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**DOCTORAL (PhD) THESIS
BOOKLET**

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Tool Sizing for Latin American People

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**DOCTORAL SCHOOL ON SAFETY
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Table of Contents

Summary in Hungarian Language	3
Antecedents of the Research	4
Formulation of the scientific problem.....	7
Objectives	9
Hypotheses of the research	9
Research Methods and Challenges	10
New Scientific Results.....	11
Possibility to utilise the Results	13
References.....	14
Publications.....	17
Scientific Publications Related to the Thesis Points.....	17

Summary in Hungarian Language

Ez a disszertáció az ergonómiai és biztonsági kihívásokat vizsgálja a kéziszerszámok használatával kapcsolatban, különösen a latin-amerikai lakosság körében. A kutatás középpontjában az izomfáradtság, a kockázateszlelés és a munkahelyi sérülések állnak. A dolgozat öt fő fejezetből áll, amelyek mindegyike egy-egy sajátos módszertani megközelítést alkalmaz, hogy hozzájáruljon egy átfogó modell kialakításához az eszközválasztás és sérülésmegelőzés érdekében.

Az 1. fejezet egy szisztematikus irodalmi áttekintést mutat be a PRISMA módszer alkalmazásával, melynek célja az izomfáradtság kimutatására alkalmas módszerek azonosítása az elektromiográfia (EMG) segítségével. Meta-analízis készült 35 tanulmány alapján, amely szignifikáns korrelációt mutatott ki ($r = 0,520$, $p < 0,001$) az EMG-alapú mérések és a munkával összefüggő kézi rendellenességek megelőzése között. A jelfeldolgozási technikákat, fáradtsági indexeket és kockázati tényezőket (például szerszámtervezés, ismétlődő mozgás) elemezték az eszközoptimalizálás és a munkahelyi tervezés céljából.

A 2. fejezet a munkahelyi kockázatok kategorizálására koncentrál, többkritériumos döntéshozatali (MCDM) eszközök, nevezetesen az Analytic Hierarchy Process (AHP) és a Best Worst Method (BWM) módszerek segítségével. Egy 10 ecuadori ergonómiai szakértőből álló minta alapján felmérést végeztek a fizikai sérülésekkel, ergonómiai megterheléssel és szerszámkárosodással kapcsolatos kockázatok értékelésére. Az eredmények egyértelműen megmutatták, hogy a fizikai sérülések jelentették a legkritikusabb kockázatot 73,06% (AHP) és 73,62% (BWM) súllyal, alacsony inkonzisztencia-mutatóval ($CR = 0,0492$) és megbízhatósági aránnyal (0,1978) validálva.

A 3. fejezet a Domain-Specific Risk-Taking (DOSPERT) skálát alkalmazza annak felmérésére, hogy a magyar és az ecuadori munkavállalók hogyan észlelik és kezelik a kéziszerszám-használathoz kapcsolódó kockázatokat. Egy összehasonlító felmérés kulturális és kontextuális különbségeket tárt fel: az ecuadori dolgozók magasabb kockázatvállalást mutattak a társadalmi-gazdasági nyomások miatt, míg a magyar dolgozók nagyobb kockázatkerülést tanúsítottak, amely összhangban állt a szigorúbb szabályozási környezettel. A statisztikai és faktoranalízis szignifikáns csoporton belüli különbségeket mutatott ki az észlelt kockázat, az elvárt előnyök és a viselkedési attitűdök tekintetében.

A 4. fejezet egy kísérleti tanulmányt ismertet, amely az EMG alkalmazásával vizsgálta az izomfáradtságot ismétlődő szerszámhasználat során. 12 résztvevő hajtott végre markolási feladatokat ergonómiailag módosított fogóval. A fáradtság jelei a 25. ismétlés környékén jelentkeztek ($p = 2,22e-07$), és az EMG-csúcsérték 38,8%-kal csökkent az első és a negyvenedik ismétlés között. A gépi tanulási modellek megerősítették, hogy az EMG-jel hasznos a valós idejű fáradtság-érzékelésre, alátámasztva azt a hipotézist, hogy a mesterséges intelligencia javíthatja a biztonsági visszacsatolási rendszereket.

