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Decision Support Systems Implementation Approaches for Enhanced Decision Making Capabilities in Precision Manufacturing

Modernizing DSS in Composite Precision Manufacturing Operations

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ABSTRACT

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The nature of this work tackles the implementation and optimization of Decision Support Systems (DSS) in corporations engaging in micromachining projects and facing growth, the work focuses on understanding how DSS are best utilized in precision manufacturing environments and how the advancements in software technology helps branches of this nature optimize operations at a micro and macro level. This work is mainly contextualized by a case study focused on NTN's Sentinel One bearing production line, the case's main premise is that this particular manufacturing department experienced a significant increase in demand, which required management to revamp their DSS from a generic ECC version to SAP S4 CORE106. Based on this premise the primary angle of this project is to go over the implementation process of updating the department's DSS system while measuring the effectiveness of each decision. It also discuses various development alternatives based on different corporate needs which may arise (e.g., SDLC, rapid prototyping, end-user development) always keeping in mind that innovation in this industry is dependent to setting user friendly systems where the front end has priority over the back-end. This work will therefore discuss ways to customize a DSS to make a system more adaptable to users.

The theory behind this work is built upon existing literature on DSS in manufacturing, with a focus on ML integration. This research contributes to the academic discourse on DSS and manufacturing management by providing actionable insights for industry practitioners. It offers a pathway to enhance collaboration and innovation within the workforce by focusing on DSS adoption and optimization. The study's findings are expected to benefit cage assembly and similar manufacturing organizations by providing a structured "start to end counsel" to DSS implementation, ultimately improving operational efficiency and decision-making capabilities in high-volume production environments. This work contains both managerial and technical insight.

Keywords dss, decision support systems, manufacturing, optimization, supply chain management, management solutions, consulting

1 INTRODUCTION

In the corporate world there is intrinsic value in implementing the most appropriate tool to enhance the decision making process. The formal approach often requires challenging mixtures between organizational, technological and strategic initiatives. These initiatives might be of different disciplines, however they tend to go hand in hand and are blended through a single interface that finds its place within certain platform. One of the primary challenges to materialise such a platform lies in identifying the right solution, one that aligns with given organizational needs, even though those needs might not be easily evidenced.

The diverse range of commercial options available from retail software solutions range from a wide array of data modelling systems and communication interfaces. It is therefore the duty of the manager to find the best decision making system that best integrates a given software infrastructure to the company's specific operational requirements. Additionally, integrating these systems with existing technologies can be complex, especially for organizations that heavily rely and have become dependent to an existing system that may not seamlessly support modern addons or integration initiatives. Some of these old systems might need to be replaced all together and the cradle of the decision must be on weather it would be the right call to do so.

Understandably, factors such as the cost of implementation that the holistic software acquisition might concur is not a straightforward account, not to mention indirect expenses such as retraining of stakeholders and further system customisations, and why not sunk costs based on what the change initiative can bring about and foster. So in a general view it is apparent that leveraging these sorts of decisions is not an easy task. But despite these challenges, the benefits of implementing robust decision support tools can be extraordinary since these systems have the potential to empower organizations to make more informed and timely choices, based on the thorough aggregation and analysis of large volumes of data from multiple sources.

1.1 Background and Context

In the last decade there has been an exponential evolution on how mid tier management within the grand manufacturing corporate structure use Decision Support Systems to develop and grow business operations. The general blueprint of DSSs is ideally set in place to enhance processes though innovative services and in NTN Metallurgie France its integration has brought forth new types of jobs, enhanced communication lines and generated methods that kindled industries into expanding their limits when it comes to achieving competitive advantage. Let us first contextualise DSSs historically and understand its modern applicability: the beginning of the technology overhaul of systems of a similar intent following this particular knowledge base achieved mainstream discernment when Doug Mcllroy theorized how UNIX could sort records in real time and implemented it in Bell Labs (Kernighan 2019).

The approach conceived by Mcllroy inspired every procurement, sourcing and communication department of major companies, be it big or small to utilize some sort of tool to process data and enhance their directionality through data and statistics (Gibadullin 2020). Nowadays, there is a whole ecosystem around this practice since there is an array of application service providers with the specific mission of hosting solutions tailored to DSS implementation needs. These solutions are tailored to problems that arise when testing for compatibility and creating a sturdy technical infrastructure to run DSSs and, as these systems grow in sophistication, there is increasingly more demand to create knowledge portals tailored to business intelligence (Bulusu et al. 2021). Managers of any discipline keep on high regard the way they structure and capture data because the better that is arranged, the better a company is able to perform operation analysis and make the best possible decisions given each circumstance.

1.2 Preliminary Overview of DSS in Precision Manufacturing

A Decision Support System is a collection of integrated systems and applications set to triage information in a way that aids businesses into building data integration and management databases, SACs (Security Access Controls), process operations and make decisions regarding situations or activities. This term is more specific than that of Computerised Decision Support, which is a more broad and antiquated direction of the same idea (Jao 2015). In the decision making process the output of the DSS presents statistically driven results based on data analysis and the manager can make judgement based on these suggestions to do a myriad of things such as rationalize the selection of the best supplier, realize optimal supply quantity, set the aggregate spending limits for the quarter, optimize inventory from a supply/demand/space/cost perspective, keep track of elements to be standardized in terms of maintenance, optimize capital expenditures (CAPEX) following price optimization functions (MIN Func through PLM), setting the optimal e-sourcing layout, among others (Gibadullin 2020).

