

# INDUSTRY PERSPECTIVE OF STAKEHOLDER RELATIONSHIPS IN THE TECHNOLOGY TRANSITION AND AUTOMATION OF HEAVY-DUTY MOBILE MACHINERY

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## ABSTRACT

Application areas of heavy-duty mobile machines (HDMMs) such as construction, mining, and material handling have maintained traditionally stable mechanical engineering oriented and fluid power technology dependent relationships between suppliers, manufacturers, and end-users of HDMMs. However, shortage of skilled labour, safety issues, economic uncertainties, and environmental concerns related to HDMM operations have increased the research and development efforts on automated and autonomous HDMMs, thereby leading to a technological transition in the HDMM industry. Accordingly, current research and development addresses highly technical challenges and multidisciplinary topics. However, research on non-technical topics in the HDMM industry such as future business models and collaborative ecosystems are still in their nascent stages, thereby posing challenges for the practical deployment of automated HDMMs, barring limited use cases. In this study, we utilise mixed-methods to explore the changing stakeholder relationships associated with the technology transition in the HDMM industry. We create a comprehensive stakeholder mapping of the HDMM industry and bring hidden/new stakeholders to the fore. Furthermore, we analyse the stakeholder relationships as a network of relationships among different actors in the HDMM industry, thereby highlighting collaboration potentials and directions for future research on the technology transition in the HDMM industry.

**KEYWORDS:** Automation, Autonomy, Mobile Machines, Stakeholders, Technology Transition

## 1. INTRODUCTION

Heavy-duty mobile machines (HDMMs), also known as mobile working machines, non-road mobile machinery, off-highway machinery, and mobile machinery, among several other terminologies, are machinery used in predominantly outdoor application areas such as construction, mining, forestry, logistics, etc. The HDMM industry has maintained, over several decades, traditionally stable relationships between suppliers and Original Equipment Manufacturers (OEMs) of HDMMs, wherein suppliers provide fluid power products and technologies such as hydraulic system architectures and components, while OEMs successfully integrate such fluid power technologies within their HDMM product offerings to provide

functional HDMMs to end-user groups. Consequently, majority of the research and development (R&D) in the HDMM industry has focussed on highly technical topics such as energy efficiency, emission controls, powertrain system architectures, and fluid power simulations. However, the focus on non-technical topics related to HDMMs from the fields of business, management, and economics has been minimal [1].

Such a highly technical focus of R&D in the HDMM industry in the past is justified given that the main premise of HDMMs for the past few decades was that of one human machine operator, operating one single HDMM in a specific application area. These application areas play a significant role in the society such as ensuring the supply of raw materials and food, infrastructure construction, enabling logistics, etc. However, recent societal developments such as the shortage of skilled labour to operate HDMMs, aging populations, as well as poor safety records due to HDMM related accidents adversely affect the HDMM industry and its application areas [2]. Thus, the HDMM industry is working towards developing several automation solutions such as partially automated, teleoperated, and autonomous HDMMs [1, 3, 4], and require a multidisciplinary technology transition across several technical domains such as powertrain system architectures, robotics, AI methods, work process simulations, as well as non-technical domains such as business cases and safety/liability topics [2]. Such technology transitions also open new paths for added value creation, for example, through condition monitoring systems and servitization, compared to traditional HDMMs simply performing their intended task [1, 2]. Thus, it is imperative to address the non-technical topics in the HDMM industry to harness the added value from these technology transitions [1], which may require new skills and competences otherwise missing from the traditional stakeholder relationships in the HDMM industry [2].

Currently, the automation solutions deployed on HDMMs are predominantly operator assistance functions, wherein higher Levels of Automation (LOA) without a human operator exist only as 'islands of automation', for example, autonomous haulage systems in mines, despite the pervasion of autonomous driving research in the automotive industry [1]. Automation of HDMMs is challenging due to the very nature of the primary working principles of HDMMs: firstly, manipulation/working functions wherein the HDMM changes the shape, size, form, and/or location of external materials, and secondly, driving/navigation/propelling functions wherein the HDMM moves or navigates from one location to another [4]. Accordingly, it is important to use a common framework and understanding of LOA, such as the automotive SAE J3016 used in [1], wherein the authors highlight that as the LOA increases from partially automated, to semi-autonomous, to fully autonomous, traditional customer-supplier roles would need to change to accommodate new business models and risk-ownership arrangements [1]. In [4], a LOA taxonomy specific to HDMMs is proposed wherein four primary parameters need consideration, i.e., system control, environment perception, decision making, and worksite communication. Thus, for any change in the LOA of HDMMs, at least one of the above-mentioned four parameters needs to be modified, thereby requiring a technology transition such as the addition of external perception sensors, using AI methods, digital twins, mobile network connectivity, high performance computational hardware, etc., [2, 4], which have an effect on the business models, ecosystem collaborations, and associated stakeholder relationships, beyond the boundaries of a single firm [1].

Thus, in this study, we investigate the influence of the changing technological landscape on the stakeholder relationships in the HDMM industry. The main research question is to examine and map out the existing stakeholder relationships and how they are expected to change in the future. This study follows a mixed-methods abductive reasoning approach where experts from the HDMM industry and the associated value chain are invited to participate in an online survey to study their understanding of stakeholder theory. The short survey is followed by personal semi-structured interviews to gain insights into stakeholder perceptions in the HDMM industry. While there has been an uptick in non-technical research in the HDMM industry, the novelty of this study is that it will be the first study that specifically highlights the different stakeholders related to the technological transition in the HDMM industry, rather than thinking of stakeholders from a generic, project-based, or corporate social responsibility perspective. Secondly, this study examines the stakeholder relationships as a network of relationships among different actors in the HDMM industry, thereby paving the way for future business and innovation ecosystem frameworks in the HDMM industry.