Antecedents of the Research

The manufacturing industry is working to improve the management system and create an ideal, healthy workplace, focusing on the best way to reduce accidents and maximise resources [1], [2], [3]. Hand tools are increasingly being used as the primary tool in a wide range of industrial operations. One of the most important control points in the industry is focused on the needs of specialised areas. Ergonomics and safety regulations are linked, as both contribute to a safe and healthy working environment. Ergonomic requirements encompass the design of workplaces, tools, and equipment to minimise physical strain on workers and enhance their well-being. Safety requirements, on the other hand, focus on identifying and mitigating hazards that could lead to accidents, injuries, or ill health. The high number of injuries each year is a major concern for these types of businesses. By addressing ergonomic elements such as posture, equipment design and work organisation, organisations can avoid ergonomic hazards and reduce the incidence of musculoskeletal disorders. Workers are trained to recognise and deal with ergonomic problems when ergonomic concepts are incorporated into safety practices, resulting in an integrated approach to occupational safety and health that improves worker safety, comfort and productivity [1], [4].

Especially in sectors that depend on hand tools, ergonomics and appropriate risk management must be integrated to ensure worker safety and security. Long-term health problems and lost productivity are caused by musculoskeletal illnesses, which are exacerbated by poorly designed tools and repetitive manual labour. To reduce injuries and improve worker well-being, companies should evaluate ergonomic risks, choose the best tools, and provide appropriate training. In addition, acceptance of global safety regulations and risk-reduction strategies contributes to a decrease in workplace dangers, guaranteeing a more secure and effective setting that safeguards workers and corporate operations. To reduce the likelihood of a worker becoming ill in the future, it is necessary to assess the recurring and elemental forces during work and then design the workstation using methodical tool selection. The market's reliance on tool size will be a constraint in this situation, as tool manufacturers focus on designing for everyone, which can be challenging for specialist workers now, to reduce the possibility of getting a future illness due to the lack of a tailored device [5].

A two-stage process is used to identify management requirements. The aim of the first level is to group tasks according to the requirements of the project and application. This level involves main stages such as allocation, elicitation, analysis, specification, validation, and approval, ensuring that requirements are identified, analysed, documented, and validated before final approval. The second level consists of actions to manage the process focuses on maintaining control over these requirements through configuration identification, baseline management, change control, library control, status accounting, and review audits to ensure consistency and traceability throughout the project lifecycle [6], [7], [8].

Industrial risk assessment tools aim to identify occupational diseases that affect different levels of the body. They are constantly refining their methods for identifying and mitigating the causes of accidents to reduce them, considering the requirements of Engineering [1], [9], [10], [11].

Industries have tracked musculoskeletal disorders in a variety of ways based on observation and workplace organisation, so tool selection is an important feature of workplace design or organisation to reduce the possibility of future conditions [12]. Because it requires flexion and extension of the wrist, repetitive performance of the manual activity with excessive muscle effort is a serious ergonomic concern [13]. Cumulative trauma disorders of the extremities must be recognised as a serious ergonomic hazard by the ergonomics management of each factory.

According to the US Bureau of Labor Statistics, there are approximately 100,000 hand tool-related accidents per year, which illustrates the high frequency of accidents in this industry and the need to propose a viable solution strategy. The information provided relates to accidents involving hand-held power equipment and hand tools. The number of incidents and the average number of days lost due to work-related accidents involving equipment and hand tools will increase significantly between 2015 and 2021. From 59,830 cases in 2015 to 125,297 cases in 2021, equipment injuries resulted in an average of seven days lost from work. In comparison, hand tool-related injuries increased from 52,030 in 2015 to 108,903 in 2021, resulting in an average of five days off work. The total number of hand injury accidents, which includes accidents involving both equipment and hand tools, will increase from 111,860 in 2015 to 234,200 in 2021, indicating a worrying upward trend [15] - [18].

In a globalised environment, the quest for greater efficiency affects all organisational structures that seek to standardise the response to a similar activity across multiple locations. In this view, a "human reliability analysis" is used when the operator is at the centre of a cognitive process that leads to judgments, whose dependence increases the overall safety of the use of the equipment [18], [19]. Monitoring and controlling both components of this combination to manage the "human factors" in the production process is the best way to achieve high safety standards, highlighting the need for risk prevention techniques targeted at specific hand tools.