This information will guide the manager to be a better judge and lay the best sequence of actions for each situation a department faces. DSS is most profitable for high-level managers because the software clears the fog best at a macro level. From a corporate standpoint, DSS can also be applied for financial decision making since it can be set to analyse large volumes of unstructured financial data and accumulate information to optimise expenditure practices.

In general terms the ability to make informed, data-driven decisions is critical within manufacturing companies and more so within the precision equipment industry. This is an industry that has changed a great deal in the last decade in terms of operation management and in terms of machine technology. Just within the bearings manufacturing industry we observe a great deal of improvement in what machinery can do and what is expected from a product. Materials that used to be impossible to work with are now on the table as there has been a significant push towards harnessing the power of micromachining processes capable of working with materials that would otherwise not be malleable when working at the Nano level (Maghsoodloo & Huang 2001). This evolution is driven by the increasing demand for enhanced material performance in various applications, companies now want their products capable to withstand certain temperatures, or environmental conditions and if one company is able to offer that solution the whole industry will pivot to offer that same solution or lose its market leverage.

For instance, one of the most crucial micro features in the bearings manufacturing industry is the micro-hole and its design and precision plays a vital role in various outcomes such as the bearing lubrication efficiency, its weight reduction, and its capability to be compatible with other features such as sensor integration reading (Leach & Carmignato 23). To meet these challenges, the bearings industry has evolved to the point that daily operations need to be outsourced to third party service providers that specialize within specific areas of expertise and those departments needing to constantly communicate between each other, it is clear therefore that the development of new machine techniques has made operations much more intrinsic.

Studying the empirical process of the nature of this technology should be structured through contextual grounds and the best method to attain this is by portraying its relevancy through a case centred in NTN, a leading bearing manufacturer in France known for constantly innovating the precision equipment industry. The case depicts how the company finds itself at a pivotal juncture prior 2023 and how a need to implement an advanced Decision Support System arises. The study goes into detail on how the company transitions from an antiquated management information system to a more sophisticated solution, aiming to enhance its capacity to meet different production targets within their particular market context.

1.3 Research Approach and Theoretical Framework

The research will be centred in the impact of implementing a bettered DSS and the degree of efficiency these changes bring to the table. This will be measured through different variables such as system efficiency for decision-making, competitive edge of the company contrasted with the industry, ease of usage, among others.

The study aims to achieve two main objectives: (1) to compare the effectiveness of various DSS implementation approaches on NTN's ability to optimize its cage assembly processes, and (2) to evaluate the departmental experience of implementing the chosen DSS to enhance operations with the intent of up scaling production as central variable. The theoretical framework for this study is grounded in a thorough contrast within the different directions micro machine technology state of the art practices are taking, depicting the general components of DSSs and benchmarking DSS implementation based on observable measurements within the manufacturing process and its relation to information systems technology.

This will be attained through gathering insight from existing literature on Support Systems in the manufacturing environments, with a particular focus on the unique challenges and opportunities presented by NTN’s case study about a very specific set of problems set in the nucleus of a demand overhaul dilemma. The applicability of this study lies in its relevance to offer practical insights into the complex decision process that goes about when a major technological change is required, in this case setting a new DSS within a high stake environment. As organizations like NTN grapple with the *build or buy* dilemma and weigh the merits of packaged solutions against custom developed systems, this research aims to provide a comprehensive analysis of the factors influencing whether a decision pivots to the side of buying a pre set or building a customised system from scratch.

The findings from this study are expected to benefit not only the manufacturing industry but any industry that experiences changes in production volume. This work provides insights into the selection, implementation, and optimization of decision support systems within different layouts. Furthermore, this research contributes to the broader academic discourse on the role of DSS advanced analytics, particularly in the context of high-volume production environments, and how having this tool can benefit managers to make better decisions based on reliable data analytic tools facilitated by the system itself.

1.4 Problem Statement

The central research problem this study addresses is the challenge of selecting and implementing the most appropriate DSS solution to enhance decision-making capabilities within the specific context of NTN's cage assembly department’s need of transition due to their production overhaul on 2023. Despite the potential benefits of advanced data systems when it comes to operational efficiency and enabling a department to withstand operational transformations, the implementation process often encounters significant barriers, specially so in such a complex industry such as the precision manufacturing one. These barriers would often pose the question on whether it is worth it to revamp a legacy data system in the first place. It is hard to measure the difficulties of maximizing transition efficiency during system integration poses. Furthermore, there is little academic research on the true impact of updating a DSS within the precision manufacturing trade.

1.5 Research Objectives and Questions

Four key research questions guide this investigation: (1) how should operational challenges within a department be studied to benchmark their data management needs? (2) How should companies push their DSS development direction in terms of tailored customisation? (3) How a company’s ability to transition to a better DSS impacts operational needs and its short and long term goals. (4) How can an implemented DSS be benchmarked to measure improvements within the manufacturing process, the communication process, the supply chain process, the production parameter selection and the equipment and maintenance scheduling?

1.6 Relevance of the Study

This study is relevant since it would be useful to benchmark DSSs in terms of efficiency within the precision manufacturing industry. By analysing a real life example of a DSS implementation, managers in a similar position would have an extra tool to decide whether it is a good idea to implement system changes within their own department.