The remainder of the article is structured as follows: section 2 highlights the theoretical background related to stakeholder theory, section 3 highlights the qualitative methods used, section 4 provides the results and discussions, and section 5 concludes the paper.

## 2. THEORETICAL BACKGROUND

According to Freeman (1984), a stakeholder is anyone who affects or can be affected by the outcome of an organisation [5] but this definition is considered too broad since everyone can be considered as a stakeholder [5, 6]. Furthermore, Freeman's definition of stakeholders is interpreted as having two main themes- a strategic theme which seeks to 'manage' interests and a moral theme which seeks to 'balance' interests [6]. However, the assumptions about business when capitalism was the only prevalent theory of business were that economics alone were important, while issues of values and ethics were insignificant [5], leading to the *separation fallacy*, wherein business decisions and ethical decisions are treated as separate decisions [5]. This leads to the exclusion of stakeholder groups that have no economic interests in the organisation [7] while also ignoring the organisation's purpose in the society beyond economic goals [8]. However, ethical interests, business decisions, sustainability, and social responsibility have become increasingly important topics in the broader society, thereby in the business context too [5, 7]. Since the organisation's interests may diverge from its stakeholders' interests, leading to potential conflicts of interest [5, 6, 7], identifying and classifying such conflicting interests of stakeholders is an important step in managing stakeholders. To manage such interests, four different archetypes of stakeholders are proposed in [6]: *Claimant*- has legitimate claims/stakes/vested interests in the organisational activities, wherein the stakes originate from meaningful interactions with the organisation (e.g., employees, internal departments, customers, shareholders, etc.); *Influencer*- has an ability to influence, i.e., assist or hinder the activities of the organisation (e.g., competitors, new entrants, employees, etc.); *Collaborator*- collaborates with the organisation for joint value creation (e.g., universities); *Recipient*- is a recipient of the outcomes (risk and/or advantage) of the organisation's activities, (e.g. customers, competitors, society, etc). These four archetypes are combined to form 15 stakeholder groups (e.g., claimant-influencer, collaborator-recipient, etc.) [6]. In [9], a framework to identify, classify, and manage stakeholders as well as *non-stakeholders* is described using 3 primary attributes: *power, legitimacy, and urgency*, wherein stakeholder attributes are contextual, dynamic, and subjective. The importance of an organisation's culture in stakeholder management is described in [10], while [8] highlights the effects of the perceived social status and influencing power of stakeholders on stakeholder relationships. [11] discusses a framework for the onboarding of new stakeholders from the perspective of entrepreneurship and new venture creation, while [12] highlights how managerial hierarchies prioritise different stakeholder groups and interests.

Research literature specifically addressing non-technical topics in the HDMM industry is scarce [2]. However, [1] proposes a business maturity framework specifically for automated HDMMs by performing a qualitative case study, wherein 32 expert interviews are conducted across four OEMs of mining equipment, their digitalisation partners, and industrial mining customers in Sweden. The framework in [1] proposes automated HDMMs as a business solution from three automation perspectives based on SAE J3016 LOA: Operator Assistance systems; Semi-Autonomous solutions; and Full Autonomous solutions sans human operators. For each automation perspective, the framework in [1] proposes three focus areas: technology development, i.e., type of technologies needed; ecosystem configuration, i.e., changing supplier-customer relationships; and finally, business models, i.e., traditional product sales compared to digital servitization. While [1] does not specifically address stakeholder theories, the focus on innovation ecosystems and business models provides valuable insights on changing stakeholder relationships due to the automation perspectives. For example, OEMs may prefer hybrid business models for semi-autonomous solutions rather than pure outcome-based (i.e., product as a service, direct OEM to end-user relationship) business models because equipment dealers or rental companies are currently the biggest customer-stakeholder groups of the OEMs [1]. Another study analyses the cost-benefits of harmonisation of road-safety requirements for HDMMs in EU countries but only considers a narrow range of stakeholders such as OEMs, their intermediaries (rental companies and distributors), end-users, EU Member States' authorities and third parties, all mentioned in a footnote [13]. A study on commercial agricultural robots investigates the low adoption of robotics in farms and the associated challenges in adopting successful business models [3], and indirectly addresses stakeholders by highlighting the usefulness of their research to robotic companies, investors, farmers, insurance organisations, policy makers, and researchers involved in field robotics [3]. Thus, the literature on stakeholder relationships in the HDMM industry is scarce, fragmented, and at most, indirectly addressed.

### 3. METHODOLOGY

This study followed a mixed-methods research methodology and abductive reasoning- which is the logical process of making observations and subsequently deriving hypotheses which sufficiently explain those observations. The mixed-methods consisted of a literature study, a survey with qualitative and quantitative response fields, and qualitative semi-structured expert interviews. Firstly, we performed a literature study on stakeholder theory and its antecedents, thereby formulating a set of research questions much wider than the scope of this study, as part of a broader stakeholder analysis. Next, we planned to perform expert interviews of industry professionals from 3 primary work functions: sales, R&D, and executive management, with specific focus on the automation of HDMMs. The intention of the survey was to capture the perceptions of industry experts on the concepts of stakeholder theory and their own organisation prior to the interviews.