Hand tool-related injuries, which make up a large portion of occupational incidents each year, are frequently caused by poor ergonomic practices, repetitive strain, and inadequate tool selection, which can result in long-term health risks and increased costs for businesses. Guaranteeing that ergonomic principles are followed in tool design, workstation setup, and work processes is crucial in reducing accidents, minimising musculoskeletal disorders, and improving overall worker well-being.

Physical damage caused by commonly used devices, for example, pliers, hammers, and chisels, screwdrivers and other hand tools during the performance of normal work duties can be considered and classified into several groups based on the severity and medical care required, ranging from mild (Level I) to severe (Level IV). The trauma level percentage distribution is according to the cause (cutting, machine-related, etc.). Machine-related injuries increase significantly from 11.61% to 88.2% when the trauma level rises from Level I to Level IV, whereas cut injuries fluctuate, reaching a peak of 38.39% at Level III before falling precipitously at Level IV [20].

The European Union Directive 89/391/EEC [22] encourages the adoption of policies to enhance employees' health and safety at work to reduce the risk of job-related injuries. In addition to adherence to the mandates of numerous international standards, hand and wrist injuries account for over 17% (740 million) of total annual medical and production costs due to the above factors.

Adopting appropriate safety measures improves productivity by preventing lost workdays due to injuries, in addition to lowering the direct medical and compensation costs related to workplace injuries. It is even more important to address ergonomic issues to create a safe and sustainable workplace as industries continue to change and strive for greater efficiency.

Occupational Safety in Hungary vs. Ecuador

Occupational safety strategies differ between Latin American and European countries due to differences in risk perception and tool use. Ultimately, workplace procedures, training methods and technology adoption all affect worker safety outcomes, and these factors are strongly influenced by cultural factors. Advances in technology, improvements in low-cost manufacturing and globalisation are strongly correlated. In Latin America, occupational safety regulations are often reactive, and with fewer resources and less emphasis on prevention, workers tend to take more risks. In contrast, proactive safety measures are typically prioritised in European countries, where they are supported by stricter regulatory frameworks and a greater focus on compliance, ensuring better risk reduction and preparedness [21], [22], [23].

Based on a culture that values personal accountability and following rules, Hungarian employees are more likely to prioritise safety and recognise possible risks, while Ecuadorian employees, who frequently deal with financial strains and less structured systems, may choose to accept or downplay risks to keep their jobs [24], [25], [26].

