PLM OR ERP, THE CHICKEN OR THE EGG: TOWARDS AN ENTERPRISE LEVEL MASTER DATA MANAGEMENT APPROACH FOR IMPROVING INNOVATION AND SUPPLY CHAIN COLLABORATION

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ABSTRACT

Manufacturing is the confluence of product development and product life cycle management (PLM), and supply chain management (SCM) often represented as an Enterprise Resource Planning (ERP) system. PLM and ERP are in many companies contradicting. Product development is not fully coordinated with the supply chain, which leads to suboptimal or delayed products. SCM is struggling with implementation of new products in regards to supply chain efficiency, supplier collaboration and product management. The processes are profoundly related to data. The Master Data Management (MDM) discipline relates to systematic approaches to ensuring data in respect to quality, relevance, effectiveness and precision. At least when it comes to SCM. Innovation and quality of innovation, as framed by management of technology, is dependent on, but also limited by, lack of data quality. This paper is reviewing shortcomings in the relation between PLM and ERP as a key element in ineffectiveness for management of technology, innovation and new product development. Based on four case studies in highly different industries this paper proposes a PLM-ERP model where data fundamentally are regarded as shared. Furthermore is a set of analytical requirements proposed consisting of contextualisation, temporality, transparency, integration, and dynamics. The sharing of data is divided between the supplier-oriented functions, the manufacturing, and the customer-oriented functions. Data is suggested to be governed under a broader life-cycle perspective than typical, also including data at conceptual level with appropriate control systems.

Key words: Innovation; operations management; master data management, management of technology; supply chain collaboration

INTRODUCTION

In modern day manufacturing companies, master data is critical to precision and communication on product specifications, components, modules and manufactured items (Otto, 2012a; Silvola et al., 2011; Richardsson, 2010; Sammon et al., 2010). Attention on master data is essential in terms of precise, unambiguous communication throughout the organisation and its partners. Attention is fuelled by recognised problems of deficiencies, incompleteness, and rapid growth and changes in expectations on definitions and availability (Hüner et al., 2011; Knapp & Hasibether, 2011; Batini et al., 2009; Eckerson, 2002; Vosburg & Kumar, 2001). Normally data are assumed to be "born" in the PLM (PDM) system in processes connected to design and engineering of products (Bruun et al., 2015; Wu et al., 2014; Zhao & Yu, 2013). However, substantial data are coming from the supply chain (Hüner et al, 2011)) related to e.g. customer orders, customer specifications, standard components, supplier supplied data, standard raw materials, corporate policies, and backlogs. In many organisations, substantial effort is used to ensure alignment between the product development organisation's use of data (PLM) and the data represented in the supply chain and manufacturing organisation (ERP) (Lee et al., 2011; Knolmayer & Röthlin, 2006). The purpose of this paper is to add precision to the discussion on data ownership, master data management and sequencing of data availability especially by reviewing the interactions within the enterprise between PLM and ERP.

The interest for data is growing in terms of big data, data-driven business (models) and data "as the new gold" (Rasouli et al., 2015). Quality of data is fundamental, but data are reflections of rapidly changing business environments and susceptible to change (Russom, 2006). Master Data are assumed to be more persistent in contrast to transactional data, however constant redefinitions and contextual interpretations of Master Data is itself creating difficulties in precision and integrity (Cui & Qi, 2006). In a management of technology (MOT) perspective (Kim, 2013; Lindén, 2013; Cetindamar et al., 2009;), and in perspectives of innovation and new product development (NPD) (d'Avolio et al., 2015; Nadia et al., 2006), imprecision of quality of data can lead to wrong decisions, overstocking, quality failures, and in general be adverse to change. Here a risk is furthermore that SCM tend to institutionalise supplier and customer interaction without giving NPD and engineering functions the fullest and most precise data necessary for change and innovation. Data effectiveness is obtained e.g. when PLM and ERP represent the same data of the same item transparently, in real-time, and without massive manual processes involved (Fitzpatrick et al., 2012; Goel, 2006; Lankhorst, 2004).

This paper is discussing and analyzing the impact of the commonly two-sided master data representation in ERP and PLM. This paper proposes a closer integration of data models with a better life-cycle management in both early and late stages of the overall life-cycle. This paper concludes with a recommendation of a more holistic approach to data in order to consider data quality on the level with product quality for the overall requirements of improving efficiency in MOT, NPD and innovation. The paper asserts originality in reviewing master data management as an incomplete process of corporate (information) governance but with distinct implications to MOT, NPD and innovation in terms of limitations to knowledge and technology acquisition and exploitation.

