ratings to determine the best solutions and constantly update it with new developments. Visualization of data through the F4W solutions would enable workers to find blueprints and schemas on demand. The goal is to centralize the knowledge management system so that employees can easily find information and avoid stress in the workplace.

5. Methodology

Literature was compiled from a wide array of scientific databases to review motivational theories and its applicability in work places. Keywords such as “Industry 4.0”, “Motivation of Employees”, “Motivation in Factories and Manufacturing” were used to generate results in scholarly databases and identify developments in the field. The reviewed literature was used to narrow down results in the field of SDT theory and TAM research in workplaces.

The research design primarily uses a descriptive approach to describe the motivational characteristics of the sample under study. The sample here refers to the control group or employees without treatment and the experimental or employee group who were using the F4W solutions. The nature and scope of the F4W project directs us to describe and analyze the sample on the basis of context specific uses cases. Employees from the F4W industrial partners were interviewed both using qualitative and quantitative assessment measures. However, this thesis only focuses on the quantitative data compiled from the employee responses in the Impact Assessment (IA) questionnaire (see Appendix 10.1). Longitudinal evaluations were performed in most use cases with a time dimension of 1 representing the first evaluation and 2 representing the second evaluation with a more mature artefact.

The IA questionnaire was designed using Likert scales to understand the workers self-assessment in four major blocks including;

1. Willingness to include new ways of doing
2. Project Awareness
3. Innovation Skills
4. Job Practices and Satisfaction

The questions in each block were related to one or more of the chosen dimensions of willingness, awareness, autonomy, competence, relatedness, variety, protection and innovation skills. For the purpose of the thesis, to elicit the workers motivation the classical SDT constructs of autonomy, competence and relatedness were chosen as suggested by the literature review. Each response was assigned a corresponding weight on the autonomy, competence and relatedness construct and converted to a scale between 0 representing the lowest and 1 representing the highest attainable value.

Table 5 shows the number of cases that were selected for the study after elimination of invalid and missing responses.

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Competence + Autonomy + Relatedness	120	92.30%	10	7.7%	130	100.0%

Table 5. Summary of Valid Cases

Hypotheses
H0: F4W solutions have no impact on the motivation of its adopters, i.e. autonomy, competency and relatedness levels among the CG and F4W workers are the same H1: F4W solutions have a positive impact on the psychological motivation i.e. autonomy, competency and relatedness of the workers using the technology.

Table 6. Hypothesis testing

The data was computed in IBM SPSS statistical program and the hypothesis was tested using one-way ANOVA to find statistical significance of the mean of the control and F4W group. A p-value of 0.05 was chosen, indicating that results below 0.05 are significant enough to discard the null hypothesis where as those above cannot be concluded properly (Statsdirect, 2019). The 0.05 value for p was chosen at the 95% confidence interval. A pilot TAM model was suggested and tested in one of the industrial partners using the questionnaire attached in Appendix 10.2.

5.1 ANOVA

Analysis of variance (ANOVA) is a statistical method which is used to determine differences or variation among different groups by comparison of their means (Investopedia, 2019). ANOVA provides a powerful base to test hypothesis, where a null hypothesis can be rejected in the light of statistically significant p value. It is also known as Fisher analysis of variance due to its founder Ronald Fisher. ANOVA first appeared in Fisher's book titled 'Statistical Methods for Research Workers' in 1925 and was utilized in experimental psychology and later utilized in other fields. ANOVA is often used in an experimental data set and is best suited for small sample sizes. It is often used for testing three or more variables. Analysts currently use this method to determine the impact of independent variables on the dependent variables during a regression study.

The formula for F used in ANOVA is given by F where,

F = MSB/MSW

MSB = between group variance estimate

MSW = group variance estimate

Every variance estimate has two parts, the sum of squares and the rim (SSB and SSW) and degrees of freedom (df) (Girden, 1992).

ANOVA are of two types: one-way and two-way. As the name suggests one-way consists of one independent variable affecting a dependent variable while two-way consists of two independent variables affecting a dependent variable (Baur and Lamnek, 2007). One-way ANOVA is used to determine if there are any differences between the means of three or more independent unrelated groups. Two-way ANOVA is used to investigate effect of two independent variable on the same dependent variable.

5.2 PLS

Partial least least squares (PLS) is a technique that combines principal component analysis and multiple regression. It is best utilised to predict a set of dependent variables from a large number of independent variables. PLS first originated in 1966 but was soon utilised on social sciences as a multivariate technique for non-experimental and experimental data (Abdi, 2003). Multiple linear regression (MLR) is used to convert data to information when factors are less in number, are not collinear and have a well understood relationship to responses. However, if any of the above three mentioned conditions are not met MLR can be inappropriate. PLS is a method of constructing predictive models when the factors are many and highly collinear. However, PLS becomes inappropriate to filter out factors that have a negligible effect on the response (Tobias, 1995).

The most important part of a PLS analysis is the estimation of weight relations. Though distributing equal weight weights for all factors could be the simple solution, they have two distinct disadvantages. One, the assumption of equal weights make all results highly arbitrary and two, some factors genuinely are more reliable than others then they should receive higher weights as Chin et al stressed (2003b). Hence, being a limited information approach, PLS has advantages such as involving no assumptions about the population or scale of measurement as well as works without distributional assumptions with nominal, ordinal and interval scaled variables (Haenlein and Kaplan, 2004).

6. Results

The following section will be divided on the basis of individual results compiled for each of the use case scenarios, concluding with an overall analysis, which will present us with a reliable sample and a macro level perspective of the effect of the solutions on the workers motivation. The table and figures shown while comparing means, use a normalized value of the responses gathered from the questionnaire to form a scale from 0 (minimum) and 1 (maximum).

6.1 EMO Results

The analysis of variance shown in Table 7 indicates that effect on relatedness between the Control Group (CG) and F4W groups is statistically significant at a chosen p-value of 0.05 significance level. If we compare the means of the two groups in Figure 7, we see that the F4W group consistently scores higher on each of the three motivation constructs. Using both Table 7 and Fig 7, we can reject the null hypothesis for the relatedness construct and conclude that the F4W solution had a positive effect on the motivation of the workers.

Construct	*F-Value*	*Significance*
Autonomy	2,721	,109
Competency	2,683	,112
Relatedness*	**4,220**	**,049**

Table 7. ANOVA results for EMO

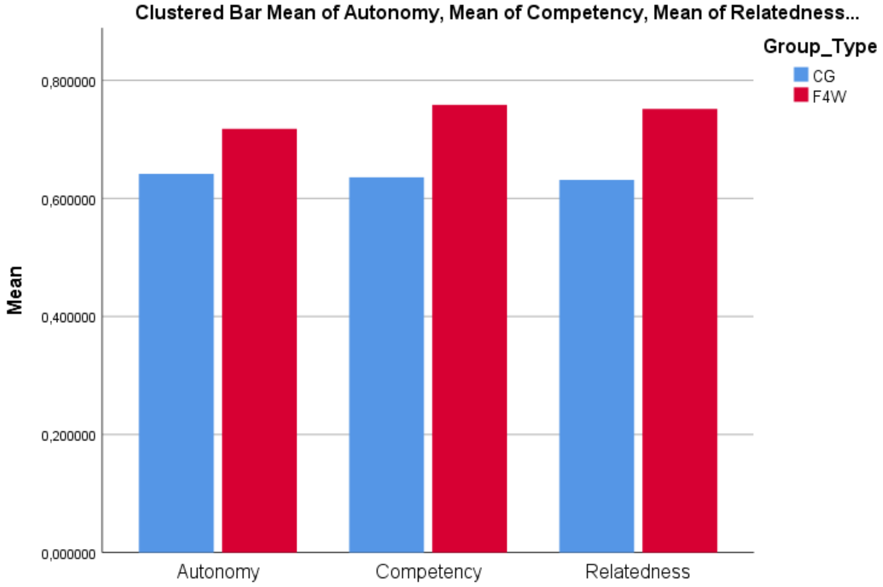

Figure 7. Comparison of means between CG and F4

Figures 8, 9 and 10 provides a deeper look into the range of the responses gathered across the two observation groups and is also divided into discrete observation periods. Since the sample are independent, no direct comparison or correlation can be drawn between the two phases and the outliers cannot be questioned further owing to the anonymity of the respondents. This box plots should reveal a consistent impact on the two worker groups across t1 and t2 evaluation phase if other factors chosen for the study does not have an impact on the values of these constructs. It is pertinent to mention again that at t2 evaluation phase, the artefacts were improved and responses in the F4W group might change owing to the maturity of the solutions.