Every departmental process requires a support system of sorts to handle operations and ensure reaching set goals efficiently and companies tend to handle them in a very different way. It is accepted as a staple that newer support systems enhance managerial activities by providing the right tools at the right time. However, the effectiveness of an overhaul is tightened to how well the system is integrated into the department making an objective measurement of the process quite useful. This work should therefore be a guide to transition processes of this nature and can be used to gauge how much a certain DSS enhances operations in a measurable context, for instance how the alleged better system could enhance order fulfilment times given increased order demand, or how would variables such as handling costs, overhead and order requisitions would improve with a system overhaul.

Furthermore, this work answers questions about how the communication pipeline within the supply chain management of an enterprise can be optimized to meet specific departmental goals and delivery time constraints. Particularly this project would measure how better or worse the decision system standpoint of a company would be after a DSS update. This would be accomplished by comparing how the updated system directs operations in different circumstances. Also how the newer system sets priorities to improve how certain operations are handled.

Finally, it is fair to say that the effectiveness of a DSS update depends on how well it is implemented and integrated into existing systems. This study aims to explore different implementation approaches and their impact on NTN's historical ability to optimize its operations and hopefully other companies will find similarities between this case and their current situation.

1.7 Structure of Thesis

This study employs a comprehensive research approach, combining analytical research, literature review, ethnographic research and case study methodologies to provide a holistic understanding of how DSS implementation really looks like within contemporary mid size manufacturing environments. For this we will focus specifically on NTN's cage assembly department for any sort of objective contextualisation. This will be performed first though analytical research by rigorously examining NTN's production processes, performance metrics, and operational efficiency pre and post implementation. The analysis will focus on the search of activity areas where implementing a new DSS might have directly or indirectly been a driver of change. The analytical research will also encompass a comparative study of NTN prior to its update. This approach will provide concrete insights into the development of NTN's operations and the impact of DSS implementation.

This work will be further supported by a well selected literature review accompanied by a detailed analysis conducted to establish a robust theoretical framework for the evolution of DSSs and its applicability in the precision manufacturing sphere. This includes analysing peer-reviewed articles about similar management systems, DSS strategic management reports, and other case studies related to enhancing supply chain performance through decision systems. The literature review will cover topics such as general DSS design, specific modern resource service management applicability tailored to manufacturing, database architecture, emerging trends within data systems worth keeping an eye on, among others.

Finally, a detailed case analysis of NTN's cage assembly department as it stands in the year 2023 will be used to further contextualise this research. This will involve an in-depth examination of the department's current processes, decision configurations, and technological infrastructure. The case study will explore NTN’s journey of updating their DSS from ECC to S/4 HANA where its old and new specific operational context is discussed aswell as the challenges the implementation brought to the table. We also analyse the opportunities the new system brought to NTN cage assembly department, providing a realistic perspective on the consequences of DSS implementation. The case study will highlight the consequences of adopting a new DSS brings to a company in terms of managerial computing power.

2 THEORETICAL FRAMEWORKS AND LITERATURE REVIEW

Decision Support Systems have become indispensable tools for enterprises of all sizes and they fare particularly well to process supply chain management orders in the manufacturing industry. They are designed to assist managers aswell as line workers by providing an interface that oversights operations, aswell as enabling more informed decision-making. This section dwells into key aspects of DSS, its architecture, its application and its integration process

In highly complex production environments, DSSs play a critical role in managing large volumes of data emanating from processes like metallurgic assembly, quality testing, and analysis of material properties. From the captured data, a well informed manager can oversight daily operations, set better machine parameters, and predict endeavours within the supply chain process. There is particular talk about new DSS updates that are able to optimize operations through dynamic machine learning algorithms that provide recommendations based on AI. Also DSS is a communication tool set to promote collaboration by establishing an ecosystem of teamwork that gives access to project interfaces to the right workforce.

Developments in Nano Feature Manufacturing for bearings are an example of how DSSs augment innovations in precision machining processes. Advances in CNC machines have recently enhanced positioning accuracy, allowing for the generation of complex micro features. Advances in technologies such as femtosecond laser micromachining provide precise ablation of hard materials with small heat-affected zones. Similarly, electrochemical micromachining also offers cheaper ways of producing detailed micro features. In the following sections it is to be discussed how machine metrology systems such as optical interferometry and atomic force microscopy can ensure precise radial fitting diameter measurements through DSS.

DSS integration within these advanced machining processes are almost a requirement to maintain precision and push technological boundaries in contemporaneity. For instance, precise databases are required to contain exact information regarding shaft and fitting diameters. Therefore this section will also cover how linking machine setups to DSSs help users achieve tighter control and consistency specifically within micro machining.

Despite their benefits, the installation of a DSS does not only present opportunities but also challenges. This section will cover the hurdles in the implementation of these systems. It would be useful to have a contextual example on how integrating a DSS with legacy systems that were deeply embedded in critical functions like inventory management and financial reporting can represent a loss for a company by the standards of multiple stakeholders. It would be worth to make an account of the implementation costs coming from this sort of infrastructure development and all the indirect expenses that are implied, such as training programs. This section will finally dwell within the integration process of the system's critical organisational workflows, and it will be depicted through the lenses of the key stakeholders involved.

2.1 Defining Decision Support Systems and Understanding Its General Components

Along with Jao's brief definition (found in the introduction) we can define DSS more extensively as an interactive database deployed as information system within a computer network designed to assist the user in visualising, storing and using data to make decisions or perform tasks (Hernández et al. 2012). DSSs offer models to solve unstructured problems through data analysis and they are used daily to create and follow supply chain activities and perform production tasks. The most observable purpose of such a system is to improve the efficiency of operations within the supply chain pipeline by enhancing communication between stakeholders through customisable grid layouts. DSSs integrate modelling and simulation functionalities to visually represent the flow and the communication route of inter and intradepartmental daily activities and to predict disruptions (Bui et al. 2003).