METHODOLOGY

This paper uses a qualitative research approach with a blend of an extensive literature review and four case studies (Yin, 2009; Dubois & Gadde, 2002). The literature review included search terms such as "master data management", "plm", "management of technology". The search ended with several hundred scientific contributions and some standards and industry papers. This was reduced to fit the format of this article. The four case studies are longitudinal using mostly a qualitative approach with interviews. The cases have also been reviewed as parts of university – company collaboration. In this process there were elements of a post-positivistic systems theory approach (Crotty, 1998) along with a series of design science activities developing software-based proof-of-concepts (Peffers et al., 2007; Järvinen, 2007; Cole et al., 2005).

Table 1. Methodological characteristics of the four case companies

	TeCo	SiCo	HiCo	BeCo
Company size	SME	MNC	SME	MNC
Research window	2015-2016	2010-2017	2015-2017	2008-2016
Design science approach	Action research style of implementing MDM governance and training	Computer modelling of data precision. Action research initiatives of improved governance. Analytics for fault finding.	Coding of data exchange software, reviewing its quality	Design of governance structures, data extraction and analysis. Modelling of data flows and database integration.
Software	X++, SQL	ABAP, SQL	X++, PTC	SQL, .Net, SAP BW
ERP platform, mostly	Microsoft AX	SAP	Microsoft AX	Bespoke Oracle
PLM platform, mostly	Autocad	Teamcenter	Autocad	Indesign

MDM is by itself suggesting various methodological concepts for deriving actual master data, analysing and designing governance structures, measuring impact of initiatives and assessing quality and maturity (Huergo et al., 2014; Dahlberg et al., 2011; Wang et al., 2009; Batini et al., 2009; Batenburg et al., 2005; Rajaram, 2001). These contributions are used within the case processing.

THEORY

Master Data Management

Master Data Management (MDM) is about forming policies and principles for the pool of enterprise data in relation to strategic directives and technological opportunities / limitations (Smith & Keene, 2006). Smith & Keene (2006) define MDM as a predominantly non-technical discipline although the solutions would most be of technological nature. MDM must be effective to ensure avoidance negative impacts on business; Jonker et al. (2011) propose a maturity model based on the company's ability to demonstrate governance procedures combined with the impact of low quality along the value chain.

Reichert et al. (2013) suggest a reference model for MDM separating strategic, tactical and operational activities, where the strategic activities include vision, business – IT alignment, targets, responsibilities, roadmaps and communication. Reference models are widely used as generalised analytical models in developing models and governance (CEN, 2013; Oberhofer & Dreibelbis, 2008; Otto et al., 2012c). Here master is closely related to enterprise architecture setting the guidelines for implementation of strategic management in technology (Bernard, 2012; Spewak & Hill, 1993; Zachmann, 1987).

MDM is pathway for enterprises to organise data, but not without difficulties. Haug & Stentoft (2011) pinpoint a number of problems and suggest to reformulate MDM is a model of responsibility for maintenance, rewarding validity, control routines, build competencies and improve software support. As master data often tend to be managed by ERP systems, Haug et al. (2009) suggest to analyse data in ERP from a two dimensional model of (1) Data Accessibility (2) Intrinsic Data Quality, where the latter highlights the range of systems and processes ensuring precision, relevance, integrity, uniqueness and organisational responsibility.

MDM is normally aimed at structured data (fixed texts, number, …) even as large parts of corporate data exists as unstructured data (free text, graphics, …); Murthy et al. (2012) suggest to integrate learning on governance principles and technologies from each of these fields.

Master data is normally assumed to exist within a well-definition organisational framing, however in distributed manufacturing and complex manufacturing networks, master data should typically be viewed a distributed with subsequent risk for incompleteness, redundant, overloaded and with unclear responsibilities (Dahlberg et al., 2011).

Master data might be used colloquially for the full amount of “static” data in the company, however difficulties arise when the term is used randomly for data related to NPD (Engineering PLM), supply chain operations (represented in the ERP system), and fully externally defined data. Life-cycle is also used ambiguous as data with product development, with manufacturing, with the “life” (Kokemüller & Weisbecker, 2009) of the individual data, and in the full life-time of product until end-of-life (Romero & Vieira, 2014; Fitzpatrick et al., 2014; Cui and Qi, 2006; Batenburg et al., 2005).