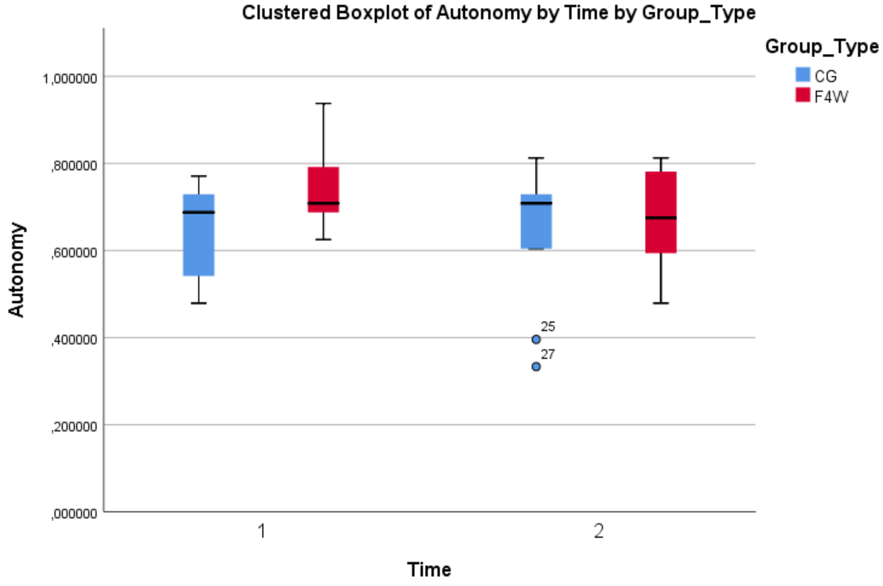

Figure 8. Boxplot of Autonomy, EMO case

Fig 8, demonstrates that at t1 evaluation phase, the F4W group's range of responses is above the bottom quartile of the CG responses. At t2 however, the both groups have a similar upper bound but the CG median is slightly above the F4W median. It is difficult to explain the drop in F4W responses at t2 without considering the impact of other factors such as job description of the worker or their age.

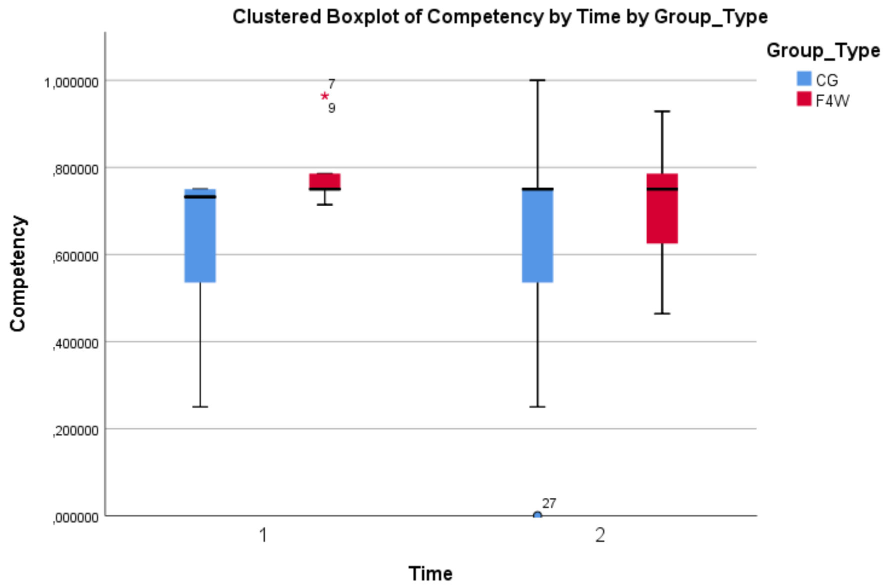

Figure 9. Box plot of Competency, EMO case

T1 evaluations for competency as shown in Figure 9, reveal a small range of values for the F4W sample, indicating the solutions had a consistent impact on the F4W group. The CG displays a wider and thus inconsistent range of values with around two quartiles of the responses below the lowest respondent of the F4W group at t1. The median values for all the evaluation group remains more or less constant throughout the evaluation phases but there is a drop in the lower range for F4W group at t2.

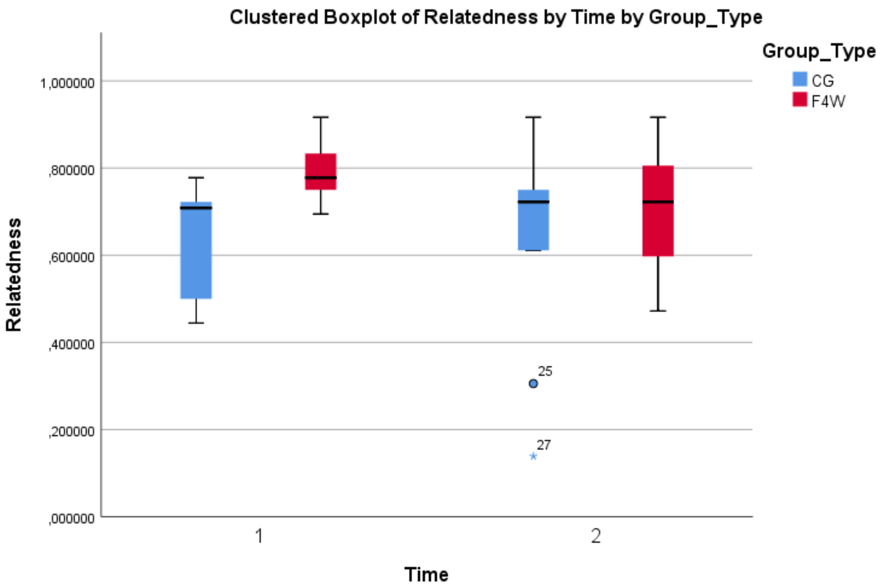

Figure 10. Box plot of Relatedness, EMO case.

The box plot for relatedness in Fig 10, shows similar characteristics to the box plots of Autonomy and Competence in fig 8 and fig 9. T1 evaluations favor the F4W group and more than top three quartiles of the responses for the F4W group are above the median for the CG. T2 evaluations however show no discernible difference between the CG and F4W in terms of median and upper bound values.

To conclude the across all the three constructs of autonomy, competency and relatedness, the F4W solutions had a more consistent impact on the F4W group at t1 when compared to the t2 evaluation phase. The F4W group also fares better than the CG at t1 evaluations whereas the same cannot be said for the t2 evaluation phase. There seems to be two outliers in the CG data at t2 evaluation phase, represented by point 25 and 27 on Fig 8 and Fig 10, which are significantly below the computation range for the CG and seems to have brought down the mean value for the CG at t2 evaluation phase.

6.2 Schaeflller (SCA) 2 Results

The results from SCA2 are computed using data from the t2 evaluations owing to improper responses in the t1 evaluation phase. The ANOVA results as shown in Table 8, do not indicate any statistical significance in the constructs between the CG and F4W group. Fig 11 shows that the F4W group scores marginally higher than the CG in terms of relatedness and autonomy while there is greater difference in competency.