Since several disciplines have ontological theoretical assumptions about domain-specific expertise according to postulate 9 in [14], wherein experts from the HDMM industry were chosen using purposive sampling based on the personal contacts of the authors, as well as informal methods and peer nomination [15]. Purposive sampling was deemed to be sufficient [15] since the HDMM community is close-knit and the topic regarding the automation of HDMMs is relatively new. Thus, a total of 38 industry and academic experts were identified and contacted via email, out of which 13 experts agreed to and answered the online survey via Microsoft Forms. After collecting the responses from the online survey, we performed a descriptive statistical analysis due to the small sample size ( $n < 30$ ) of the survey participants. Furthermore, a word cloud and stakeholder maps were generated on a MIRO board, based on the qualitative response fields in the online survey. The respondents of the online survey were then invited for expert interviews. Of the 13 initial online survey respondents, only 11 respondents participated in the expert interviews. Subsequently, 2 additional experts were contacted and participated only in the expert interviews. All 13 interviews, wherein 12 or more participants can be considered significant for theoretical saturation [16], were conducted using Microsoft Teams. The interview transcripts were polished, anonymised, and/or pseudonymised in some cases to maintain context. This study utilises only certain elements of the interview dataset since the interviews are part of a larger dataset based on the broader stakeholder analysis study.

### 4. RESULTS AND DISCUSSION

#### 4.1.1. Respondent Profiles

The characteristic profiles of the respondents are summarised in Figure 1 and Table 1. Among 38 invited participants for the stakeholder analysis study, only 13 participants responded to the survey study, with a response rate of approximately 31%. The majority (54%) of the survey respondents indicated their current location as Germany, 31% of the respondents as Finland, and 15% of the respondents as Austria. The survey respondents were from 8 different organisations with 46% indicating their organisation type as an OEM (manufactures end product, i.e., HDMM), 31% as a supplier (usual interactions with OEMs), 15% as add-on solution providers (usually deals with or retrofits the end-user's HDMMs, e.g., fleet management, BIM, etc.), and 8% from academia (research, education, training).

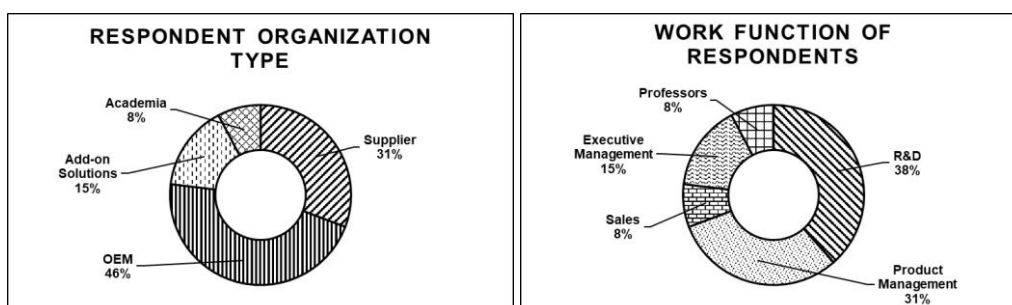


Figure 1. Short Survey Respondent Profiles- Left: Organisation Profiles, Right: Work Functions

Table 1. Survey<sup>α</sup> and Interview<sup>β</sup> Respondent Profiles.

ID/ Type	Type of Experience	Regions Lived/Worked
SMR <sup>αβ</sup> / S1	Supplier, Executive management- automated HDMMs, >22 years	Germany, France
SMO <sup>αβ</sup> / S2	Supplier, Executive management- automated HDMMs, >22 years	Germany
SMC <sup>αβ</sup> / S3	Supplier, Executive management- automated HDMMs, >12 to <22 years	Finland, Germany
SRD <sup>αβ</sup> / S1	Supplier, R&D- automation of HDMMs, >7 to <12 years.	Germany, USA
SSM <sup>αβ</sup> / S1	Supplier, Sales and project management for HDMMs, >22 years	Germany
ORD <sup>αβ</sup> / O1	OEM, R&D- automation of HDMM, >7 to <12 years	Austria, Germany, Finland
ORS <sup>αβ</sup> / O2	OEM, R&D- Automation of HDMMs, >4 to <7 years	France, Germany
ORA <sup>αβ</sup> / O2	OEM, R&D- Automation of HDMMs, >4 to <7 years	Germany
OPM <sup>αβ</sup> / O1	OEM, Product management- HDMMs, <4 years	Austria, USA
OPI <sup>αβ</sup> / O2	OEM, Product management and innovation- HDMMs, >7 to <12 years	Germany, APAC
AoMV <sup>αβ</sup> / Ao1	Add-on solutions, Product management- digitalisation, >12 to <22 years	Finland
AoRL <sup>αβ</sup> / Ao2	Add-on solutions, R&D- automation of HDMMs, >7 to <12 years	Finland
APD <sup>β</sup> / A1	Academia, Full Professor- R&D on HDMM, >22 years	Finland, USA, Japan, Russia.
APR <sup>α</sup> / A2	(Survey only) Academia, Academic professor	Finland
OPC <sup>α</sup> / O3	(Survey only) OEM, Product management	Finland

#### 4.1.2. Respondents' Understanding Regarding the Concept of Stakeholders

In the short survey, the respondents were asked to rate their familiarity and awareness regarding the concept of stakeholders on a 5-point Likert scale. Awareness was defined as *'having a general or surface level understanding of something that exists'*. Familiarity was defined as *'having specific or deep knowledge and understanding of something that exists'*. After responding to the initial question about their level of awareness and familiarity regarding stakeholders, a stakeholder definition using the claimant-influencer-collaborator-recipient architypes [6], described in section 2, was provided to the respondents to understand their change in perceptions. The level of awareness and familiarity are shown in Figure 2.



