Research and Practice Agenda of Industrial e-Maintenance: Information Logistics as a Driver for Development

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ABSTRACT
This paper presents an inquiry into the domain of e-maintenance, particularly of industrial entities. As a domain of research and practice, e-maintenance is understood to offer great opportunities, however it seems to be driven by the development of applications of Information and Communication Technology (ICT). This ICT-driven approach is unfortunate, as ICT has no value in itself, rather its benefit comes for how it processes information, and more broadly how it forms its contextual activities. To remedy this situation, a conceptual framework is proposed, to guide both the practice and the research of e-maintenance operations. This framework combines the seminal Industrial Value Chain framework and then the Buyer-Consumer Value Chain, and articulates their intersection with a set of defined categories derived from Information Logistics. This provides one possible structure for the conception of e-maintenance, which needs to be populated with the published research and practice results. This, in turn, may uncover white spaces where research efforts deserve particular attention and are driven by value generation – whether economic or other – instead of experimental ICT application developments. The presentation of this framework is accompanied with a brief example that contrasts an event-driven versus a plan-driven approach to e-maintenance.

Keywords
Research Design, Information Logistics, Sustainability, Industrial Value Chain, Customer Value Chain, Maintenance

1. INTRODUCTION
This paper presents a conceptual framework that may guide the design of both research and practice of maintenance operations of industrial entities. This introductory section puts this into its current context.

While the application of Information and Communication Technology (ICT) to industrial and business organisations started shortly after the World War II, it is since the 1990's arrival of the Internet and the mobile technologies that the range and the implications of such applications has become dramatic. The initial focus of the electrification of the industrial value chain focused mainly on one or two particular kinds of activity streams in the industrial value chain. Thus, the Enterprise Resource Management Systems support the manufacturing and warehousing, then the Supply Chain Management Systems extended to encompass the whole supply chain, then the Customer Relationship Management Systems support the marketing and sales activities, while the e-commerce enables electrification of the commercial transactions. More recently, the electrification of the industrial maintenance activities, i.e. e-maintenance, has emerged as a promising enabler, particularly as the maintenance phase represents often a significant, if not the largest amount of the total cost of ownership of an industrial entity [1], [2], [3], [4], [5], [6]. Attentions to the role of ICT in general planned for the conduct of maintenance have been made for some time now [7], [8], [9] and more recently the role of the Internet and mobile technology [10] which has given rise to the concept of 'e-Maintenance' – the electronification of some or all activities of a particular maintenance operation. This has found various areas of application, such as aircrafts [11], the power plants [12], the semi-conductor plants [13], or water management [14], residential buildings [15] among many others.

However, this emerging field of e-maintenance seems to be predominately ICT-driven, meaning that the creation of innovative engineering solutions advanced the practice and research of e-maintenance. There are very few initiatives that tackle the business processes in relation to e-maintenance [6]. The limitations of this have sporadically made attention to suggesting a business process driven [16] and an asset management driven development [17]. The field of e-maintenance needs a clear vision, where subsequent objectives may be articulated. The latter could include the handling of the Total Cost of Ownership of an industrial entity, various quality aspirations such as security, safety, or sustainability aspects of fossil product consumption. In more general terms, however, the field of Strategic Management has shown that ICT has no inherent value in itself; rather ICT's benefit emerges from how it is used in its context [18], [19], [20].

1.1 Research Approach Assumed
To remedy this situation of ICT-driven e-maintenance research and practice, the present inquiry starts from the basic assumption, which is the context that provides the value of ICT. In the most

general terms, such context may be understood as various kinds of human activity chains, or as Checkland's seminal notion of a Human Activity System [21], which has also been extended to provide context for ICT [22]. This means that our human, social and industrial affairs are organised in a manner so that a large set and variety of activities are conducted in the form of a set of activities that transform something into something else: for example when baking a cake. The first question of this inquiry was thus to identify a suitable context for e-maintenance and its ICT, which is here assumed through Porter's seminal Industrial Value Chain [18], and the Buyer-Consumer Experience Value Chain [23].

The second starting point of this inquiry addresses the content of ICT handling: the information. In the particular case, the domain of Information Logistics has shown a particular importance for e-maintenance [11], [24], in its ability to comfort industrial entities with various actors acting upon them. More specifically, Information Logistics is here understood as the practices of providing the right information to the right actor, at the right time, place, format and cost [25], [26]. The key contribution of Information Logistics is therefore to provide the right information about an industrial entity to the needing actors, whether human or machine.