Construct	***F-Value***	***Significance***
Autonomy	,646	,439
Competency	1,809	,206
Relatedness	,075	,790

Table 8. ANOVA results for SCA 2

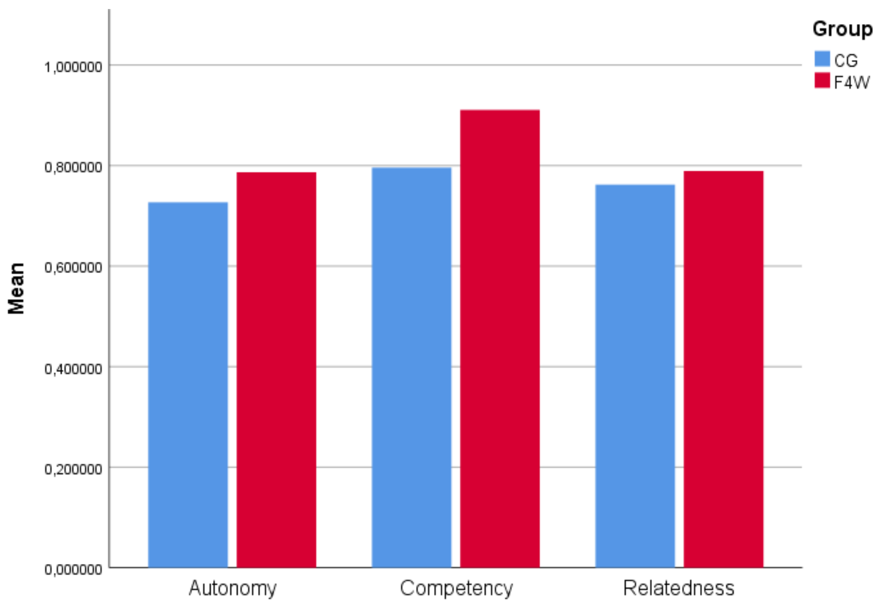

Figure 11. Comparison of means between CG and F4W, SCA 2 case

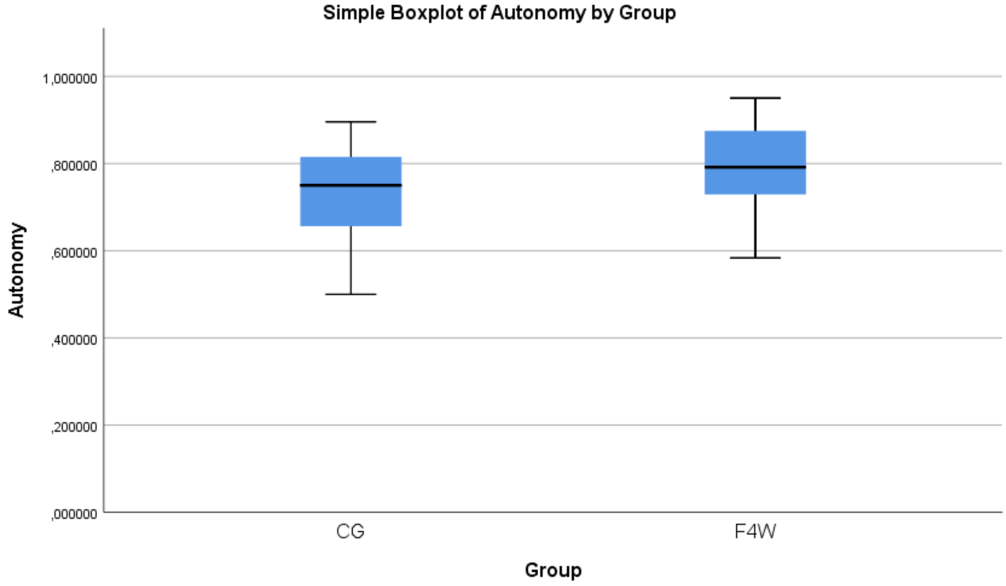

Figure 12. Box plot of Autonomy, SCA 2 case

The median and maximum value for autonomy in the F4W group is marginally higher compared to the CG as shown in Fig 12. The lowest response level of autonomy for the F4W group is also higher when compared to the CG.

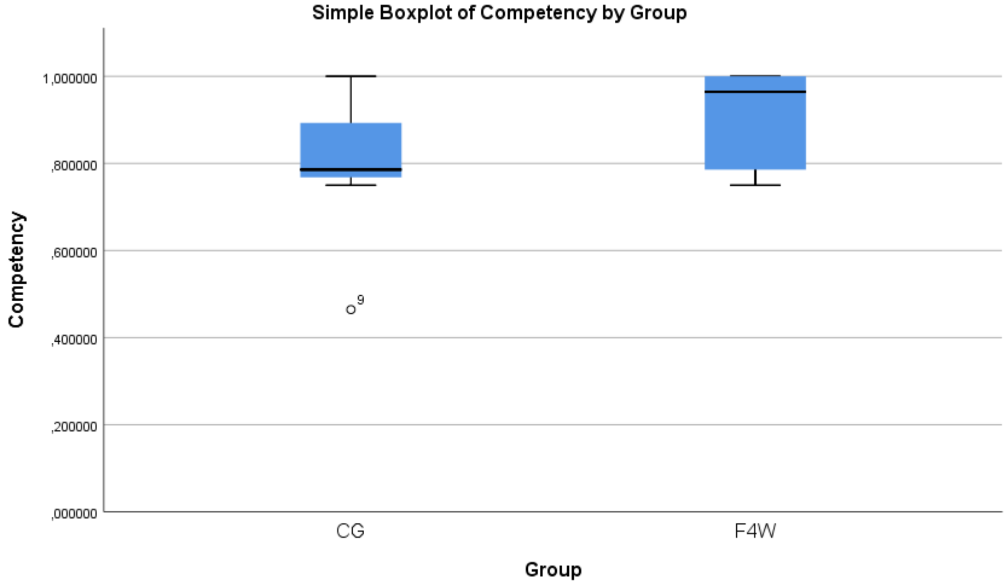

Figure 13. Box plot of Competence, SCA 2 case

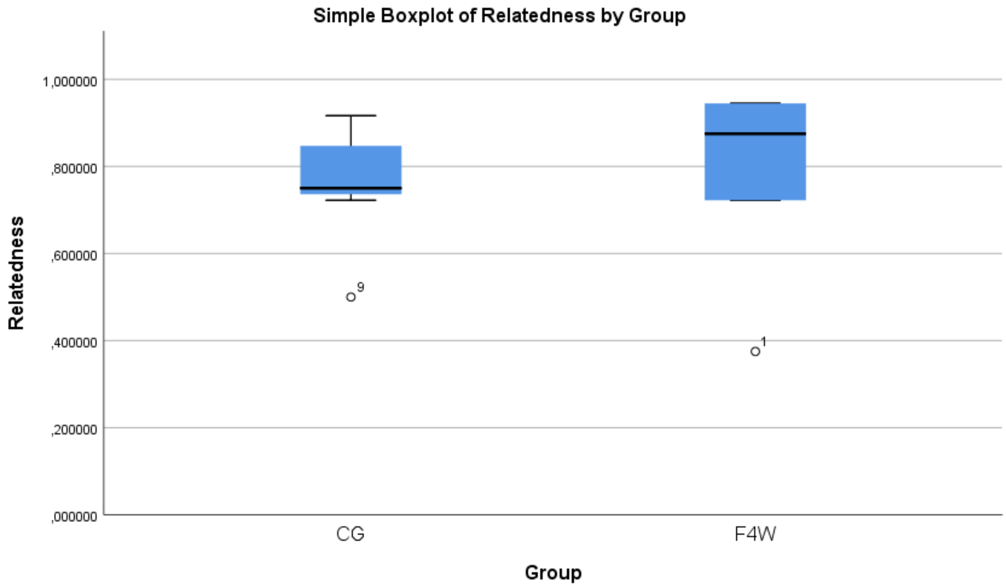

Figure 14. Box plot of Relatedness, SCA 2 case

Competence and relatedness as portrayed in Fig 13 and Fig 14 display a much higher median value for the F4W group while the range of values are similar for both the groups. Both the above mentioned boxplots reveal an outlier in the CG represented by point 9 which is unusually low compared to the rest of the sample and would have definitely skewed the average to a lower value.