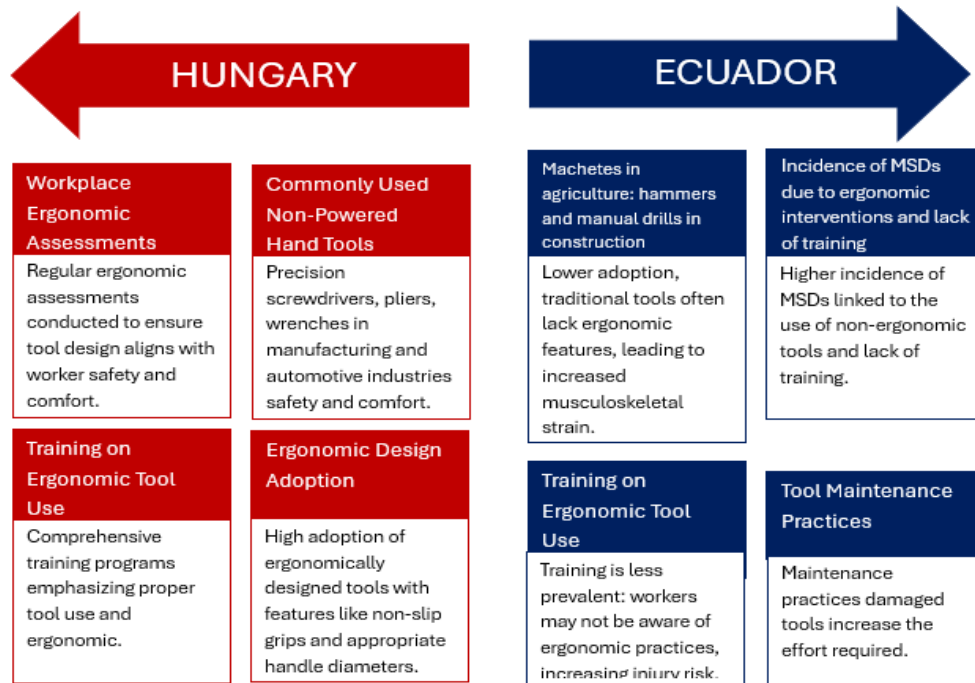


Figure 1 Occupational Safety in Hungary vs. Ecuador

In Hungary and Ecuador, non-powered hand tools show significant differences in several aspects of ergonomics and occupational safety, as shown in Figure 1. In Hungary, tools used in the industrial and automotive sectors are ergonomically designed with non-slip grips and optimal handle diameters. These tools are used in accordance with regular ergonomic assessments and training programmes. In contrast, in Ecuador, machetes, hammers and hand drills are commonly used, often without ergonomic modifications and with limited assessment and training, especially in the informal sector. In contrast, machetes, hammers and hand drills are commonly used in Ecuador, with little ergonomic modification and limited assessment and training, especially in the informal sector. This leads to higher rates of musculoskeletal disorders (MSDs), such as knee (7.4%) and hand (5.3%) osteoarthritis. In Hungary, regulations are in place but are not consistently enforced, and tools are not maintained, leading to a higher risk of injury.

Older or less ergonomic equipment, more hazardous working conditions and laxer enforcement of safety laws may all contribute to a greater awareness of potential risks in Ecuador. In addition, fewer people have access to organised training and medical care, which can make incidents seem more serious [21], [22], [23].

Formulation of the scientific problem

A complex problem requiring creative solutions at the interface of ergonomics, safety standards, tool design, workplace optimisation and human reliability analysis. This complicated subject has several interrelated elements, each of which presents scientific difficulties and opportunities for progress. The large number of

injuries that occur each year in the manufacturing industry, particularly those involving hand tools, has become a major concern. The overall aim is to improve the management system and prevent future hand tool-related disorders.

Combining ergonomic concepts with safety requirements is a major scientific challenge. New approaches are needed to achieve a harmonious balance between designing workspaces, tools and equipment that reduce the physical demands on workers (addressing ergonomic concerns) and identifying and mitigating hazards to prevent accidents and injuries (ensuring safety). The design of workstations requires a systematic and scientific strategy to measure recurrent and elemental forces during work. The scientific challenge is to develop effective methods for the use of tools in workstations, considering individual variations in tasks and applications, while meeting the varying needs of workers across multiple projects.

Hand tools are widely used in many different industries, especially in Latin America. However, there are still insufficient integrated ways to evaluate and reduce the ergonomic, physiological and perception-related dangers associated with their repeated and prolonged use. Current procedures often overlook culturally influenced perceptions of occupational risk, the anatomical diversity of users, and the initial signs of muscle fatigue. The high prevalence of musculoskeletal problems, hand injuries and lost productivity is aggravated by the absence of formal examination techniques. Specifically, there is a lack of expert-driven frameworks for systematically classifying ergonomic hazards, culturally sensitive tools for evaluating worker risk perception are lacking, and surface electromyography (EMG) is not being used for real-time fatigue monitoring.

Understanding the physiological implications of flexion and extension of the wrist and excessive muscle effort is crucial in developing preventive measures and ergonomic management strategies to minimise the concern of cumulative trauma disorders.

Objectives

- Develop strategies and measures to prevent future hand tool-related disorders by applying cause identification.
- Establish systematic and scientific strategies for measuring forces during work and develop effective methods for the use of tools in workstations using new technology.
- Gain a comprehensive understanding of the physiological implications of repetitive manual activities on the wrist and muscles for avoiding possible degradation.

Hypotheses of the research

Hypothesis 1 (H1): Electromyography (EMG) can be used to identify the onset of muscle fatigue in individuals using hand tools by analysing changes in EMG signals during sustained gripping tasks to prevent injury and cumulative trauma disorders related to work.

Hypothesis 2 (H2): Risks associated with the use of non-powered hand tools can be effectively identified, categorised and prioritised through the integration of individual factors using Multi-Criteria Decision-Making (MCDM) methods, by applying structured approaches like the Analytic Hierarchy Process (AHP) and the Best-Worst Method (BWM), to develop targeted risk reduction strategies that lead to a reduction in both the frequency and severity of hand-related injuries in the workplace.