The next section advanced the conceptual framework proposed here, while the section thereafter provides a brief illustration of its application to e-maintenance practice.

2. CONCEPTUAL FRAMEWORK FOR RESEARCH INTO E-MAINTENANCE

In this section, the very core proposition of the present inquiry is advanced. This starts with a brief recall of Porter's seminal Industrial Value Chain and thereafter with an account of a Buyer-Consumer Experience Value Chain. These two value chains are then synthesised into the proposed e-Maintenance Framework, which is presented in more details.

2.1 The Industrial Value Chain

The seminal notion of the '*value chain analysis*', firstly popularised by Michael Porter in 1985, is assumed here as the starting point for the understanding of the maintenance operations and their context. This value chain of industrial firm states that firms, as a collective within a specific industry, conduct certain generic value adding activities, and that the products delivered to their customers and finally consumers must pass through these generic activities. While there are various slightly differing notions regarding which activities constitute an industrial value chain, the present elaboration assumes the following kind of value adding activities: the research and development, the production, the distribution, the marketing and sales, and the customer service – see Figure 1 for an illustration.

The following example of an auto-making firm illustrates the industrial value. The research and development is responsible for the design of a new model of a car, the production accounts here both for the inbound logistics and the manufacturing process; the distribution includes the out-bound logistics to the various retailing actors; the market and sales influences the potential buyers and transforms some of them into actual buyers; and, finally the services support the car owners and users with the various maintenance and repair activities. The lastly mentioned activity illustrates the position of the maintenance operations of an industrial entity.

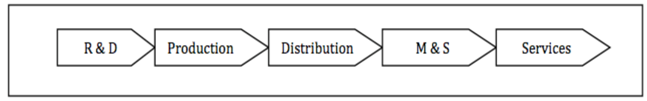

Figure 1. Illustrates the Industrial Value Chain constituted by the generic producer activities: the research and development, the production, the distribution, the marketing and sales, and the customer service – adapted and modified from [18].

2.2 The Buyer-Consumer Experience Value-Chain

The second assumed conceptual framework is the so-called '*Buyer Experience Cycle*' [23]. This accounts for all the kind of experiences that a product exposes the buyer and consumer for. More descriptively, this framework is called here the *Buyer-Consumer Experience Chain*, and it constitutes the following five kinds of experiences: the purchase, the delivery, the use, the supplements, the maintenance, the disposal – Figure 2 illustrates this.

The following example of a mobile telephone device illustrates this Buyer-Consumer Experience Chain. John may buy his new mobile phone in the local store, with all the advisory services provided by the sales staff, or through an Internet based shop, without such advisory, yet for a lower price. Therefore, in the first instance the delivery may be conducted instantaneously in an over-the-counter mode, by the sales staff and include some instructions for the initiation of the device. In the second instance, the delivery is made through postal services and will require three working-days to complete the transaction. While the use of a mobile phone seems obvious to most, various brands differentiate in terms of their functionality and usability provided. Also, different supplements are mandatory or optional, such as batteries and power chargers, or the head-phones. While the maintenance activities of a mobile phone typically do not exist or are limited, they may include the cleaning of the device, the change of batteries, and more recently the update of relevant software, either to improve the current functionality or to add new. Finally, while the disposal may be regarded as unproblematic, unfortunately too many mobile phone batteries are put into places not advised for them. In this context, the maintenance-experience activities of a product clearly articulate the here elaborated research addenda.

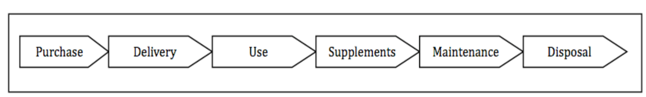

Figure 2. Illustrates the Buyer-Consumer Experience Chain that accounts for the generic experience that a product exposes the buyer and consumer for; this chain is constituted by six kinds of experiences: the purchase, the delivery, the use, the supplements, the maintenance, and the disposal – adapted from [23].