6.3 SCA 1 Results

The SCA 1 evaluations did not include a control group and thus results had to be compared between the first and second evaluation phase of the F4W group. A more mature artefact can be expected to positively influence the motivation of the F4W group at the second evaluation phase and although Fig 15 shows marginal improvement in the means of the second evaluation phase, the difference is not of statistical significance as shown in the ANOVA Table 9.

Construct	***F-Value***	***Significance***
Autonomy	,196	,664
Competency	,002	,961
Relatedness	,175	,682

Table 9. ANOVA between t1 and t2 for F4W group, SCA 1 case

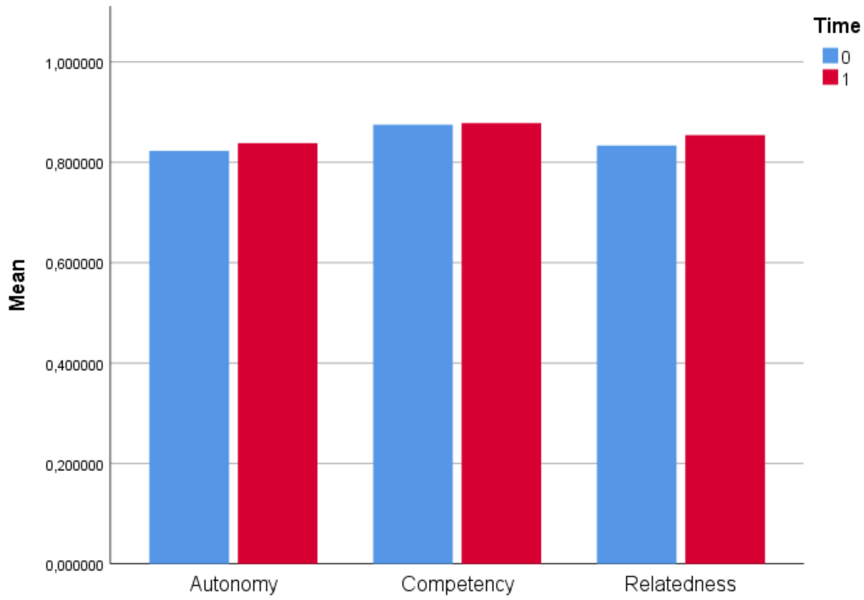

Figure 15, Comparison of Means between t0 and t1 for F4W group, SCA 1 cas

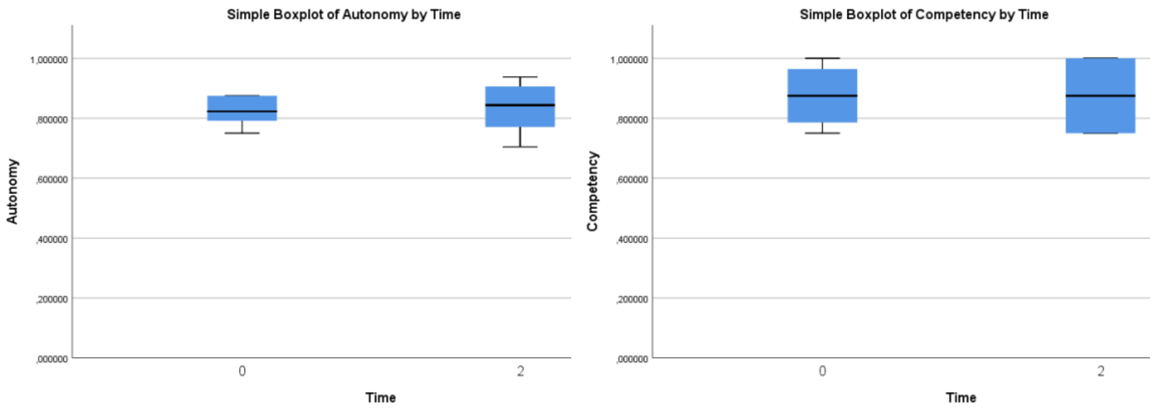

Figure 16. Boxplot of Autonomy (left) & Boxplot of Competency (right), SCA 1 case

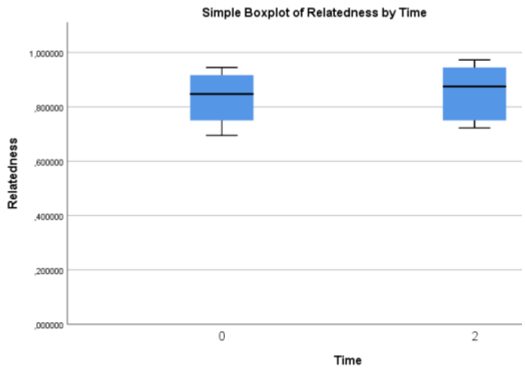

Figure 17. Figure 13. Boxplot of Relatedness, SCA 1 case

The differences exhibited by Fig 16 and Fig 17 in median value or range over the two evaluation phases across all the constructs are trivial and do not warrant any extended analysis. The solutions seem to have affected the workers uniformly over the two evaluation phases, which is an indicator of consistency. However, without a control group to benchmark against, no valid inferences can be drawn from the SCA 1 case.

6.4 HID Results

Table 10 and Fig 18 suggest that the solutions had no effect the autonomy of the F4W group when compared to the control group. Although, competency and relatedness seem to be higher for the F4W group, the difference is not in the order of statistical significance as shown in Table 10.

Construct	***F-Value***	***Significance***
Autonomy	,001	,972
Competency	1,824	,187
Relatedness	,841	,367