Data from a management of technology perspective

Already Sarkis et al. (1995) stated that successful organisations must be designed from a perspective of processes and governance structures to ensure rightful management of technology, this is also entailing appropriate exchange of data for design, specifications, test-expectations, recording of assumptions and discrepancies. Also Snow (2008) is discussing how well-managed master data can be an imperative for the manufacturing industry.

Technological innovation is typically described as life-cycles of several years (Kim, 2013), data and data quality is critical in the management of such processes. Management of technology is the studies of technology vs human, micro vs macro levels of business / society understanding, and the subjective vs the objective in the stakeholder perception analysis (Beard, 2002). Managements of technology (MOT) most closely interact with the operations management foundation of the enterprise (Gaimon, 2008) and data associated with the enterprise operations. Cetindamar et al. (2009) highlight a range of critical points, when discussion how data is required in management of technology, e.g. identification of new technologies (parts, item, systems), selection processes (comparison and fit analysis), acquisition of technologies, and embedding of technologies in to the operational framework.

Apostol (2007) defines Enterprise Data Management (EDM) as a combination of data related activities with the main purpose of promoting innovation. Engineers and other innovations are relying on unhindered access to external technologies and data associated with this (Arnold, 2010). Close interaction between product development activities and manufacturing is also more and more recognized as critical in many industries (Wu et al., 2014); Wu et al. (2014) emphasize the joint sphere of interest between PLM and ERP as Engineering Change Management (ECM) which also underlines collaborative processes’ meaningfulness for product variations, versioning, customisation. All of this must be reviewed as a collaborative data-driven process (Loser et al., 2004; Xu & Liu, 2003).

MDM has specifically called for interest in areas of analytics and business intelligence as deficiencies will impair the meaningfulness of such initiatives (Amalfi, 2009; Mukherjee, 2013; Bracht et al., 2012).

The ERP – PLM interface

Integrated PLM systems are complex software packages designed for complex problem solving in product innovation, however less resources (compared to ERP) are spent on adaptation of PLM to overall enterprise requirements, which leads to dissatisfaction with PLM as overall contributor to enterprise improvement (Bokinge, 2012). The PLM system must record and keep track of data changes during the New Product Development (NPD) process (Nadia et al., 2006) especially changes represented as Engineering Change Requests (ECR).

ERP systems are normally representing structured data (Murthy et al., 2012); PLM systems embrace both unstructured and structured data along with complex engineering data that only give a structured meaningfulness within the PLM system, e.g. a drawing.

Hüner et al. (2011) is presenting a case study, where master data is mapped for governance and validity control. Extended views on master data are presented, e.g. “dangerous goods indicators”, “marketing artwork”, in total up to 800 attributes. PLM is here understood as a module within the ERP framework. Hüner et al. (2011) thereby are not taking a broader definition of PLM into account where PLM would be separate systems addressing e.g. design, calculations, computer simulation. It is important to note that several definitions of PLM exists.

In general, companies aim at relying on (semi-) automated software for integrating PLM and ERP (Nedunov et al., 2013; Mishra, 2011; Menet & Lamolle, 2009; Cui & Qi, 2006). This can aim at integrating on a database-to-based level, but mostly it is required to use dedicated interfaces (SOA, API, messages …) within the ERP and PLM systems to use the logics already within these systems. Here is also a challenge managing highly complex systems without having full insight (Popoaca, 2017).

Theoretical model

The overall theoretical model of this study is related to two key timelines: the NPD – PLM development life-cycle timeline, and the supply chain management timeline. Each activity with this generates data, and these data must be reviewed for relevance for other parts of the timeline. This is e.g. stipulated in the leading methodologies for automotive manufacturing and similar areas of highly concurrent engineering and briefly discussed by Menet & Lamolle (2009) and Nadia et al. (2006).

The theoretical model furthermore is considering suppliers and customers as major providers of master data. Suppliers in the form of early and later data related to technologies, parts and assemblies along with logistical master data. Customers in the form of specifications, requirements, experiences and customer driven master data requirements, e.g. barcoding.

The theoretical model will now be used on a set of cases from Northern European industry.

EMPIRICAL CONTRIBUTIONS

TeCo is producing parts of exhaust systems for the automotive industry. TeCo is following automotive industry standards for receiving, developing, approving and manufacturing the parts. TeCo's manufacturing processes are relatively robust and mechanical product quality problems are rarely a critical issue. However, TeCo's main quality issues are identified as mainly being related to master data - broadly defined. In implementation of a new ERP system, TeCo identified master data as "typical" data related to the manufacturing like customers addresses, drawing number, diameter of pipes, surface treatment. In a review of the ERP system implementation it was realised that the customers viewed master data much broader than expected. Information exchanged during the development process and stored in TeCo's PLM systems were in general considered as master data by the customers. Work instructions, production knowledge, design principles and expectations for data exchange were increasingly regarded as master data internally in the company.