2.3 The e-Maintenance Framework

While the notion of Industrial Value Chain represents the operations of the development, production and delivery of an entity, the notion of Buyer-Consumer Experience Chain represents the activities of the buyer and consumer of such an entity, which makes these two conceptual frameworks complementary. Further, within the first mentioned framework there is the articulation of the Customer Service generic activities, while within the latter framework there is the implicit articulation of the Maintenance activities. In this, the latter's maintenance activities are the primer's service activities; this intersection manifests the core of the present elaboration where the maintenance operations must be understood in terms of both, the producer and supplier and the buyer and consumer.

With this intersection as a starting point a further articulation of interactions between the various generic activities of the producer-deliver and the buyer-consumer may be conceived – see Figure 1.

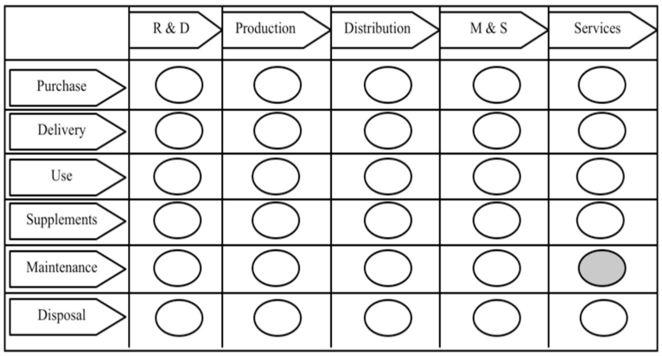

Figure 3. Illustrates the intersection of the generic activities within the Industrial Value Chain (horizontal) and the Buyer-Consumer Experience Chain (vertical). The starting point of the conception of the e-Maintenance is the intersection between the Services and the Maintenance. Elaboration into the remaining intersections opens further opportunities for the conception of e-Maintenance.

In the following, a further elaboration is exercised for the points of intersections between a producer-supplier and the buyer-consumer; this is made in terms of the involved actors and their interactions, the information logistics, and the potential value of such interactions and information exchanges.

To start with, the most obvious situation is where the buyer-customer maintenance activities are conducted by the service activities of the producer-supplier. In this, at least two actors are typically involved: the firm that produces an entity say a truck, and the firm that has bough and utilises the truck. However, more than two actors may be involved, as for example the maintenance activities of a truck may be ordered by the road carrier firm that owns the given track, the order may be received by the vendor company, and then forwarded to a third part supplier of maintenance activities, which during the very execution of these activities may be required to receive competence or spare parts assistance from the vendor, and further, to make the situation even more intricate, the service staff may need to inquire the driver of the specific truck, for specific information, who in turn may be self-employed or employed at another firm that specialises in the providing of truck drivers. In this case, the truck driver may be a source of certain information, about some conditions of the specific vehicle, while the service maintenance provider may be the receiver of this information. The latter may then obtain a more informed understanding of the maintenance need, along with the information that the vehicle's information system provides.

However, also the producer of a truck may find both the information provided by the truck-driver and the truck's information system beneficial for its development activities of new models of trucks, for example, to eliminate a specific and structurally determined malfunction inherent in a current model of the truck.

Another example of an intersection between the two value chains, is when the Marketing and Sales operations of the Producer-Supplier interact with the Use operations of the Buyer-Consumer. Elementary information about the status of the use of trucks, owned by a road carrier firm, may have significant value for both the marketing and sales efforts of the producer-supplier, and also the latter's production activities. In the first case, the customer targeting and subsequent sales resource allocation, may be informed by the fact that a particular road carrier company utilises only, for example, 75 % of its available vehicle road-time. The sales effort may thus be redirect to another road carrier that approaches the limits of its vehicle-time. In the second case, the generic production activity at a producer-supplier, may find significant value from this information about the truck utilization time. The producer-supplier's forecasting process, that determines the forthcoming truck production volume, may be informed by, for example, a very recently emerging decrease of the utilisation road-time for trucks in one or several markets. In such a case, the forecasting process may direct a lowering of the production volume, which in turn will eliminate a certain level of storage cost and their capital binding generated by unsold trucks, due to a decreased market demand.