Hypothesis 3 (H3): The probability of risk perception examined through the Domain-Specific Risk-Taking (DOSPERT) among users during tasks involving non-powered hand tools is significantly associated with individual factors such as previous hand-related injuries, task-specific variables such as tool complexity and duration of use, and ergonomic considerations such as tool design and workplace environment, which could lead to users experiencing hand-related disorders.

Hypothesis 4 (H4): By recording and analysing electromyography (EMG) signals from the muscles involved in using hand tools, an ML algorithm can accurately detect signs of muscle fatigue in individuals performing repetitive or prolonged manual tasks. This information can then be used to develop targeted interventions to prevent injuries and improve workplace safety.

Hypothesis 5 (H5): By training an artificial intelligence (AI) system using electromyography (EMG) data, we can teach the AI to accurately identify muscle fatigue signals and provide real-time feedback to workers, thereby improving their productivity and reducing the risk of injury.

Research Methods and Challenges

In preparing my thesis, I have divided my research into four parts, as shown in Figure 2. In the first part, I conducted a systematic review to determine the application methods of electromyography (EMG) and fatigue wave detection in the electromyographic response of hand muscles. In the second part, I developed a survey and data analysis to determine users' risk perceptions of different hand tool use scenarios and a country comparison to determine workers' behaviour in dealing with hand tool risks. In the third part, EMG data collection and machine learning (ML) techniques are applied to determine the muscle wave response to determine the best data identification method for AI data classification.