Figure 2. Level of Awareness and Familiarity of Respondents Regarding the Concept of Stakeholders. Left: Before Providing a Definition of Stakeholders, Right: After Providing a Definition of Stakeholders

Based on their prior knowledge, while most respondents had a decent awareness, the level of familiarity was relatively lower, with none of the respondents indicating high familiarity regarding the concept of stakeholders. After providing the definition of stakeholders, respondents with moderate (except one) and high awareness prior to the definition had no change in their level of awareness. The respondents who were somewhat aware of stakeholders changed their perception to either a moderate or high awareness. On the other hand, while a majority of the respondents improved their perception about the level of familiarity after the definition, respondents with a moderate level of familiarity (except one) did not change their perception even after the definition. Two respondents who were somewhat familiar with the concept of stakeholders had no change in the perception even after reading the definition. The definition of stakeholders had no effect on respondents with Executive Management and Product Management (except one) respondent profiles.

### 4.1.3. Machine as a Stakeholder

The survey respondents were asked to indicate if they would consider a machine as stakeholder based on the current technological progress as well as in the future. Figure 3 highlights the differences in perceptions of the respondents. Majority of the respondents would not consider a machine as a stakeholder based on the present scenario. Only one respondent from the Add-on Solutions Provider considered machine as a stakeholder in both scenarios. One OEM respondent was uncertain in the present scenario but would consider a machine as a stakeholder in the future scenario. One supplier respondent was uncertain in both the scenarios. In the future scenario, several respondents from organisations other than suppliers were uncertain about considering a machine as a stakeholder.

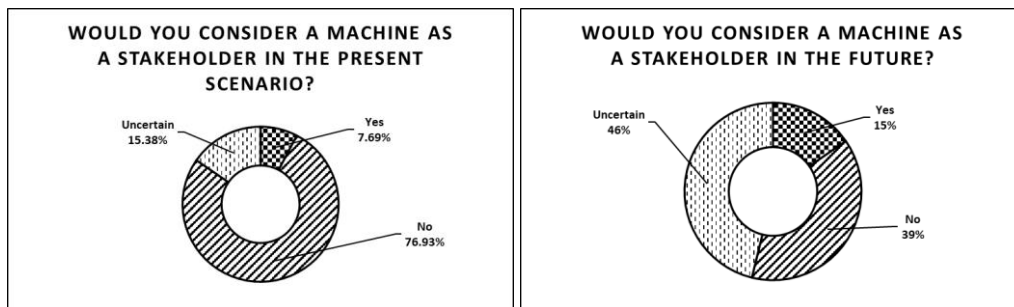


Figure 3. Machine as a Stakeholder, Left- Present Scenario, Right, In the Future

### 4.2. Stakeholder Mapping of Organisations

The survey respondents were asked to enter their primary and secondary stakeholders in the order of importance, i.e., from the most important stakeholder to the least important stakeholder, via an open-ended response field. The associated stakeholders for a single organisation type are shown in Table 2. Primary stakeholders were defined as 'stakeholders that are essential for the organisation's survival, and usually engaged in some exchanges (material, information, capital, etc.) with the organisation while secondary stakeholders were defined as 'stakeholders who influence or affect, or are influenced or affected by the organisation but are not essential for its survival [12]. Depending on the work function as well as organisational perspective of the respondents, the prioritisation of stakeholders was different. For example, while one executive management from the supplier considered competitors as a primary stakeholder, the other respondents considered competitors as secondary stakeholders.

Table 2. Organisations and their Stakeholders in Order of Importance (Most Important to Least Important)

Organisation	Primary Stakeholders	Secondary Stakeholders
Add-on Solutions Provider	Infra contractors, infra owners, machine rental, machine operators, supplier, OEM, engineering consultant, employees, distributors, standards organisation, government.	BIM vendors, machine vendors, competitor, universities, society, research organisation.
OEM	Customer, employees, management, sales, external service partners, shareholders, technology supplier, machine distributor/vendor/dealer, logistic partner, trade association, R&D team, universities, research organisation, regulators organisation, certification organisation.	Competitor, international and national regulatory organisation, logistics partner, government, retrofitters, standards organisation, mass media, HR & IT support, local community, insurance organisation, university, legislation, funding partner, worker's council, trade association, research community, NGO.
Supplier	Customer, employees, top management, R&D team, department management, competitor, manufacturing, local and national sales, external service partners, plant management, technology supplier, distributors/vendors, logistic partner.	Government, machine operator, end-user, norms and legislation working groups, international and national regulatory organisation, competitors, standards organisation, R&D team, cities, trade association, universities, unions, mass media, local community, graduate students.
Academia	Research group, department, students, employees.	Global and national academics, industry.

### 4.3. Stakeholder Mapping of the HDMM Industry

The stakeholders from Table 2 were mapped as a network of connections as shown in Figure 4. This stakeholder mapping was used as a visualisation aid during the expert interviews. The value chain follows a left to right linear supply chain logic wherein suppliers provide fluid power technologies to OEMs who integrate these fluid power technologies in the HDMM, and sell the HDMMs to end-user groups. The add-on solution providers act as a retrofitting interface between the OEMs and end-user groups.