All this gives rise to expression of the contribution of this inquiry. It is a conceptual framework that articulates a structure of operational domains, and actors that execute activities their in, the information logistics requirements upon the involved actors, and then the benefits that may arise from such information logistics – Table 1 illustrates this in terms of a matrix constituted by a set of categories and their interrelations. This matrix is called here the Supplier-Consumer Information Logistics matrix; or 'SCIL-Matrix' in short. As illustrated above, each intersection between two generic activities, one at the producer-supplier, and the other at the buyer-consumer value chains, may be articulated in terms of the actors involved – human and artificial – their interactions or network, then the information logistics patterns emerging in these networks, thereafter the new and informed behaviour of one or several actors in the network, and finally the emerged value that such informed behaviour may give rise to.

The proposed SCIL-Matrix may serve for at least two principally distinct purposes. One is to guide the development of concrete maintenance operations within and between organisations and their actors, for various ends such as efficiency gains or quality improvements. A second potential function of this matrix is to guide the design and execution of empirical research into the maintenance operations of industrial entities. The questions to be addressed include: what are the current patterns of actor interactions and their information logistics in current maintenance practices? And then: what benefits are gained by such patterns? And then what benefits are unexplored? This kind of knowledge would inform the development of the current practice of the maintenance operations.

Table 1. Illustrates the key contribution of this inquiry: the Supplier-Consumer Information Logistics Matrix. Horizontally illustrated are the key generic activities of the producer-supplier value chain, while vertically shown are the generic activities of the buyer-consumer value chain. Each such intersection that these generic activities give rise to, may be understood in terms of the actors involved, their interactions and hence network, the information logistic streams realised in such network, the informed and new behaviour of one or several actors, and finally the emerged value from such new behaviour.

	R&D	Production	Distribution	M&S	Services
Purchase	Actors-network	Actors-network	Actors-network	Actors-network	Actors-network
	Info-exchange	Info-exchange	Info-exchange	Info-exchange	Info-exchange
	Informed behaviour	Informed behaviour	Informed behaviour	Informed behaviour	Informed behaviour
	Value emergence	Value emergence	Value emergence	Value emergence	Value emergence
Delivery	Actors-network	Actors-network	Actors-network	Actors-network	Actors-network
	Info-exchange	Info-exchange	Info-exchange	Info-exchange	Info-exchange
	Informed behaviour	Informed behaviour	Informed behaviour	Informed behaviour	Informed behaviour
	Value emergence	Value emergence	Value emergence	Value emergence	Value emergence
Use	Actors-network	Actors-network	Actors-network	Actors-network	Actors-network
	Info-exchange	Info-exchange	Info-exchange	Info-exchange	Info-exchange
	Informed behaviour	Informed behaviour	Informed behaviour	Informed behaviour	Informed behaviour
	Value emergence	Value emergence	Value emergence	Value emergence	Value emergence
Supplement	Actors-network	Actors-network	Actors-network	Actors-network	Actors-network
	Info-exchange	Info-exchange	Info-exchange	Info-exchange	Info-exchange
	Informed behaviour	Informed behaviour	Informed behaviour	Informed behaviour	Informed behaviour
	Value emergence	Value emergence	Value emergence	Value emergence	Value emergence
Maintenance	Actors-network	Actors-network	Actors-network	Actors-network	Actors-network
	Info-exchange	Info-exchange	Info-exchange	Info-exchange	Info-exchange
	Informed behaviour	Informed behaviour	Informed behaviour	Informed behaviour	Informed behaviour
	Value emergence	Value emergence	Value emergence	Value emergence	Value emergence
Disposal	Actors-network	Actors-network	Actors-network	Actors-network	Actors-network
	Info-exchange	Info-exchange	Info-exchange	Info-exchange	Info-exchange
	Informed behaviour	Informed behaviour	Informed behaviour	Informed behaviour	Informed behaviour
	Value emergence	Value emergence	Value emergence	Value emergence	Value emergence

3. FROM EVENT-DRIVEN TO PLAN-DRIVEN ENTITY MAINTENANCE

The above elaboration presents the key contribution here, the SCIL Matrix, aimed for guiding the design of research and for the design of practice, all within maintenance operations of industrial entities. For the purpose of illustration, an effort is made in this section to present an instance of such a design of maintenance practice.