SiCo is producing wind turbines. Several thousand engineers work in a range of PLM systems for various purposes, like design, load/strength analysis, electrical systems, vibration analysis, heat control, acoustics and manufacturability. More thousands are employed in the manufacturing organisation using the ERP system as key data repository. The ERP system is providing data for numerous suppliers who are getting more and more responsibility for supplying the right parts. Despite an 'approved parts pool' continuously agreed between the SCM and engineering teams, 30 – 50 employees are constantly working on BOM's with unapproved parts and part consolidation. Engineering teams are likewise lacking substantial support for insight in the supply chain and supplier capabilities and parts data. Departments related to service of wind turbines are additionally "left in the dark", as production BOMs are the resultant of the 'struggle' or compromise between engineering and the supply chain organisation often leading to installation turbines without BOMs or wrong BOMs that needs post-install registration.

HiCo is producing trucks for urban sanitation. Around 30 engineers are designing sanitation trucks, and around 200 persons are working in the production, assembly and services organisation. The purchasers are highly dependent on insight in production plans and bill-of-materials (BOM) items. The engineers are balancing between having insight in approved parts, items and stocks and use the (perceived) right parts according to their design considerations. An automated system, PTC, is installed to transfer data between ERP and PLM. Despite of this, HiCo is on a daily basis having PLM BOM's new parts unapproved in the SCM organisation with either production delays or expediting purchasing as resultant.

BeCo is selling clothing. BeCo is designing, marketing, sourcing and distributing clothes around the global market with center-point in Europe. BeCo is not addressing clothes at a bill-of-materials level, but rather prescribing the final products from general standards (T-shirt, jeans, …), visual impressions and standardised mechanical measurements. Master Data is traditionally measurements, colours, shapes, features, materials, packaging, customs codes and barcoding. After introduction of widespread e-commerce, more elements are added to the pool of Master Data, e.g. consumer-friendly pictures, marketing texts, relatedness to other products (clusters, seasonal features. A lot of manual effort is spend in BeCo as each function along the value chain define a different need for master data than the former. E.g. salesmen regards an initial text for product description "as just for purchasers". Likewise are physical retailers and online retailers disagreeing on needs for pictures, cross-sale clustering, discount-rates, etc.

Table 2. Comparative case assessment

	TeCo	SiCo	HiCo	BeCo
PLM characteristics	Mechanical Visual	Complex mechanical and electical	Mechanical Simple electrical	Graphical Data-driven
ERP characteristics	Customer make-to-order	Complex sourcing and assembly	Simple Sourcing and assembly	SCM with ongoing replenishment
PLM – ERP integration	Manual	Semi-automated	Semi-automated	Integrated at sourcing and B2B level, no B2C support
Master data understanding	Drawing no. Materials Basic mech. Spec.	Part or subassembly with or without revision	Part or subassembly at number level	Drawing no. Materials Basic mech. Spec.
Governance principles	What is basic need for EDI	Large scale, but conflicts between engineering and SCM unresolved	Sparse dialogue facil	Manual control procedures
Loopholes PLM - ERP	Verbal agreements between salesmen and customers	Complexity and rapid new product development	Informal attitude to data precision	Verbal agreements between purchasers and suppliers
Product life-cycle Annual new products	10 yr 300	25 - 30 yr 12	15 yr 12	2 yr 15.000

Further analysis across the cases show that not only exists automatic or semi-automatic software for transferring data between PLM and ERP, transfer do often fail due to misalignment with business processes. E.g. can a part number for a PLM-BOM not be transferred to ERP before various manual approval processes are resolved, this can relate to high different processes such as stock-out or stock-reserved, failed creditor approval, unannounced supplier change, part number consolidation, unregistered goods arrival, damaged packaging. To mention a few. The companies all follow different methodologies in product data assurance in the NPD functions, but are related by having timelines and evolving maturation in common.

DISCUSSION

The cases above highlight a great deal of confusion, dynamics and lack of context in the MDM activities in companies. It also represents that any enterprise unit will seek to understand its own requirements probably more than understanding and accomplishing the overall enterprise requirements. Several contributors stipulated during the early 2000s that data access across systems and organisational boundaries would be easily fixed using Service Oriented Architecture (SOA)

(Huergo et al., 2014; Kheder et al., 2011; Wolter & Haselden, 2006; Dreibelbis et al., 2008). A range of indicators points to SOA as insufficient or at least not have contributed to more clarity.