To give context to this let us extrapolate the definition to a machining context, the selection of appropriate machining parameters such as cutting speed, feed rate, and depth of cut is crucial to attain the desired accuracy and productivity. A machine that is well integrated with DSS may use parameters of past machining operations, material properties, tool wear, and production outcomes, and recommend parameter values to optimise the manufacturing process. For instance, if a machine operator needs to work with a delicate alloy, he would first consult the data from the DSS to set precise cutting speeds and feed rates from previous successful machining operations on similar materials. In short, the system can predict pitfalls through data.

Within the manufacturing industry this might involve simulating production line disruptions or supply shortages. A specific example of how this comes to past is through the FST (Fuzzy Set Protocol), this component helps model the uncertainty associated with disturbances and their effects on the supply chain. FST is particularly useful when variables like production quality or supplier reliability harness degrees of uncertainty (Hernández et al. 2012).

An example of this would be when a DSS is set for FST machine performance optimisation to predict maintenance. Analysing recent sensor data in the machines such as vibrations, spindle speed variation, and temperature changes does this (Hernández et al. 2012). The DSS identifies early indications of mechanical malfunctions or wear. For example, if the system detects abnormal vibration in a spindle motor, it can alert operators to inspect the component before it fails. Moreover, the DSS can plan maintenance activities when they are needed the most using prediction algorithms. So setting a DSS not only enhances machine reliability but also maximizes equipment life by fixing issues before they occur.

2.1.1 DSS KPIs

DSSs have Key Performance Indicators embedded in the system layout to assess the impact of disturbances and the effectiveness of mitigation strategies. KPIs held by DSSs include any cypher categorised as measurable ratio. The DSS further supports the selection of the best possible operational policies based on the current operational environment of the department, it also suggests based on data appropriate mitigation or contingency plans to counter the effects of disturbances in the department (Angehrn & Tawfik 1994).

This already makes clear that DSSs are useful when it comes to giving managers tools to analyse the effects of disturbances in various areas of day-to-day operations. Managers can use DSSs to support their decisions with information that is backed with data. They are not obliged to follow the suggestions the system gives, they can just use the data sorted by the system to arrive to their own conclusions for the sake of enhancing any metric they strive for.

An example of this would be the Overall Equipment Effectiveness benchmark; OEE is one of the most common KPIs for manufacturing and quantifies the equipment efficiency with comparable parameters. It incorporates three essential measures: availability (uptime vs. downtime), performance (actual production vs. maximum possible production), and quality (defect-free product percentage). For example, a DSS can monitor real-time data from CNC devices to calculate OEE and automatically alert issues such as unexpected downtime or performance drifts (Kennedy 2017). This measure allows managers to identify bottlenecks or inefficiencies in manufacturing and find the best path to set remedies. It is not hard to imagine that the solutions lay in ancillary measures such as scheduling proactive maintenance or optimizing machine parameters for defect reduction.

Another KPI could be benchmarking cycle times for different production runs since they can be historically compared betwixt. If a disturbance is found in one section of the operation cycle the DSS could be utilised to track its cause by comparing previously set parameters. Through monitoring cycle time trends, managers are able to assess the impact of disturbances on production efficiency and implemented strategies that would lead to changes in workflows.

2.1.2 Depicting the typical DSS Architecture suitable for the manufacturing industry

Now that we have a general idea of what DSSs are and what they can do let us delve in some of their more known particular components in a technical manner. When used for manufacturing and supply chain management, DSSs are composed of 4 main segments, these do not follow any chronological order in their the hierarchy and can therefore be ostensibly portrayed in the following manner: the first segment is the Main Management System Core: this is the core of the system where the centralised repository is located.

As a standard it holds the internal database and generic file system to store programming protocols, algorithms that have a sequence and other metadata that makes the system work. It deploys particular version control mechanisms to track queries. We then have the General Repository Server: this is the repository where the model itself is stored, the content of the repository is linked to the purpose of the particular DSS and the features interacts with each other by using ML protocols and applying trial and error simulation models (Anthony & Govindarajan 2000). These servers interact aswell with metadata and are constantly managing outputs from there.

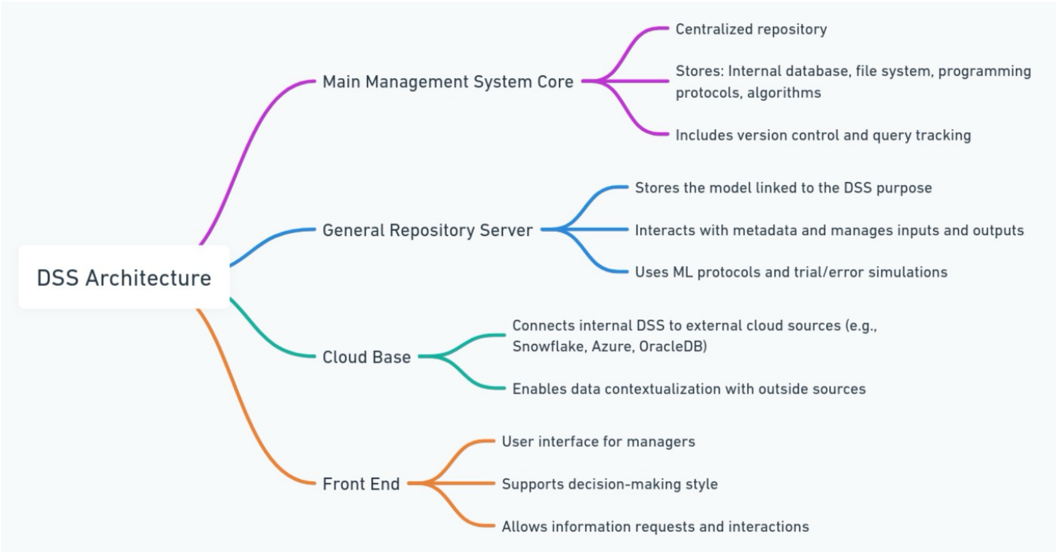


Figure 1. DSS Architecture Layout (Anthony & Govindarajan 2007)