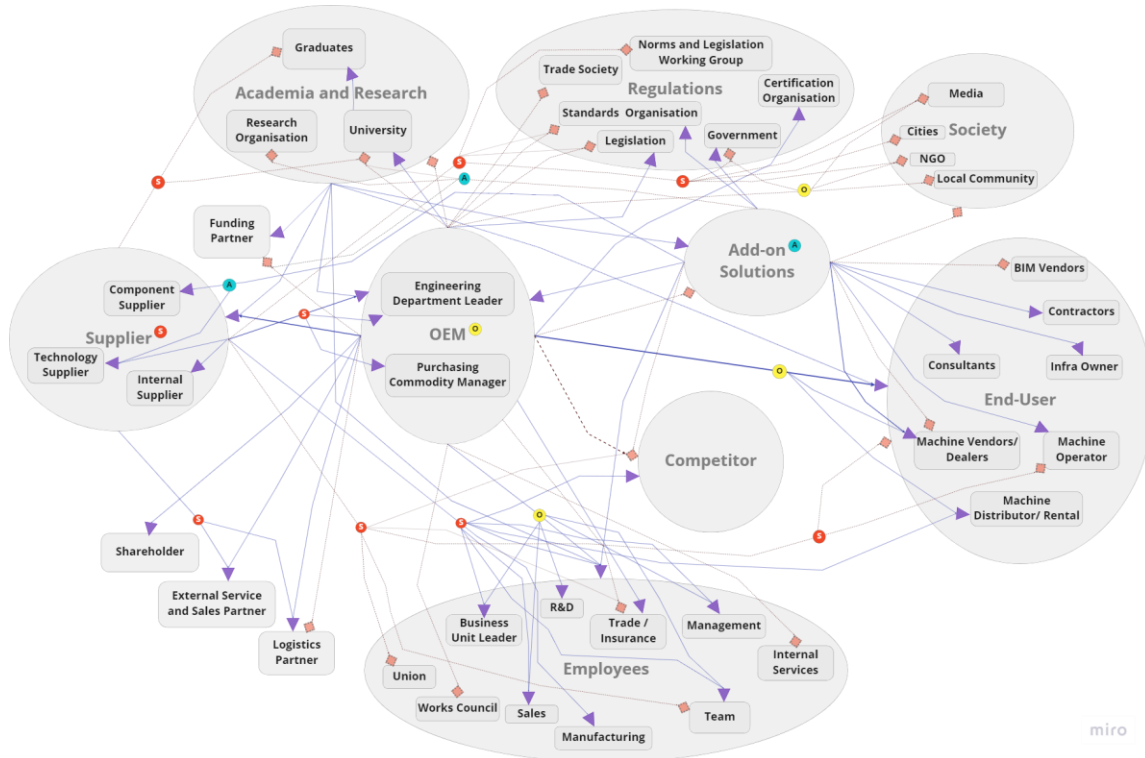


Figure 4. Stakeholder Mapping of the HDMM Industry as a Network. Connections to the triangles indicate Primary Stakeholders while Connections to the Squares Indicate Secondary Stakeholders.

While several respondents from the industry mentioned employees as an important primary stakeholder, only one respondent from the industry mentioned graduate students as a stakeholder. Moreover, only a few respondents mentioned academic and research organisations as stakeholders, which is surprising given the shortage of skilled talents in the HDMM industry. When the interview respondents were asked their reasoning for the low mention of academia and graduate students, there were different reasons, such as students not being the focus of daily activities, the lack of appropriate industry support in academic infrastructure, and the uptick of recruiting activities in university campuses. Some relevant quotes are:

“[...] maybe it's [...] because people are quite focused on their daily [...] operational business or more or less looking into tunnel [...] it's not the first thing everybody thinks about because we have so many topics and daily business. I think it's not on purpose, it's more like, just forgot about it [Supplier].”

“[...] if you look at the [...] direct stakeholders who will influence you [...] you are not looking [...] at schools, universities, employees. [...] What I do not understand is, why big companies are not spending more money [...] in the infrastructure [...] of schools, universities? [...] Such a shame [...] You have such big players [...] but they don't spend money [...] People are employees, students, and [...] if you would focus on them [...] you will not have [...] a talent war [OEM].”

“[...] students are customers in education [...] There's a huge lack of experts in industry and you can see the increasing recruiting activities of companies in university campuses [...] If you think about the R&D people of [...] HDMM manufacturers [...] it is quite easy to meet those people in events and get familiar [...] so many of our alumni, they are actually working in those groups and companies [...] The universities [...] have very important role in fighting against the labour shortage because we need to recruit internationally into this society and economy [Academia].”