Table 10. ANOVA between CG & F4W group, HID case

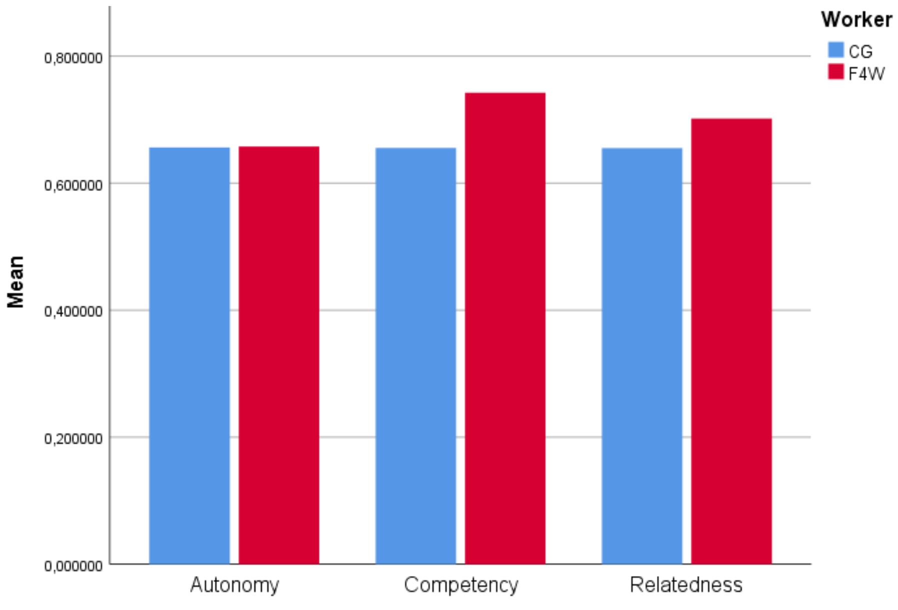

Figure 18. Comparison of means between CG & F4W group, HID case

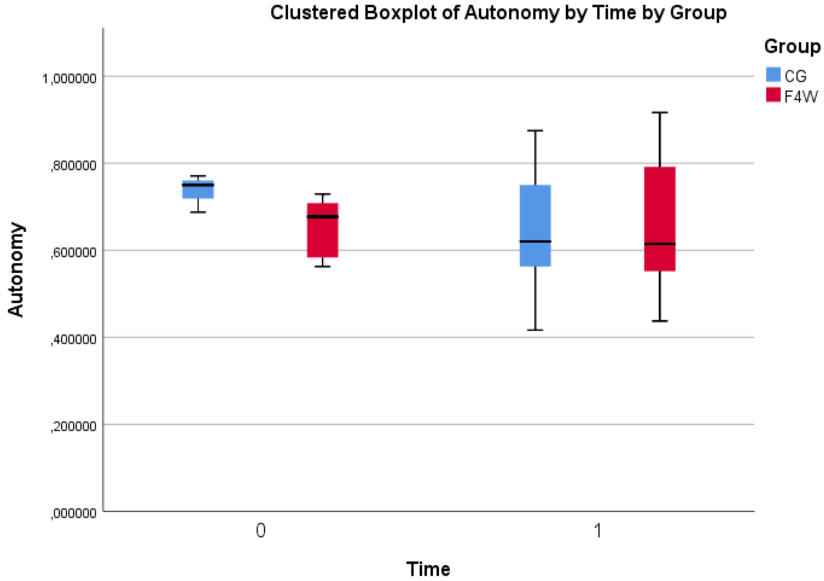

Figure 19. Boxplot of Autonomy, HID case,

Contrary to expectations, t0 evaluations as seen in Fig 19 indicate that the F4W group reports lower levels of autonomy compared to the CG. The maturity of the solutions in t1 phase however compensate towards the overall mean of the two phases by bringing the CG and F4W group to similar levels of reported autonomy as seen in Fig 19.

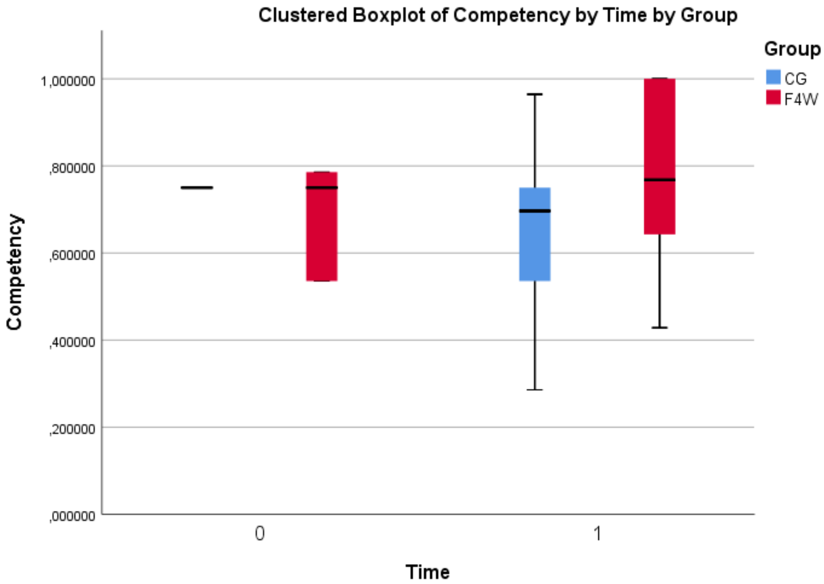

Figure 20. Boxplot of Competency, HID case

Competency levels as demonstrated in Fig 20, is also higher in the t1 phase for the F4W group. The median, maximum and minimum values are all higher for the F4W group indicating that improvements in the solution during the second phase of the solution positively affected competency levels for the target group.

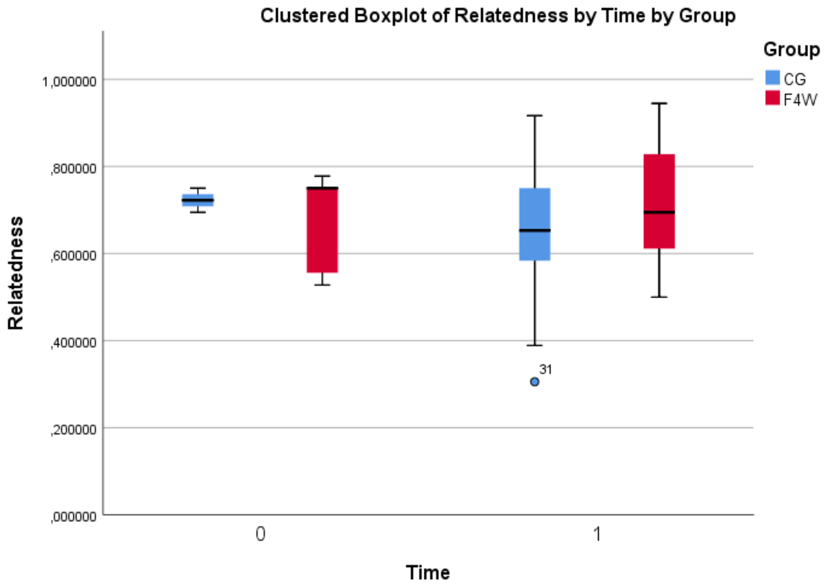

Figure 21. Boxplot of Relatedness, HID case

Characteristics for Relatedness among worker group in fig 21 is similar to that of competency in fig 20. T1 evaluations show improvements in the F4W group when compared to t0 evaluations. It is hard to derive straightforward conclusions from these results as the CG despite having lower median values in each of the three constructs in the first evaluation phase, show higher maximum values and lower minimum values in the second phase. Apart from the maturity of the artefacts affecting the F4W group, the changes in questionnaires and control environment may have affected the results.

6.5 THO Results

The THO use case reports not only higher means for F4W workers across all the three categories in Fig 22, but also very high levels of statistical significance well below the chosen p-value of 0.05 in Table 22. It is safe to reject the null hypothesis and conclude that the solutions indeed contribute to higher levels of motivation among workers. Keeping in line with the structure of the paper, it is still important to investigate the evaluation phases individually to seek additional insights into the behavior of the workers.

Construct	***F-Value***	***Significance***
Autonomy*	10,467	,004
Competency*	4,497	,045
Relatedness*	10,470	,004