The last two parts are more linked with the back-end and front-end setup, these are Cloud Base: where newer DSSs have systems integrated to their intranet where internal sources of the software can interact with cloud base external sources (Khang et al. 2021). There is a myriad of support programs with languages construed to support the infrastructure for this sort of communication such as Snowflake, Azure, OracleDB, academic databases, SAP BTP, MongoDB, etc. These complement the system because it creates the environment to contextualise data with external sources and expand it. The last part is the Front End of the system: it constitutes the interface itself where managers navigate through the system and perform requests (Anthony & Govindarajan 2000). The user can usually gauge the degree to which the DSS interprets the information ensuring that there is synergy within their style of decision-making.

Understanding the structure of this architecture is crucial because it proves that a DSS can handle the highly complex activities performed daily in NTN's manufacturing departments. All the parts described interact with one another to ensure a functioning interface with a solid front end; these qualities are paramount in companies such as NTN where production errors can be very costly. Additionally, this sort of architectural depiction of the system helps identify potential roadblocks while deploying it. Finally, having an overview of the interactions among each segment of the architecture guides system engineers to upgrade in a strategic way, ensuring integration tailored to optimised existing workflows.

Now that we have a general idea of how DSSs are composed let us contextualise it with how managers in NTN use these tools to meet high volume production targets and even upscale them: First of all daily operations data is stored and used to understand the state of the metallurgic assembly processes, quality control tests, and material properties which are the central activities we will focus on optimising through NTN's overhaul. There is an extraordinary amount of manufacturing data that comes from the process of creating products such as velocity joints and bearings.

Some evident metrics to evaluate DSS would be the degree to which the software is capable of harnessing information to optimize alloy performance, set parameters in the machinery and to which degree it helps users understand the timing of maintenance needs for the equipment used. There also is a qualitative aspect in manufacturing, which can also be enhanced with the help of DSSs since when incorporating Prometheus Modelling, these systems leverage dynamic machine learning to provide recommendations based on the product type (Khang et al. 2021). DSSs possess a myriad of addons tethered to create a teamwork ecosystem, which enables collaboration when working on a project. This changed the way projects are conducted giving mid tier stakeholders more agency than before. If mid tier stakeholders have access to the project interface they can understand and contribute better in the decision making process.

2.2 Innovations in Nano Feature Manufacturing for Bearings: Advancing Precision Machining Techniques

We ought to start by talking about the advancements in CNC machines that have taken place in the last decade, specifically about the improvements of high-speed spindles and micron manufacturing. What is new about this technology is its improvement in positioning accuracy, which allows the machine the possibility of creating more intricate micro features. Laser micromachining using femtosecond lasers enables ablation of hard materials with minimal heat affected zones, this changes completely what can be done when it comes to creating precise micro holes in bearing components. A robust DSS can address these issues by leveraging predictive algorithms to optimize cutting settings on a case-by-case basis, monitor the health of the given machinery in real time, and dynamically adjust tool paths (Gupta 2018). We can further merit technological leaps in electrochemical micromachining, the advancement comes from machines using controlled electrochemical dissolutions to create smaller and well defined micro features with high aspect ratios just like they do in microchips, it actually is the same technology but it is now more available since the price ceiling is lower.

These advancements are complemented by the integration of on-machine metrology systems, such as optical interferometry and atomic force microscopy (Walker 2014). These features basically enable more precise radial fitting diameter measurements to be set and this aids on the pursuit of enhancing the overall quality of the shaft in this industry's bearings manufacturing endeavours, also more detailed micro machines require keeping track of more precise measurements there must be a more precise database dedicated to storing precise information about precise shaft and fittings diameter and this is a primary reason to require a DSS system that can query data on demand tailored to each circumstance.

Nominal bearing bore diameter *d* mm		Cylindrical bore bearing											
		C1NA		C2NA		NA 1)		C3NA		C4NA		C5NA	
Over	Incl.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
—	10	5	10	10	20	20	30	35	45	45	55	—	—
10	18	5	10	10	20	20	30	35	45	45	55	65	75
18	24	5	10	10	20	20	30	35	45	45	55	65	75
24	30	5	10	10	25	25	35	40	50	50	60	70	80
30	40	5	12	12	25	25	40	45	55	55	70	80	95
40	50	5	15	15	30	30	45	50	65	65	80	95	110
50	65	5	15	15	35	35	50	55	75	75	90	110	130
65	80	10	20	20	40	40	60	70	90	90	110	130	150
80	100	10	25	25	45	45	70	80	105	105	125	155	180
100	120	10	25	25	50	50	80	95	120	120	145	180	205
120	140	15	30	30	60	60	90	105	135	135	160	200	230
140	160	15	35	35	65	65	100	115	150	150	180	225	260
160	180	15	35	35	75	75	110	125	165	165	200	250	285
180	200	20	40	40	80	80	120	140	180	180	220	275	315
200	225	20	45	45	90	90	135	155	200	200	240	305	350
225	250	25	50	50	100	100	150	170	215	215	265	330	380
250	280	25	55	55	110	110	165	185	240	240	295	370	420
280	315	30	60	60	120	120	180	205	265	265	325	410	470
315	355	30	65	65	135	135	200	225	295	295	360	455	520
355	400	35	75	75	150	150	225	255	330	330	405	510	585
400	450	45	85	85	170	170	255	285	370	370	455	565	650
450	500	50	95	95	190	190	285	315	410	410	505	625	720