Moreover, processes used by end-users may not be taught at universities but are rather learnt on the job, while technical innovations continue to be an output of universities and research organisations. For example,

*“Construction process, it's not taught anywhere in the universities or anywhere in academia and it's not really researched outside of the companies who are actually doing the construction [...] With autonomous machines [...] How can you actually control the autonomous machines? [...] Which sensor algorithms you use? [...] is quite heavily focused on the university side and research organisations. [...] The construction process is quite big part of the whole business side [...] (thus) the universities [...] just don't have the same knowledge that we have [Add-on Solutions].”*

Another important result is that the end-user groups are not as straightforward as simply referring to them as an OEM's customer. It is important to understand the processes used by end-user groups in procuring and operating HDMMs on a worksite. For example, HDMM rental companies and dealers/vendors are a big customer for several OEMs. Moreover, infrastructure ownership models could influence how HDMMs are used, for example, by using contractors or site operators to operate HDMMs, or engineering consultants acting as gatekeepers or influencers of HDMM purchasing and operating decisions, as highlighted below:

<p><i>“The special thing about the environment where we are at, you need to have a close look at the end users, which is not only the machine operators but kind of the fleet owners or the site operators, like in mining and so on [Supplier].”</i></p>	<p><i>“Who owns a construction site? Who is the main stakeholder of a construction site? And that can be super diverse and the tree of stakeholders on a construction site can be very widespread [...] You have no linear value chain there. Compare that to running a field and delivering grain to the powder mill. There your process is super clear [...] when you have to do what [...] and who has to do what [Supplier]”</i></p>
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OEMs had a similar opinion to the end-user bubble shown in Figure 4. Respondents from the OEMs highlighted that the application/use of an HDMM and its optimisation parameters can differ significantly with different applications even for the same type of HDMM. However, several interview respondents were surprised that the OEMs did not mention the machine operator as a stakeholder in Figure 4. For example,

*“I was surprised and shocked, talking about assistance functions with the OEMs and [...] the critical working situations with their machinery. They have no idea. So you need to talk to the end-user to tell the OEM [...] (about) critical manoeuvres of machines and [...] the solution [...] For anything [...] new, it's important to understand how the machine is used [...] that's really the operator [...] The sourcing decision [...] there you need to talk to the fleet owner [Supplier]”*

The previous quote is interesting because even though it is important to understand and identify the correct end-user stakeholder groups of HDMM solutions, the associated stakeholder personas such as influencers, gatekeepers, purchasing decision makers, fleet managers, etc., are quite important too, especially if one considers the “names and faces” approach to stakeholder identification and management. These personas are highlighted in the OEM bubble in Figure 4, where one respondent specifically identified engineering department leaders and purchasing commodity managers as primary stakeholders. Product Management respondents resonated with similar views from different application areas:

<p><i>“If you look at the construction company [...] there's the owner, operator, buying guy, mechanical guy, financial guy [...] In larger companies, there are guys who optimize the operation on the job site, there's different views on the machines [OEM].”</i></p>	<p><i>“We have all these personas [...] it's the owner of the company, fleet manager, purchasing manager, service manager, operator, and sometimes you even have like a sixth persona [...] the logistic planner [...] who is involved in finding the best [...] logistic solution for the (logistics) yard [OEM].”</i></p>	<p><i>“[...] We need to find [...] profit and loss gatekeepers because [...] you need to rely on new technology, [...] who actually knows about it [...] Typically it's an engineering consultant, [...] BIM coordinator, [...] trusted people, maybe even from different companies [...] One key gatekeeper is [...] the people who need to use the new technology, [...] who manipulate the data at the project level [...] Beyond single projects, it's typically the contractors' headquarters [...] where somebody is [...] developing decision processes [...] they don't buy anything [...] but are internal champions who help to succeed [...] The owner organisations [...] are the trickiest because [...] they have less [...] business initiative or money initiative [...] (just) focused on getting it easier and [...] with low effort [Add-on solutions].”</i></p>
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However, the abstraction level is important when thinking about stakeholders too. For example, on a general level, OEMs simply think about the “customer” as a stakeholder. However, if the abstraction is moved to the project level, specific stakeholders are given more consideration. Moreover, automation of HDMMs will likely change the roles of the human operators depending on the LOA and abstraction level, such as using assistance functions where the human is still sitting inside an HDMM or with higher LOA where one human operator is controlling a fleet of automated HDMMs simultaneously. Thus, the operator may be replaced by another role or persona at higher LOA for HDMMs. This is also highlighted in the following quotes:

*"I don't know if it's the machine operator or the end-user [...] I work on high-level software to control the vehicle [...] We have new user interface [...] For me, the user is a stakeholder, and this is what I called end-user [...] If it's a machine operator [...] we are not completely aware about the roles. Because automation changes the roles [...] it's not the same roles if you have a normal machine [OEM]."*

*"[...] You should bring [...] new technology to new machines and [...] different approach on the business [...] Perhaps the operators are driving them remotely, from a control room [...] Many times the operators [...] really want to steer the 50 ton device and it takes time to shift (mindset) [...] The full stack needs to be evolving [...] You need to redesign your equipment [...] Your personnel [...] are no more hardcore men driving hardcore devices but they are [...] productivity guys driving [...] with joystick and programming autonomous sequences and so forth [Supplier]."*

#### 4.4. Automation of HDMMs and Changing Nature of Stakeholder Relationships

The interview respondents were asked about the major drivers and barriers of automation. Accordingly, the major drivers of automation in decreasing order of importance are skilled labour shortages, better economic value, better plannability and predictability in HDMM operations especially for repeatable tasks, improved safety during HDMM operations, and the total cost of ownership focus of the HDMM industry. The major barriers of automation in decreasing order of importance are legislation uncertainty for human operator-less HDMMs, functional safety of automated HDMMs around mixed fleets and humans, mindset of the end-user groups of HDMMs, technology availability such as sensor accuracy, chips, etc., achieving robust solutions in adverse weather conditions, shortage of specialised talent especially software engineers, diversity of the HDMMs, i.e., low volume - high mix products, and a general lack of standards related to automation technologies such as communication architectures and software interfaces. One respondent mentioned an interesting barrier to the automation of HDMMs as 'Fluid Power Robotics', which highlights the complexity of robotisation solutions in the HDMM industry compared to industrial and indoor robotics.