Recognising the close interaction between NPD and SCM with data represented in the PLM and ERP systems suggests to consider data as a joint pool with joint responsibilities for maintenance and change. Problem areas would probably arise within the different scopes and precision of data in the respective fields, but less governance would be required with one rather than two separate pools of data. In BeCo it is demonstrated that the key master data is stored only once; data is e.g. numbers, customs codes, categories, measurements, materials, packing units, colours.

Several theoretical contributions suggest to measure maturity of the corporate MDM governance (Spruit & Pietzka, 2015; Jonker et al., 2011; Batenburg, 2005). The maturity models typically focus on connect between formal processes linking strategic, tactical and operational. The maturity is also assessed from repeatability, defined processes, contingencies, management & measurement, optimised. In the current context this seems like an incomplete explanatory framework. A supplementary analytical approach is proposed in table 3.

Table 3. Five analytics dimensions of MDM quality in the development-oriented organisation

Contextualisation, relevance	Master data remain within a narrow organisational context in either the ERP or the PLM system. A broader context might be needed. (Merminod & Rowe, 2012) Narrative: “Engineer: We would like to use this part. Purchaser: This part is available in two months.”
Temporality	Synchronisation in time between NPD and SCM is needed to ensure speed in the development process (Batini et al., 2009; Piprani & Dham, 2010). This is also stipulated in the VDA (2010) recommendation but not readily applied outside the automotive industry. Narrative: “Engineer: As soon as I know I will use this part, the SCM unit must be informed for supplier validation.”
Transparency, openness	Clear and unfiltered information is needed to ensure balance between NPD and SCM units (Otto, 2015; Sammon et al., 2012). Narrative: “Purchaser: I must know, why this part is needed instead of the almost similar we have. Engineer: I will tell, but also listen if I can still use the existing part.”
Integration	SCM data is mostly related to and managed by ERP-driven processes. PLM data might be distributed over several systems and platforms. Many systems are in many companies not even digital, e.g. handbooks. Integrated PLM systems are either insufficient for the full range of development activities, or have significant problems in gaining acceptance. A defined high level of integration of data related to manufacturing, procurement, and supplier/customers is needed within PLM (Kheder et al., 2011; Lee et al., 2011; Cui & Qi, 2006).

Dynamics	The ability to add new data to the pool of master data. Also the ability to remove obsolete data. New data must be added be well considered criterias including e.g. ownership, use, range, connect to temporality, quality. (Rasouli et al., 2015; d'Avolio et al., 2015)

Each of the case companies exhibit parts of these requirements, but would also benefit from a forward looking review based on the five dimensions above. Figure 1 illustrates a proposal for joint data pools idealising and suggesting solutions to accomplish with table 3. The principles of source – make – deliver from the Supply Chain Operations Reference model are used.