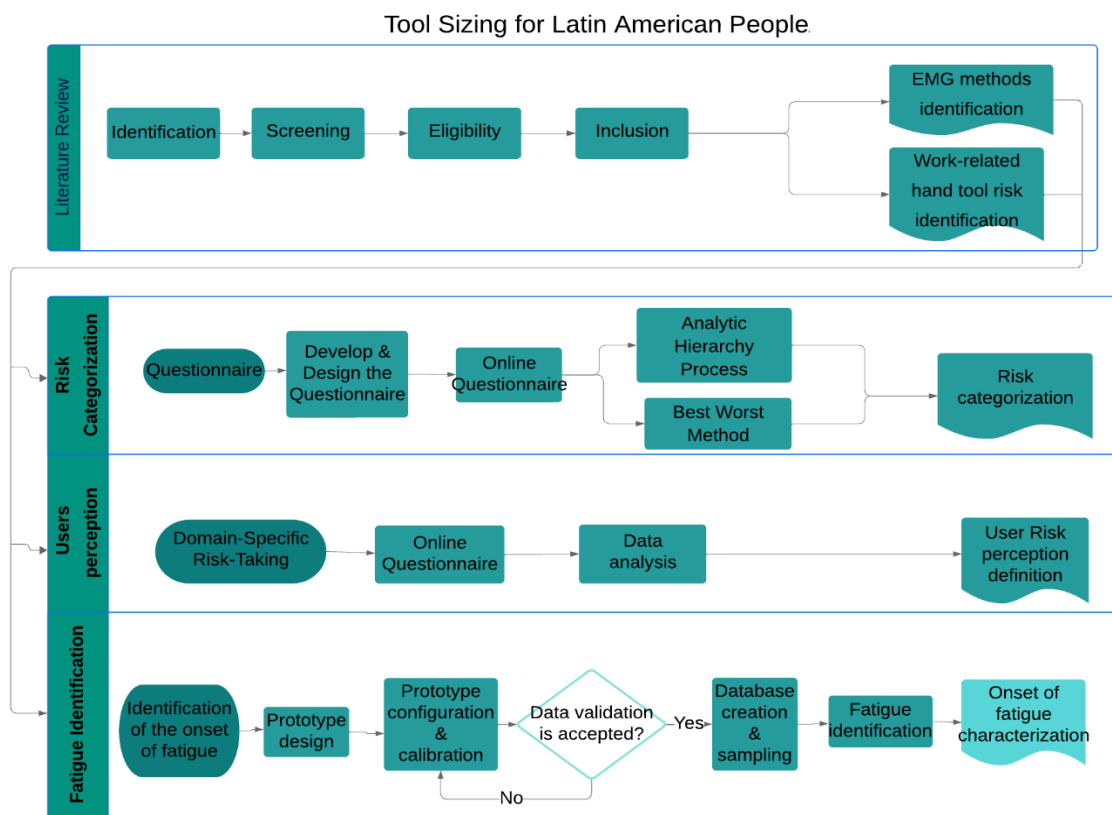


Figure 2 Tool Sizing for Latin American People Research Framework

New Scientific Results

My research aimed to develop scientific strategies and methods for measuring forces during work and to develop efficient workstation tool use techniques using new technologies. In addition, I wanted to develop strategies and measures to prevent hand tool-related disorders by establishing a detailed knowledge of the physiological effects of repetitive manual activities on the wrist and muscles and identifying their causes.

Therefore, my new scientific results are as follows:

- **Thesis (T1):** With a systematic PRISMA literature review and meta-analyses, I have proved that electromyography (EMG) collected in the forearm, including the flexor carpi radialis, flexor carpi ulnaris, and pronator teres, help prevent work-related injuries and cumulative trauma disorders by identifying the onset of muscle fatigue during over 5-second gripping tasks.
- **Thesis (T2):** By applying Multi-Criteria Decision-Making (MCDM) methods to categorize risks associated with hand tool use in a sample of 10 ergonomic experts, I demonstrated that integrating individual factors like 'tool damage', 'ergonomic risk', and 'physical injury' can effectively stratify to rank and assess the risks related to hand tool use, and it shows that 'physical injury' is the primary risk factor, with a weighted importance of 73.06% in the Analytic Hierarchy Process (AHP) (Consistency ratio: 0.0492) and cross-validated by the Best-Worst Method (BWM) at 73.62% (Reliability ratio: 0.1978).
- **Thesis (T3):** By applying modified DOSPERT risks perception evaluation related to hand tool use in a sample of 123 participants. I determined four domains: 'Material Domain', 'Personal Domain', 'Environmental Domain', 'Organizational Domain', and I proved that risk aversion was more likely in the Material and Environmental domains (b coefficient -0.0729 and -2.1639 , respectively) and risk-taking behaviour in the Organizational and Personal domains (b coefficient 0.2985 and 0.2985 , respectively).
- **Thesis (T4):** Applying an EMG smart wearable device in a controlled laboratory setting with 12 participants using standardised hand tool dimensions of 45 and 65mm. I proved that:
 - o Fatigue onset occurs around 25 repetitions with a probability of fatigue detection ($p\text{-value} = 2.22 \times 10^{-7}$)

- A pattern comparison in mean peak EMG values decrease significantly during the exercise.
- Electromyography (EMG) signals from forearm muscles in gripping tasks show a probability of force reduction detection of 3.74×10^{-16} and 4.19×10^{-13} , using standardized hand tool dimensions of 45 and 65mm.
- **Thesis (T5):** I have proved that an artificial intelligence (AI) system trained on electromyography (EMG) data can accurately detect muscle fatigue signals with K-NN method that achieved an accuracy of the model to predict the state of fatigue of 76.4% to provide real-time feedback to workers reducing the risk of MSDS.

Possibility to utilise the Results

The study could benefit the industry in tasks involving the use of hand tools by providing insight and knowledge into the appropriate tool for each worker. The results will provide information on how individual differences affect muscle fatigue and tool usability.

More tool designs and a greater range of sizes and shapes can be considered when seeking to make recommendations for ergonomic tool design that are effective. By considering these elements, a more comprehensive understanding of how tool weight, material, and grip texture can impact workers when they are in danger and impact performance may be achievable.

Designing ergonomically optimised tools with improved grip and force distribution should be prioritised. In addition, training programs for workers on proper tool-handling techniques and periodic ergonomic evaluations are provided to enhance workplace safety and productivity.

Implementing AI-driven EMG monitoring solutions in industrial environments can help identify early fatigue onset and adjust work-rest cycles, including a tailored hand tool selection according to workers' anthropometrics.

As future research, the study could integrate the effects of recovery interventions, such as stretching, rest breaks, or cooling techniques, on mitigating fatigue during repetitive tasks. This would provide a full understanding of risk prevention for workers using hand tools.

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Publications

Scientific Publications Related to the Thesis Points

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