As shown in Figure 4, several stakeholders have common stakeholders throughout the HDMM value chain, which could enable the HDMM industry to capitalise on the drivers and overcome the barriers related to the automation of HDMMs. Thus, we map out new stakeholders and stakeholder relationships in Figure 5, based on the responses from interviews, external literature analysis such as annual reports, as well as direct observations by the first author at two trade fairs for HDMMs. During the expert interviews, economic value was the overarching focus of the majority of industry respondents. However, academic respondents viewed value differently, wherein research publication output and the number of graduating students influenced global university rankings, which influenced funding and collaboration opportunities. Moreover, the withholding of information by industry participants in collaborative research projects hampered university research outputs. Conversely, a majority of the industry experts did not follow academic outputs because academic output is considered very slow. In this sense, science/technology parks located around university regions could help bridge the gap between academia and industry, provided that industrial organisations are open with their research outputs. This is important because publicly funded projects assess universities based on publication outputs and international university rankings. Quite often, academic research outputs can be utilised in policy making. Publicly funded research programs and innovation ecosystems also enable competitors to work together, which is otherwise unlikely. For example, one respondent highlighted that,

*"How to partner also with universities because they partner with other organisations or even with customers? [...] Some partnerships announced on the internet, [...] that a supplier partners with these OEMs [...] to do autonomous whatsoever [...] Very often, they have all been partners in the same public funded project [...] hosted at universities [supplier]."*

In terms of ecosystem collaborations, the traditional roles of stakeholders in the HDMM value chain and industry follows a siloed approach as also shown in Figure 5, where suppliers have domain expertise in fluid power technologies and sensor components, OEMs are system integrators of fluid power technologies, while end-users are experts of the processes where HDMMs are used. Add-on solutions providers retrofit OEM machines with machine control and guidance systems, without consideration for the make and model, acting as a bridge between OEMs and end-users to enable digitalised workflows and automated HDMMs. New entrants such as start-ups in the HDMM industry face challenges similar to those faced by incumbents, namely, automating a specific task in HDMMs. Moreover, new entrants lack the extensive service networks

of incumbents. Thus, given the current state of technological progress and status quo, a major disruption in the HDMM industry seems unlikely. However, several interview respondents highlighted that if an organisation or a new stakeholder in the HDMM industry managed to completely reinvent the processes, especially from the non-technical perspectives such as new business models, there could be a significant disruption in the HDMM industry. For example, aggregators who connect two sides of a demand and supply, for example, Uber and Airbnb type companies, can disrupt the business from a non-technical perspective by disrupting existing relationships, for example, between OEMs, machine dealers, and infra owners.