Table 11. ANOVA between CG & F4W, THO case

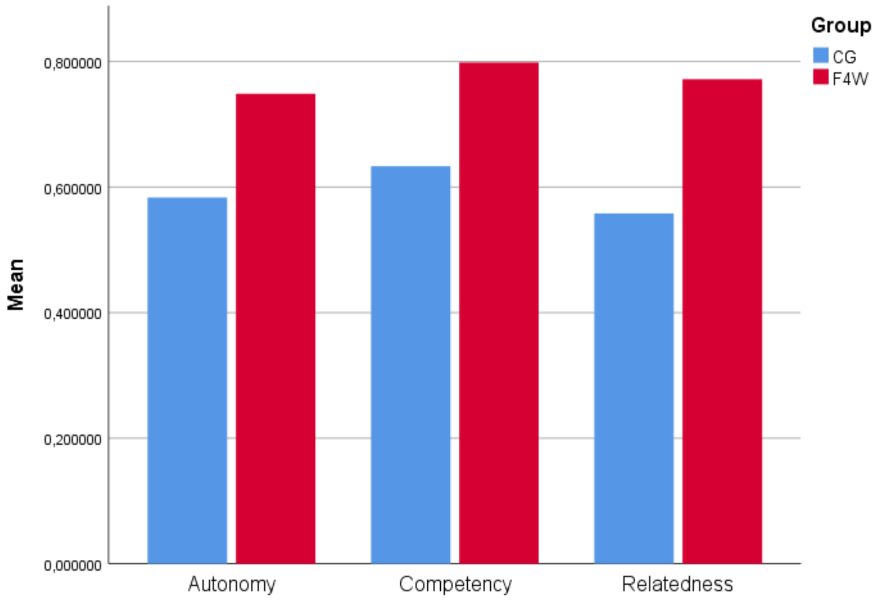

Figure 22. Comparison of means between CG and F4W group, THO case

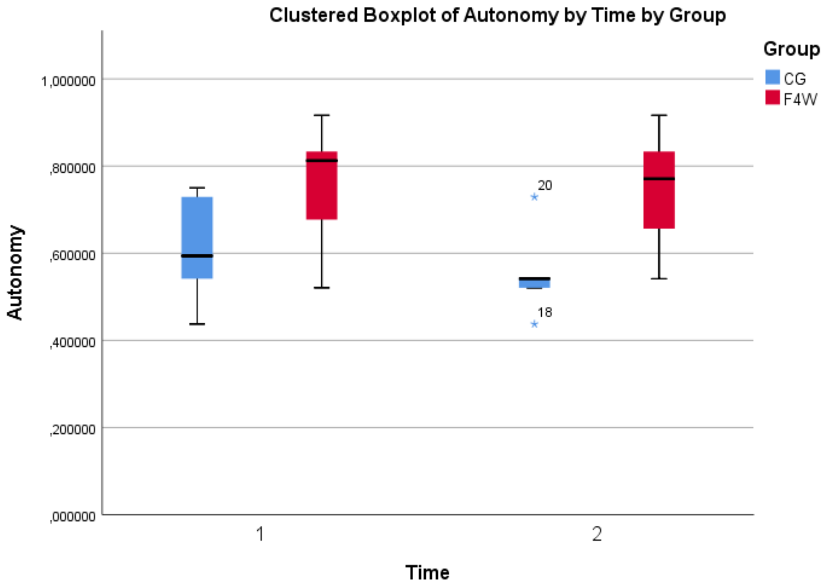

Figure 23. Boxplot of Autonomy, THO case

The boxplot of Autonomy in Fig 23 shows higher values for the F4W group compared to the CG at both t1 and t2 evaluation phases. Although, the median marginally decreases at the t2 evaluation phase for the F4W group, the distributions at t1 and t2 phase are quite similar to each other. There is a strong possibility to infer that the solutions had a consistent positive impact on the F4W group across the two phases. The distribution condenses at the t2 phase for the CG but the outlier points 20 and 18 are similar to the upper bound and lower bound values for the same group at t1 evaluation phase.

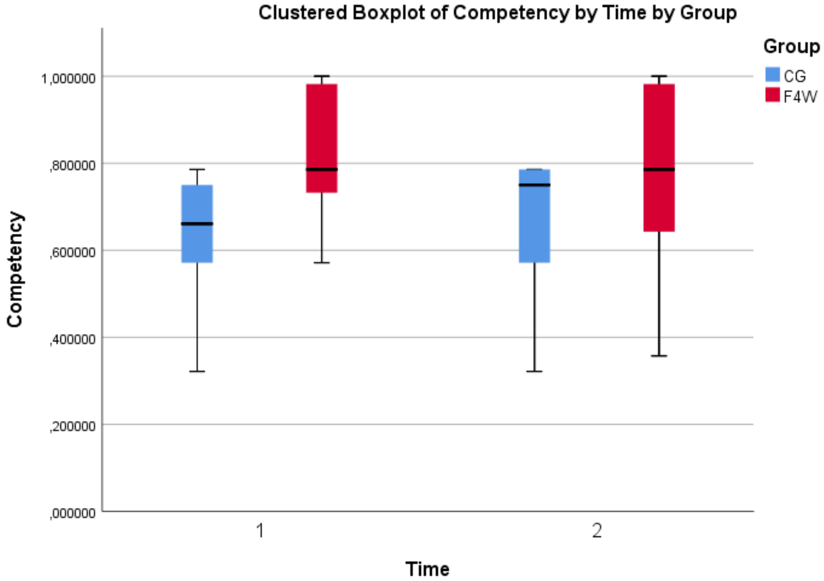

Figure 24. Boxplot of Competency, THO case

Competency levels as shown in Fig 24 is also higher for the F4W group compared to the CG in terms of median and overall distribution. While the median remains more or less similar for the F4W group at both phases, the range of values increases as the lower bound decreases at the t2 phase. The distribution and median marginally improves towards higher values in the CG group while the range remains unchanged.

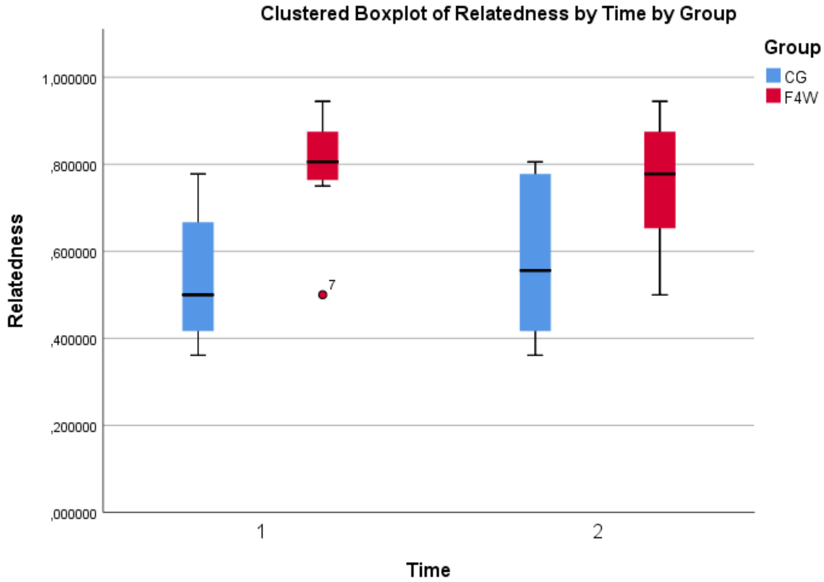

Figure 25. Boxplot of Relatedness, THO case

Relatedness levels also favor the F4W group in both t1 and t2 phase with the CG median significantly below the F4W median as demonstrated by Fig 25. Point 7 as an outlier in t1 phase for the F4W group is similar to the lower bound at t2 phase and thus does not warrant further investigation. The THO case thus validates the hypothesis of the F4W solutions positively affecting the motivation of the workers in terms of relatedness, autonomy and competency. The results are significant at both the overall level as well as individual phases of analysis.

6.6 All Use Cases Combined Results

Although the use cases are individually distinct and incomparable to each other, combining all the cases to form a larger sample could offer additional insights on a macro scale about the potential effectiveness of the F4W solutions of eradicating socio-technical barriers among a wide range of companies. Table 12, shows the descriptive of the 120 cases after filtration to remove cases with missing or invalid responses, and represents 50 CG workers and 70 workers chosen for the F4W solutions.