The starting point is the typical current practice of maintenance operations, which is here understood as '*event-driven*'. An example of this is the instance of a heavy truck's malfunctioning that triggers the call for, and subsequent execution of, maintenance activities. Such maintenance activities are re-active in the sense that an unwanted malfunctioning of the truck gives rise to extensive repair, with long truck stop-time, and thus significant costs for the truck owner. In terms of the here proposed categories, the driver or the owner of the truck detects in some manner the truck malfunction, typically too late, and thereafter reacts by calling for the maintenance operator. The information logistics in this case is typically exchanged between two human actors, probably mediated by a phone, and the information mediated characterises the malfunctioning of the truck – i.e. a symptom of the malfunctioning, not necessary the cause. The benefit of such actor interaction and their information logistics comes from the ability to repair the truck and get it back to work.

Clearly, the outlined reactive approach to repair and maintenance operations is not optimal with regard to the economic efficiency of an industrial entity. An alternative approach to remedy this is here called pre-active maintenance [27] or plan-driven maintenance, illustrated in Table 2. In this approach, sensors at the truck capture status information and transfer it to the maintenance centre for analysis. Defined parameters will suggest if some part of the vehicle is approaching its limits, and thereby anticipate a forthcoming truck breakdown. Thereby, maintenance operations may be planned in advance in a manner to both prevent the break down and to choose a suitable stop-time for the operator of the truck. In this case, the information logistics is digitally conducted from the truck's control system to the maintenance centre's analytical system, and then back to the truck operator for the booking of a maintenance stop, which could be conducted while the truck driver has an overnight stop in its transportation drive. The emerging new behaviour here is that the truck is monitored continuously, which generates status information of the vehicle's condition, which in turn may trigger the planning of maintenance operations prior a breakdown. The benefits come both to the truck owner, where the unplanned truck stop-time is eliminated and thus the cost that may emerge for this are also eliminated. Further, a proactive maintenance aims to address the cause of possible breakdown and is typically less expensive than to handle the actual breakdown, both in terms of the maintenance working time needed, and in terms of the spare parts needed.

Table 2. Provides a summary of the distinction between an Event-driven and a Plan-driven maintenance approach

Maintenance Approach	Event-Driven	Plan-Driven
Mode of work	Re-active	Pre-active
Initiated	After break-down	Prior break-down
Actors:	Truck Operator & Owner	Maintenance Operator; Truck planner
Information logistics	Truck Operator => Truck Owner => Service Operator	Truck => Service Centre => Truck Route Planner
Information	Brake Down Symptoms	Truck Status
Result	Truck recovered from break down	Truck prevented from break down
Effects	Higher costs of maintenance	Lower costs of maintenance

Next, at the maintenance operator's end, this planned approach may help to plan ahead the resource utilisation and also free-up resources for rapid handling of those breakdowns that could not be handled proactively. Table 2 provides an overview of the two approaches to maintenance here: the re-active or event-driven and the pre-active of plan-driven.

The plan-driven maintenance approach also opens for the exploration of other opportunities and benefits such as the increased efficiency of preparatory work prior the conduct of the maintenance work. For example, the maintenance operators to conduct the vehicle-maintenance, which may require travel to a truck far away, may prepare their maintenance work both in terms of formulating a maintenance plan and also to acquire the needed spare parts. Further selection of the needed competencies, in term of the right staff member, may be done more appropriately when information about the truck is available, and also the opportunity to provide the operators for an education and training module, for instance an e-learning module, may be realised.

4. SUMMARY AND NEXT STEPS

While the utilisation of ICT in the context of maintenance operations of industrial entities provides an opportunity for the development of e-maintenance practice and research, this far this seems to be mainly driven by the ICT application development. The limitation of this is that such an approach is somewhat blind and opportunistic, working mainly in a trial-and-error approach as the value of ICT steams from its context and how it is used in this context.

The present text has therefore proposed a conceptual framework, the SCIL-Matrix, to guide the development of both the practice and the research of e-maintenance operations. This framework is a synthesis of the Industrial Value Chain and the Buyer-Consumer Experience Value Chain, where the primer articulates the key generic activities of a producer-supplier, while the latter of the buyer-consumer. The intersection of each of such generic activities, in the respective value chains, is articulated in terms of a set of categories: actors, information logistics, behaviour and value. This SCIL-Matrix may thus be understood as a map for the comprehension of e-maintenance practice and also research.

This text presents only a very preliminary step in the crafting of a long-term e-maintenance practice and research. There is clearly a need to further advance this initiative, where one fundamental step would be to map the current e-maintenance research and practice into the here proposed SCIL-Matrix, and thereby identifying the white spaces of unaddressed areas.

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