Figure 2. DSS Recorded Nominal Bearing Bore Diameter of Cylindrical Bore Bearing (NTN Global 2023)

Nominal bearing bore diameter *d* mm		Mean bore 1) diameter deviation Δ_{dmp}		g5	g6	h5	h6	j5	js5	j6
				Bearing Shaft	Bearing Shaft	Bearing Shaft	Bearing Shaft	Bearing Shaft	Bearing Shaft	Bearing Shaft
Over	Incl.	Upper	Lower							
3	6	0	−8	4T− 9L	4T−12L	8T− 5L	8T− 8L	11T− 2L	10.5T− 2.5L	14T− 2L
6	10	0	−8	3T−11L	3T−14L	8T− 6L	8T− 9L	12T− 2L	11T − 3L	15T− 2L
10	18	0	−8	2T−14L	2T−17L	8T− 8L	8T−11L	13T− 3L	12T − 4L	16T− 3L
18	30	0	−10	3T−16L	3T−20L	10T− 9L	10T−13L	15T− 4L	14.5T− 4.5L	19T− 4L
30	50	0	−12	3T−20L	3T−25L	12T−11L	12T−16L	18T− 5L	17.5T− 5.5L	23T− 5L
50	80	0	−15	5T−23L	5T−29L	15T−13L	15T−19L	21T− 7L	21.5T− 6.5L	27T− 7L
80	120	0	−20	8T−27L	8T−34L	20T−15L	20T−22L	26T− 9L	27.5T− 7.5L	33T− 9L
120 140 160	140 160 180	0	−25	11T−32L	11T−39L	25T−18L	25T−25L	32T−11L	34T − 9L	39T−11L
180 200 225	200 225 250	0	−30	15T−35L	15T−44L	30T−20L	30T−29L	37T−13L	40T −10L	46T−13L
250 280	280 315	0	−35	18T−40L	18T−49L	35T−23L	35T−32L	42T−16L	46.5T−11.5L	51T−16L
315 355	355 400	0	−40	22T−43L	22T−54L	40T−25L	40T−36L	47T−18L	52.5T−12.5L	58T−18L
400 450	450 500	0	−45	25T−47L	25T−60L	45T−27L	45T−40L	52T−20L	58.5T−13.5L	65T−20L

Figure 3. DSS Recorded Nominal earing Bore Diameter Mean Diameter Deviation (NTN Global 2023)

Harnessing a precise micromachining setting oversight becomes a critical factor affecting feature accuracy and micro scale surface quality for the support unit. The slightest modification within the properties of the setup can have a great impact at the micro level, requiring well-defined modes of operation and setup strategies (To & Wang 2023). Binding machine setup to DSS is crucial to maintain accuracy and the better this is performed the further the industry can push the boundaries of what is possible when free thinking designs.

2.3 Understanding and evaluating the ideal environment to make a DSS thrive

To have better understanding on benchmarking DSS integration with the points we have previously treated, namely as a detailed tracking tool for complementing micro machining undertakings, setting a qualitative layout of the adoption process is imperative. For this we rely on some major consultancy studies, specifically one from Elliot Advisor's UK when under Barnes and Noble tutelage they examined 50 merged and acquired sister enterprises of several market capitalisation brackets across to get a qualitative overview of the DSS adoption feedback (Penner 1995).

The study evaluates DSS adoption of each case company using criteria such as growth, approval trackers, expenditure efficiency trackers, scope of classified data intake, reduction of budgeting allocated to spending cycles and costs, communication efficiency trackers, production visibility against demand and supply, budgeting framework, risk mitigation and other qualitative considerations.

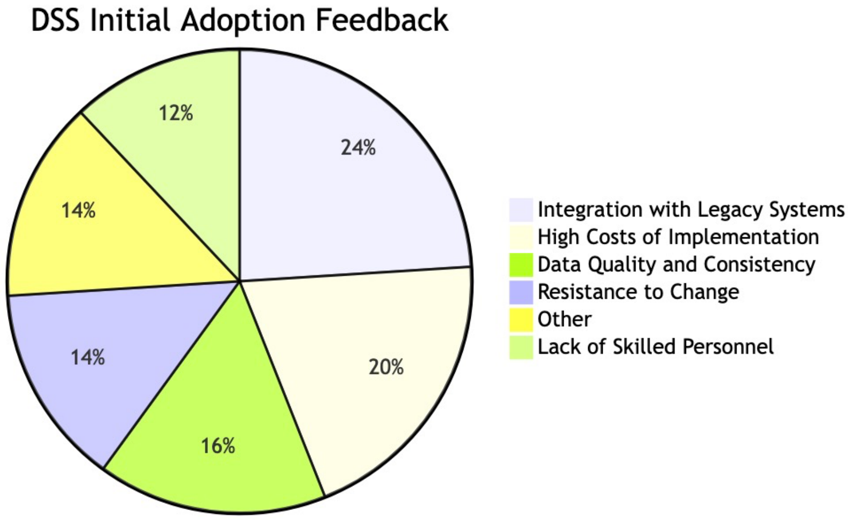


Figure 4. DSS Adoption Feedback in 50 Barnes & Noble Companies (Penner 2021)

Figure 4 offers a valuable overview of how updating a DSS is not a straightforward process since there clearly are some challenges coming from setting this system, starting with the largest categorisation of 24% coming from integrating the DSS with the legacy system which indicates that most organizations struggle to align DSS with existing systems.