					95% Confidence Interval for Mean			
		N	Mean	Std. Deviation	Lower Bound	Upper Bound	Min	Max
Autonomy	CG	50	0,646	0,130	0,609	0,683	0,333	0,896
	F4W	70	0,741	0,140	0,707	0,774	0,250	0,950
	Total	120	0,701	0,144	0,675	0,727	0,250	0,950
Competency	CG	50	0,664	0,213	0,604	0,725	0,000	1,000
	F4W	70	0,799	0,174	0,758	0,841	0,250	1,000
	Total	120	0,743	0,202	0,707	0,780	0,000	1,000
Relatedness	CG	50	0,642	0,176	0,592	0,692	0,139	0,917
	F4W	70	0,770	0,145	0,735	0,804	0,375	0,972
	Total	120	0,716	0,170	0,686	0,747	0,139	0,972

Table 12. Descriptives of Combined Sample

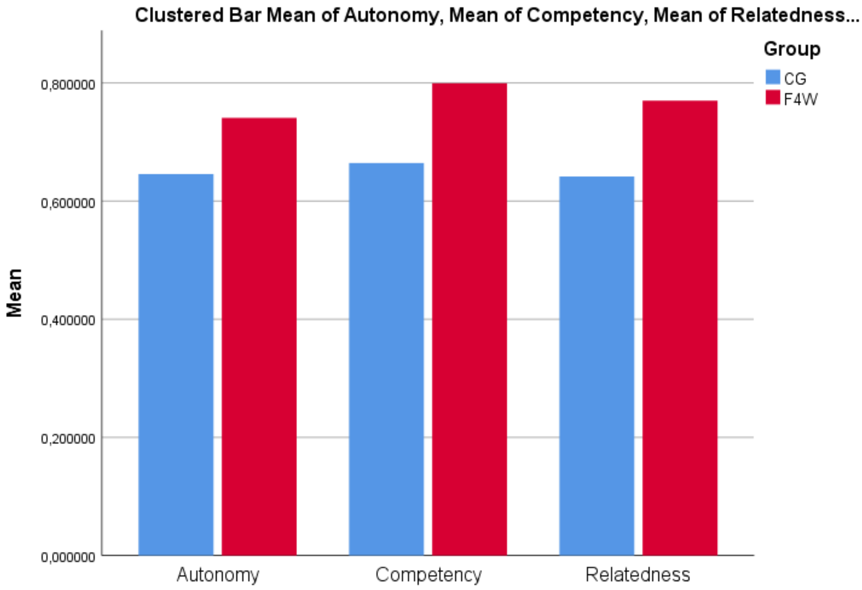

Figure 26. Comparison of Means between CG & F4W group, all cases

Fig 26 and Table 12 confirm that in each of the autonomy, competency and relatedness construct, the F4W group mean is higher compared to the CG. The results are also confirmed by the ANOVA in Table 13 indicating that the results are highly significantly with p-values well below the desired level of 0.05. Here, the null hypothesis can be rejected with high confidence to state that solutions improve the motivation of the workers.

Construct	***F-Value***	***Significance***
Autonomy*	14,214	,000256
Competency*	14,582	,000215
Relatedness*	19,105	,000027

Table 13. ANOVA between CG & F4W group, all cases

6.7 TAM Pilot Study Thyssenkrup

A TAM pilot model was tested in Thyssenkrup in the end phase of the evaluation. Fig 27 shows the model after partial least square calculations. The pilot study shows undesirable results as the sample size is only 5 and insufficient for a robust analysis. Attitude towards the solution seems to be negatively correlated with self-efficacy and outcome expectancy but these results may be discarded considering the incomplete sample.

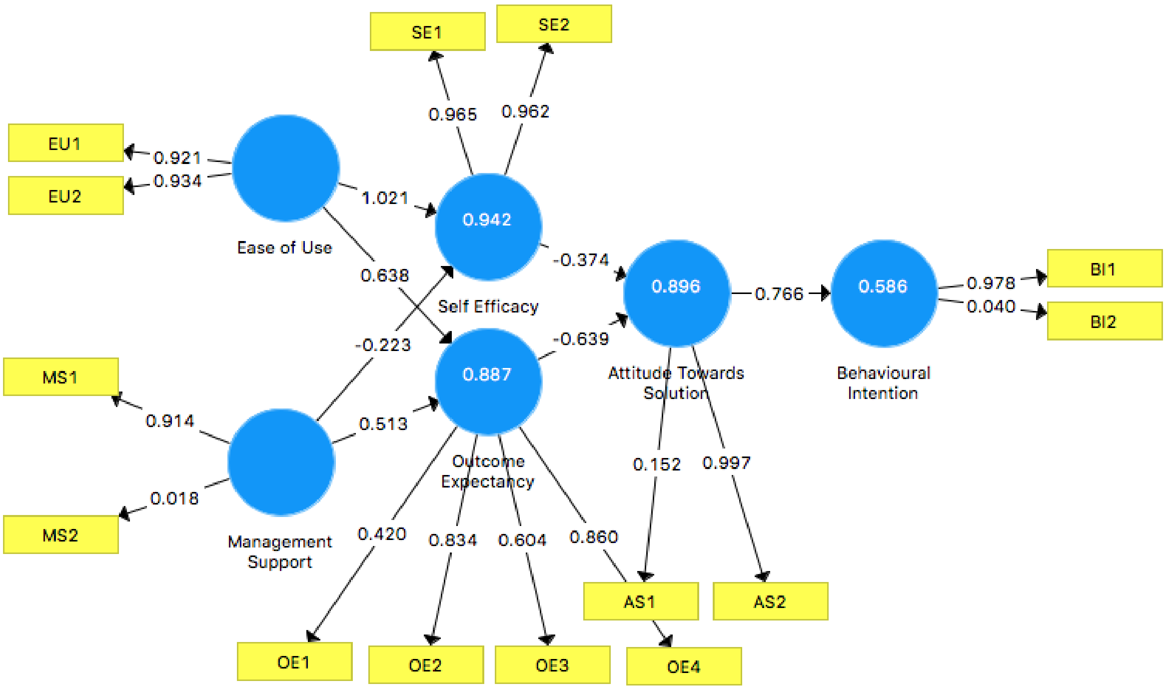

Figure 27. TAM Pilot Model Thyssenkrup

7. Discussion and Limitations

Evolution of technological in manufacturing is inevitable and worker competencies and roles are changing every day. Looking towards a socially sustainable solution, research is being increasingly focused on the development of required industrial competencies as well as on the well-being of the workers. The Facts4Workers project was aimed at developing human centric technological solutions that would ensure high job satisfaction and motivation among workers in smart factories. This thesis is aimed at validating the success of the technological solutions in enhancing the motivation of the workers especially in terms of their psychological growth. Validation of the hypothesis was done using ANOVA results and comparison of means between F4W and CG workers. The results are compiled with a view to demonstrate the effects on autonomy, competency and relatedness on the adopters of the F4W solutions.

The null hypothesis was only completely rejected in one of the 5 companies used in the analysis for the thesis. The case of THO shows that the F4W workers had higher levels of competency, autonomy and relatedness than the CG, in the order of statistical significance. The p-values reported for the comparison were 0.04, 0.45 and 0.04 for autonomy, competency and relatedness respectively. In terms of the other case companies, EMO also reported statistical significance in relatedness construct at a p-value of 0.049 while autonomy and competency did not demonstrate statistical significance. SCA2 did not employ a control group and thus analysis was only confirmed with the first and second evaluations within the F4W group which showed high consistent motivation levels. SCA 1 and HID did not report any statistical significance however comparison of means showed higher values for the F4W group when compared to the CG. The TAM pilot conducted in Thyssenkrup however failed explain causalities towards behavioral intentions of usage as it suffered from low sample biases.

When all the results from the case companies were compiled, the null hypothesis was rejected at a macro level with p values less than 0.0002, 0.0002 and 0.00002 for autonomy, competency and relatedness respectively. The combined analysis sufficiently demonstrates that the F4W solutions had the intended effect of motivating employees to higher levels.

Limitations

This research work should be carefully understood in the context of the use case of the solutions. Generalizability would require a much larger sample and consequent elimination of hidden or lurking variables. Although the questionnaire was designed to record the age and experience of the employees, the introduction of GDPR in the EU meant that the project had constraints in recording certain identity related responses of the interviewed personnel. Therefore, it is uncertain whether any other factor may have contributed to higher motivation levels across certain employees. Also, intra sample conclusion have not been made as the members of both CG and F4W group have changed during the evaluation phases.

No measures were adopted in the study to check for under reporting or over enthusiastic responses. Certain outliers were identified but follow up action was not possible to determine if it was genuine or a case of biased reporting.

Finally, the TAM pilot study is only indicative of a model that might be useful as a foundation work for future research into assessing behavioral intentions for high technology solutions in the workplace. As reported earlier, the sample size was unfortunately inadequate to determine the validity of the model.