Figure 1. From divided to shared master data along the value chain

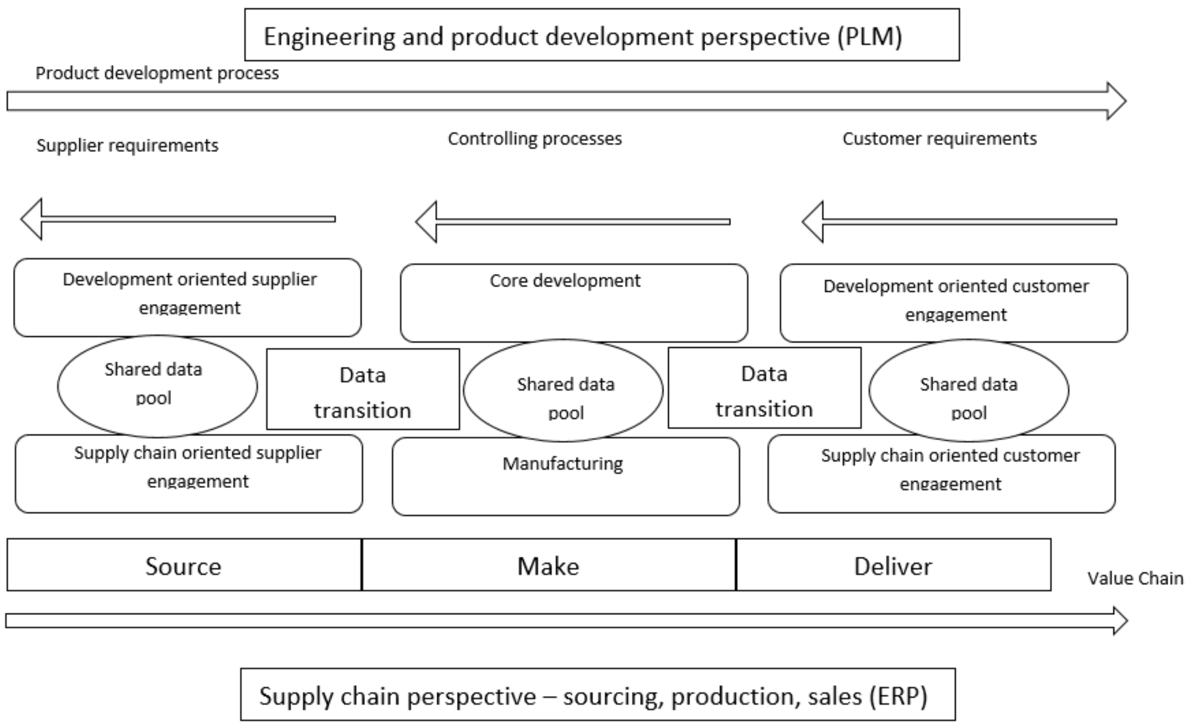

Figure 1 is highlighting a necessity to engage product development processes and sourcing processes closely. In table 3, the implications are presented. BeCo have done a lot, but is still struggling to establish new types of master data on single platform (data pools) with universal access for relevant parties. BeCo is also struggling with information (feral, shadow) systems created e.g. by e-mail correspondence challenging validity of structured data. TeCo have taken PLM and SCM so far apart that the PLM functions no longer knows how the company manufacture; organisational initiatives are taken along with a new ERP system to bring the company closer together.

Table 4. Implications, problems and initiatives for supplier, manufacturing and customer data

	Product development	Supply chain management	MOT highlight	Enterprise drawback	Drawback mitigation
Shared pool of supplier data	Safer engagement with suppliers in early involvement. Easier evaluation of new parts and products.	Early insight into potential suppliers and shift in purchasing patterns.	Search and acquisition of market knowledge is made more efficient	Extra workload in product development.	Supplier supplied data.
Shared pool of manufacturing master data	Access to existing master data. Creation of new parts master data.	Early notification of parts of interest. Early insight In proposed new parts.	Increased robustness of the product development; easier supplier engagement	Ownership gets unclear Unclear ownership leads to quality issues	Better automated ownership management Quality control automation
Shared pool of customer data	Better and earlier insight into product deficiencies. More obvious market adaptation	More real collabora-tiveness Joint learning with customers	Pipeline to market driven management of technology	Complex network of obligations and responsibilities	Change of business model

Governance processes must be introduced for ensure proper designated of relevance of data. Each data item must have a more precise life-cycle management probably with impact, timing and history. E.g. BeCo introduced a 14-step state-model for its customer orders closely related to final customer adjustments, over/under delivery, failures / cancellations at any stage. After 20 years of scholarly interest in MDM, and the chasm between PLM and ERP data, there is still in many industries and enterprise types a need for improvement.

CONCLUSION

Disintegration of master data on PLM and ERP platforms impose limitations to innovation and effectiveness in operations management. Automated systems are not solving the problem fully as is relying on quite exact timing with business processes and manual interventions.

Suggestions for further work relate to delimitation of fundamental industrial typologies and (quantitative) impact of the actual master data implementation in these contexts. Moreover is it interesting to review architectural approaches, such as those defined by enterprise architecture and enterprise information architecture, to model for a clearer alignment and life-management of data. Life-cycle management gets especially interesting when it comes to early, premature data that might evolve or might just be retracted in the systems in the style of BeCo's product MDM approach.

Conclusively is it interesting to consider data as a global frenzy of business development and MOT potential, and yet realise that corporate data is vulnerable and difficult to manage with a sufficiently high quality. The paper propose to use shared pools of data starting as early as possible in the life cycle of any product or technology. This require new governance processes within the organisation, but is anyhow fitting the working process of small highly-collaborative teams and parts of the open source / crowdsourcing philosophies. Shared pools of data along the PLM and SCM processes is suggesting the improve the general innovation capability of the development-oriented organisation. Introduction of digital business models, digital business models for physical systems, cyber-physical systems, and product-service systems will continuously challenge MDM-related processes. The models above is a suggestion for adapting to new realities while also dealing with existing challenges.

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