This can be triggered from the fact that the old system is too engrained in high stake managerial activities such as inventory tracking and financial reporting, making it hard to replace it on demand. Implementation costs are another significant concern with a 20% mark, this makes sense since the team championing the change must justify DSS expenditures against budget constraints. A DSS is not only a software update, but also infrastructure upgrades, training programs, among others. The other variables are more qualitative in nature and very valid aswell specially when compounded.

2.3.1 Approval of the adoption process from the internal users and auditors

In the same Barnes & Noble case study, based on user experience interviews post DSS adoption there is a tendency from managers and auditors to underestimate the extent of the limitations of having inefficient data management during early stages of adoption within their companies (Penner 1995). This raises the topic that there is lack of knowledge when it comes to understanding the nature of the procedure itself leading to adoption defiance.

Transitioning brings a steep learning curve since the more a user utilizes the system, the system becomes more familiar and easy to use. Users reported a slow understanding of the nature of the tool for expanding operations in their respective enterprises and they admit in interviews that a data management infrastructure was instrumental in the specific instances where their department was going through expanding endeavours (Penner 1995). The case studies companies that have adopted NACHA as exemplary of medium sized enterprises. NACHA is the central server for the ACH network, which is a financial procurement system that allows automatic B2B Buy/Sell interactions. When inquiring subjects about their adoption experience, a general consensus was perceived in which the extra elements of the system, specifically extra ID numbers, currency converters and item types, felt overwhelming (Penner 1995).

2.3.2 Empirically understanding the provenance of the data and ability to access the source of the data

The subject pool sustained that in multiple instances there is no access to the blueprint of the data specially when the sources came from outside the department. Having unidentified data sources out of the system is a problem for the user when for instance they try to fulfil a Procurement Card (Penner 1995). The lack of access could come from the fact that the DSS adopted outsources service provider data automatically and the system stores as metadata, information that would otherwise be useful.

Modern DSS systems enable data extraction routines from metadata, standardising access of information that would otherwise be hidden within the interface. This instance is made evident when an accountant is able to trace details from expenditure data from all the possible sources within the General Ledger including residual data.

2.3.3 Facilitation for created automated processes including AI integration

The feedback of AI integration in the Barnes & Noble study, specifically for this particular automation functionality was overall positive. The consensus was that automation was useful in multiple instances and that it was better than outsourcing (Penner 1995). Due to the complexity and the often-enormous pool size of the data the subjects work with, it is a relief to delegate labour intensive tasks to automation; the relief comprises a financial sense as well as an end-user sense. Problems might arise however when the add-in provides only half of the task completed and the partially completed product begins to stack in the user's desk.

A solution for this is for the manager to clearly point at the necessity to engage with the partial product by transferring the process and domain knowledge to the employee as part of their responsibility line up (Bulusu 2021). There is a big distinction between a DSS that has machine learning and AI integration and one that lacks it. Excellence in data management in the current ecosystem requires that data classification, extraction and processes that tend to be repeatable be to an extent backed and supported by AI and machine learning algorithms. When this is the case, the DSS serves an entire new purpose since the very core of the automation process is linked to it and dependable of it.

2.3.4 Degree of acceptance of DSS PRESETS when performing data sorting

The DSS Pre set benchmark measures how well pre sets are adopted on average. Some mid size enterprises are able to adopt the presented taxonomy of the software requiring very little customisation. To this it is worth adding that for many contemporary users customization is a key driver for DSS implementation success. Industry standard pre sets are enough for homogeneous industries such as electricity companies or mineral extraction firms. Industry standard pre sets are adopted faster in mid sized manufacturing departments since their information infrastructure is agreeable to standardised pre sets, particularly those ready to be used once the systems engineer sets its backend (Yang et al. 2004). This pertains to the advancement of tech industries responsible of developing DSSs since leading DSS service providers have accelerated the general adoption rate of their systems by improving their base version to meet industry standards more widely (Yang et al. 2004).

We can gather from this that innovation in this industry comes from creating user-friendly systems that are ready to function shortly after installation. It ought to be noted that many industries inevitably require some degree of customisation regardless of how good their adaptability is. That ticker is driven by the complexity of their industry standards. Examples of these are parts manufacturing companies and semiconductor companies and we will later make it clear that many departments within NTN enter into this category.

2.3.5 Leveraging the degree of efficiency in classification

Some companies require precise detail when it comes to classification arrays and for those ones there should be overwhelmingly good qualitative feedback. DSSs offer a very high level of classification benefits since most of them let the user ramify categories as much as they need (Yang et al. 2004). When classification feels efficient and snappy, the user is able to gather as precise view of categories as necessary for each commodity, customer and supplier.

An example of a successful classification protocol is for instance when a requisition order is linked to onsite tracker and its location would update based on position within the plant. The DSS would then draw detailed price information linked to outside sources such as Forex index if the value is classified as foreign currency element. The same can be done with other variables such as contracting restraints, time sensitive cost supplementation and order notes.