8. Conclusion

Among the stated objectives of the study the first step was to explore contemporary theories of motivation and determine the most suitable one in the context of the F4W project. For this purpose, the SDT theory was selected as the literature suggests a robust and practical fit for understanding the motivation of the employees and the consortium decided on focusing on specific constructs of competency, relatedness and autonomy within job satisfaction aspects of the employees.

The descriptive nature of the research is aimed at understanding the effect of the technological solutions on the employee's motivation. A distinction between a control group and treatment group allows us to compare the average or mean of the SDT constructs to analyze if the F4W solutions were successful in attaining their intended consequences. Although research on SDT evaluation has taken place in traditional workplaces, its effects have not widely been studied in the context of high technology solutions and smart factories.

In each of the use cases the F4W group demonstrated higher reported values of autonomy, competency and relatedness when compared to the CG. In terms of statistical significance only the THO case was found to report p values less than 0.05 in all the three constructs while the EMO case only reported significance in relatedness among workers. Interestingly, when the results are compiled over all the industrial partners, ANOVA reports a statistical significance in each of the three constructs.

SDT is a macro theory of motivation and thus the extended sample confirms its suitability in an industrial or manufacturing context. Although the solutions were tailored towards the needs of each industrial partner, the modular building block approach of the F4W project imply a sense of comparability and similarity in the solutions and its effect on the employees. Therefore, we can conclude that the F4W solutions were successful in enhancing psychological needs of competency, relatedness and autonomy leading to higher motivation and consequently greater job satisfaction within the employees.

The TAM Pilot model was compiled based on constructs suggested by the literature and use considering the use case of the company and the technological solutions. The sample size was ineffective in determining the validity of the model or the behavioral intentions of the employees to use the solutions in the future.

Future Research

External factors like age, years of experience, pay and position in determining motivation of adoption of high technology solution among employees may provide interesting insights and help explain causality. Research on these causalities would help both academicians and industrial practitioners in designing even more tailored solutions based on individual employee differences.

Self-reporting from employees can be cross-checked with supervisor rating to determine over reporting and under reporting in questionnaires and further research in this field would serve to eliminate any possible bias or expose hidden variables. In the context of industry 4.0, technological advances have made it possible to design Electroardiogram (ECG) bio-sensors that can objectively track mood and motivation of employees. Research in this direction would develop a new paradigm between objective psychological reality and subjective psychological experiences and pave the way for new theories in work and motivation.

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10. Appendix

10.1 Impact Assessment Questionnaire

EMPLOYEE QUESTIONNAIRE

SATISFACTION AND INNOVATION SKILLS

Instructions

(Please read carefully)

The goal of this survey is to capture your current perception about your job practices.
We will neither assess your performance nor will the data be used later on to do so!

Some tips to fill out the questionnaire:
The individual aspects are specified by a descriptive text. You can give your answer by crossing one of the five boxes beneath the description.

Example 1

I know a lot about soccer and its rules:
I strongly disagree ☐ ☐ ☐ ☐ ☒ I strongly agree

In this example the person strongly agrees i.e. she knows a lot a about soccer.

Please fill out the questionnaire completely and carefully without omitting any answers!

The analysis of the results will be carried out in anonymized form only

Willingness to include new ways of doing

How willing you are to incorporate new ways-of-doing in your daily work?
Absolutely reluctant ☐ ☐ ☐ ☐ ☐ Absolutely willing

FACTS4WORKERS project awareness

To what extent you know what FACTS4WORKERS project proposes for your daily work?					
	I strongly disagree	**I disagree**	**Neither agree nor disagree**	**I agree**	**I strongly agree**
I know that some improvements are planned to be deployed in my workplace	❑	❑	❑	❑	❑
I know the type of technical solutions planned to be deployed	❑	❑	❑	❑	❑
I know the type of organizational improvements planned to be deployed	❑	❑	❑	❑	❑

Innovation skills

- Approximately what percentage of your or your team's weekly time is made available to pursue creative ideas?

	%

- Has the open exchange of ideas between you and your peers increased since you joined the company?

YES ❑
NO ❑

	Frequently	**Regularly**	**Sometimes**	**Occasionall**	**Never**
How often do you have a vibrant exchange of ideas between individuals within your organization?	❑	❑	❑	❑	❑
How often do you take any risk by implementing a new idea/solution/decision in your daily work?	❑	❑	❑	❑	❑
How often do you share your workplace ideas with others	❑	❑	❑	❑	❑

How often do you turn you (or your team) new ideas into new or modified products, processes or services?	❑	❑	❑	❑	❑

Job practices and satisfaction with them

Ask yourself: How satisfied am I with this aspect of my job? **Very Dissatisfied:** I am very dissatisfied with this aspect of my job **Dissatisfied:** I am dissatisfied with this aspect of my job **Neutral:** I can't decide whether I am satisfied or not with this aspect of my job **Satisfied:** I am satisfied with this aspect of my job **Very Satisfied:** I am very satisfied with this aspect of my job					
	Very Dissatisfied	**Dissatisfied**	**Neutral**	**Satisfied**	**Very Satisfied**
The chance to develop new and better ways to do the job	❑	❑	❑	❑	❑
The chance to do something that make use of my abilities	❑	❑	❑	❑	❑
The chance to be responsible for planning my work	❑	❑	❑	❑	❑
The chance to make decisions on my own	❑	❑	❑	❑	❑
The spirit of cooperation among my coworkers	❑	❑	❑	❑	❑
The chance to work independently of others	❑	❑	❑	❑	❑
The chance to do something different everyday	❑	❑	❑	❑	❑
I can take decisions in my daily job based on information acquired or on my own experience	❑	❑	❑	❑	❑
I am able to solve problems that arise in my daily tasks on my own or with the help of coworkers	❑	❑	❑	❑	❑

I am able to propose new ways of doing or new solutions to existing needs or problems	❑	❑	❑	❑	❑
I am involved in my daily tasks closely with my colleagues	❑	❑	❑	❑	❑
I am aware of what's going on, in general, in my company	❑	❑	❑	❑	❑
I deal with a manageable amount of information and inputs in my daily tasks	❑	❑	❑	❑	❑
Lack of stress and manageability with my job and daily tasks	❑	❑	❑	❑	❑
The way I enjoy my coworkers	❑	❑	❑	❑	❑
Communications within this organization	❑	❑	❑	❑	❑
Explanations about my job assignments	❑	❑	❑	❑	❑
Number of tasks that I have to perform daily	❑	❑	❑	❑	❑
The way I enjoy my job	❑	❑	❑	❑	❑
The diversity of tasks I can perform during my daily work	❑	❑	❑	❑	❑

Background information

I am currently working as		
I am working there since		years
I am	…………….	years old.
I am	☐ Female ☐ Male	

10.2 TAM Questionnaire

Employee Motivation Questionnaire

Instructions
(Please read carefully)

With this questionnaire, we are trying to understand the motivations to adopt these solutions in the factories. In no case do we try to determine your performance or the results will ever be used to do it. Please complete this questionnaire completely, carefully without omitting any response.

Please read the following questions and answer them accordingly. Scale used:

5 – Strongly Agree

4 – Agree

3 – Neutral

2 – Disagree

1 – Strongly Disagree

Self-Efficacy

1. It would be easy to acquire the necessary experience to use the application.
2. I have previously used such application

Ease of Use

3. My interaction with the solution is clear and comprehensible
4. I find the solution easy to use

Attitude towards F4W Solutions

5. Interacting with the solutions are often frustrating
6. The solutions are rigid and inflexible

Outcome Expectancy

7. The application makes my tasks easier (information quality)
8. The solutions save my time on any given task
9. The solutions improve my quality of work
10. Overall, I find the solutions useful in my work

Management Support

11. I would voluntarily use this type of solutions in my workplace without the need for direction
12. I have received the appropriate training and supervision for the use of the application.

Behavioral Intention

13. I would like to apply the solutions to support the production of more parts or the realization of more tasks in the future.
14. I would feel more comfortable and positive with the application with more usage