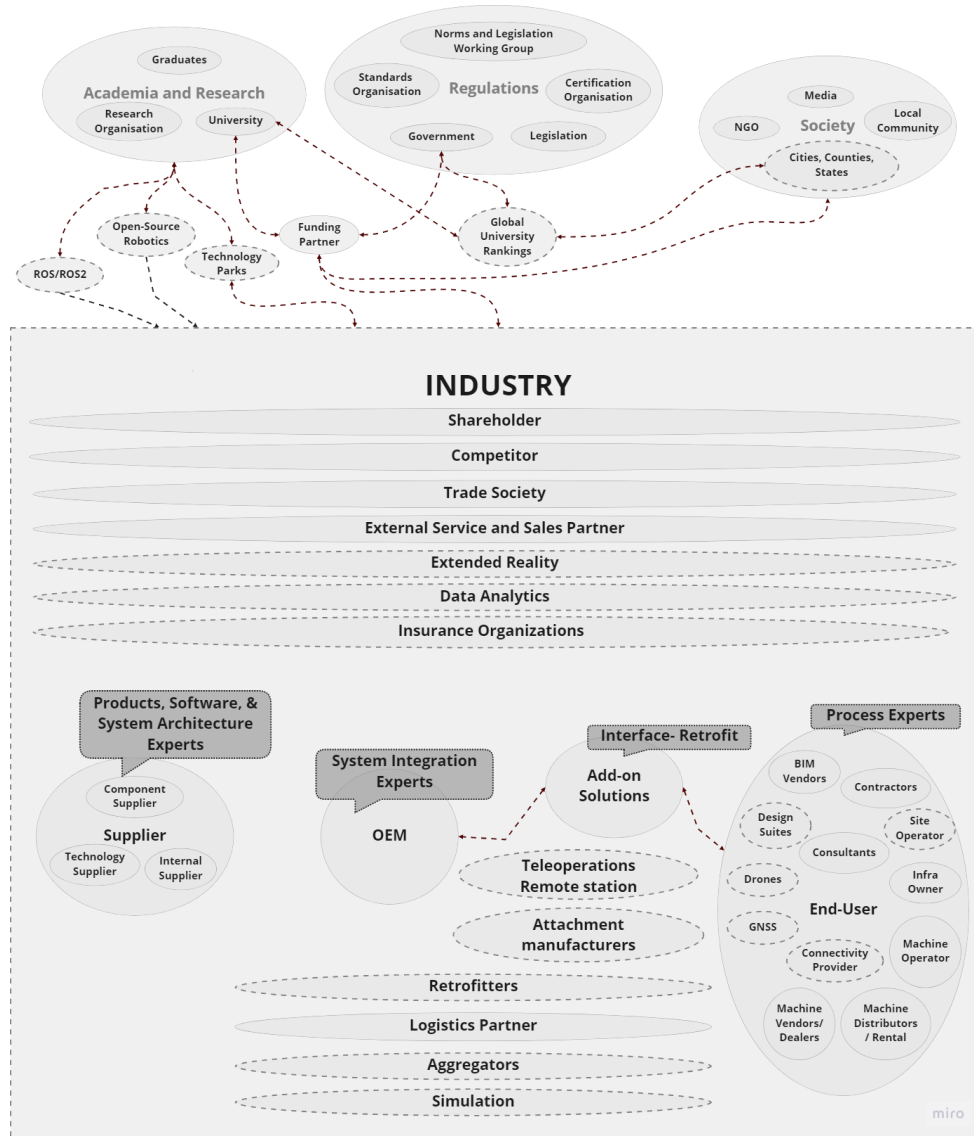


Figure 5. New Stakeholders in the HDMM Industry Value Chain. Dotted Bubbles are New Stakeholders

Similarly, retrofitting companies could emerge anywhere in the supply chain, especially when there is uncertainty regarding powertrain technologies such as electrification, fuel cells, hybridisation, etc. Here, other industries could influence the HDMM industry as well. For example, one OEM respondent mentioned that,

*“We are quite small compared to other industries like trucks. Our customer might have big truck fleet and only a handful of earth moving machines and then the decision might be that the trucks go with [...] liquid hydrogen [...] If we develop [...] hydrogen [...] in a gas form [...] it might create a problem because you invest a lot of R&D effort in a certain solution and the end customer goes a different way [...] As a smaller player in the whole field [...] we have a problem [OEM].”*

Thus, there can be synergies between technologies from other industries too. For example, [3] highlighted a company using commercially available global navigation satellite systems (GNSS) and drone autopilot software for autonomous agricultural robots. Similarly, the pervasion of certain software and middleware at the university level such as ROS/ROS2 would mean that new talents are graduating with specific skill sets, which need to be accommodated in the HDMM industry. Conversely, regulatory changes such as the

European Sustainability Reporting Standards, new AI Act, and the new Machinery Directive may require new roles and stakeholders in the value chain. For example, one company at a trade fair had a business model of buying a new diesel HDMM, stripping the diesel engine, and retrofitting it with electric batteries to accommodate newly mandated CO<sub>2</sub> reduction targets. Another company was solely focussing on software related to sustainability management and supplier assessment with respect to ESG performance. This is especially important from an end-user perspective, for example, in mining, wherein the society becomes a very important stakeholder to mine owners who may require a “social licence to operate”, thereby also placing important demands on the type of HDMMs used. Similarly, data analytics and extended reality services could emerge anywhere and disrupt the value chain, for example, in the commissioning of new HDMMs, maintenance, and service support, thereby also enabling new entrants to build up a service network without having a significant geographical presence. Moreover, since higher LOA require new sets of technologies [2,11] dependent on data, connectivity providers and connectivity technologies would become very important, for example, public networks, private networks, WLAN routers on a worksite, network edge slicing, etc. Several respondents mentioned teleoperations, as also witnessed at the trade fair Bauma 2022, wherein one human operator can remotely operate several HDMMs at a sufficiently high LOA at once. An academic respondent made an important departing comment regarding teleoperations and autonomy,

*“I believe that [...] remote operation is more effective in many applications than full autonomy. Even though full autonomy would be possible, it is so expensive that the human operator can do the same thing with lower cost and better adaptivity. There is some limit in the autonomy in which the human becomes a competitive option [Academia]”*

This is especially important since the two main drivers of automation were shortage of skilled HDMM operators and economic gains, while the two major barriers were legislation and functional safety of automated HDMMs. Such technological trends and technology transitions in the society require careful considerations towards the changing nature of stakeholder relationships and multidisciplinary collaborations that would be required to realise the deployment of automated HDMMs, in research and in practice.

## 5. CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

By performing a mixed-methods study and combining several perspectives, we have created a comprehensive stakeholder mapping of the HDMM industry. Thus, using the stakeholder maps created in this study, lesser efforts will be required during future stakeholder identification heuristic exercises, since the most important stakeholders have been identified from different value chain perspectives in the HDMM industry. Furthermore, this study highlights certain hidden and/or new stakeholders and provides a visualisation of the HDMM value chain from the perspective of automation of HDMMs. Since business and innovation ecosystems require collaboration between several organisations such as competitors, academia, regulatory organisations, etc., the bridges and interfaces between the different stakeholders highlighted in this study can be used to conceptualise ecosystem collaborations for automated solutions in the HDMM industry, for example, when using tools like the value proposition canvas, business model canvas, or the platform canvas. One key limitation of this study is that the end-user group perspectives, along with the perspectives of legislative groups, research institutes, and trade societies are missing. These perspectives would be a valuable supplement to this study. In future research, we plan to use the broader stakeholder interview dataset to examine the fit of stakeholder theories within the HDMM industry, such as for creating a formal stakeholder ranking and prioritisation framework/methodology from the perspective of new business models. For other researchers and practitioners in the HDMM industry, such as those working on technical topics like energy efficiency, powertrain solutions, etc., we recommend using the stakeholder maps generated in this study to create new stakeholder maps and personas of stakeholders, to map and identify the target end-user groups as well as the collaborations required to realise your solutions in practice.



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DATA NOTICE: The interview and survey dataset will be opened and published according to the FAIR principles in a database with a unique persistent identifier on a later date, after complete anonymisation. Currently, the data is not available for review.