2.3.6 Availability of user manuals and library of knowledge

This pertains to the creation of user-friendly instruction manuals, which should be scrutinised after every major update in any systems. People in charge of instruction manuals are usually senior engineers and it goes without saying that they should strive that a good portion of users are satisfied with the level of detail they offer (Yang et al. 2004). Of course, each DSS solution provider has different approaches for user manuals but the general consensus is that the end user should feel the questions they have are solved after browsing the manual in question.

In general there are 3 major brackets that need to be satisfied when it comes to instruction manuals, the first one is sequence of action/classification guidelines, the second is the program's knowledge base and the third one is the content core of the user interface hands-on for the system model (Yang et al. 2004). As long as the service provider fulfils requirements over these three ramifications, it can be said that the user manual fulfils its purpose.

2.4 Ranks of Data Classification within the DSS Data Directory

In the implementation of Decision Support Systems, data classification defines how data is treated. Classifying it properly through rankings will establish the degree of importance of datasets and define whether a particular cluster of data should be completely stored or only partially stored. This practice is crucial for WMS (Warehouse Management Systems) since data typically comes from multiple areas of the supply chain pipeline, there are three ranks of data classification commonly linked to DSS practices, the following is an explanation what each rank entails and its significance in the process.

Data classification allows manufacturers to categorize information into ranks based on its significance to operations. This is important for managers because they can set priorities during departmental operations. For example, high-priority data such as assembly errors must be processed and fixed immediately to prevent disruptions that would otherwise take place in production. By prioritizing data, managers can also prevent system overloads and reduce storage costs significantly. Let us see how DSS data is commonly classified:

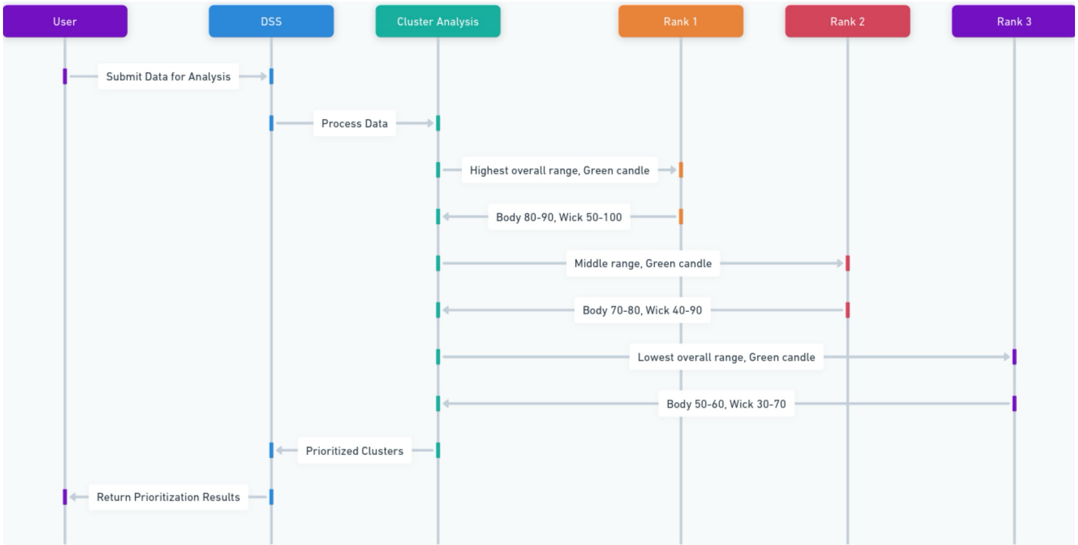


Figure 5. Ranks Of Data Classification Commonly Linked To DSS Practices (Schwabish 2021)

Rank three: General aggregate of variables containing procurement information publically available. Includes quarterly aggregates of final products manufactured and commodities that the company is interested in buying from their suppliers. These could range from materials related to cage assemblies to technical specifications of standard products the company offers as long as they are not confidential. This rank of classification is often made available to external auditors so they have an idea of the nature of the operations the company conducts (Schwabish 2021).

The benefit of this level of classification is that it provides a general summary of the aggregate data within the system. It is the prefect level to identify challenges and opportunities from a macro level while keeping the company's sensitive information confidential. Another positive aspect of scrutinising data on this level is that the company can use this type of data to comply with regulatory requirements and using it to communicate with competitors while staying relatively confidential.

Rank two: Internal purchase and spending data including detailed base item categorisation. This includes internal data such as production schedules, general levels of inventories, production mix, supplier order history, item categorisation and standard instructions set for the DSS procedures (Schwabish 2021). The advantage of this particular level of classification is that it gives a deeper view of the company's activities to managers. This sort of data can evidently be used to strategize about future departmental operations. Decisions such as purchasing mix, supplier selection, expenditure position framework and commodity allocation comes from this level of data scrutinizing.

Rank one: Detailed information within item level. This is very specific data including metadata such as machinery protocols, machinery setup history, traceable item level history, design specifications and customer specific information (Schwabish 2021). Upper level management would certainly find good use to this particular slab since it offers detailed visibility of spending timelines, which are classified at specific item levels. This data needs to be encrypted on at least two protection protocols and only be made available to the pertinent staff in the organisation. Indirect users can request permission to access certain portion of this data and the DSS interface should be able to grant that, an example of this is when financial data related to cage assembly production costs is requested by accountants to solve incongruences in their department.

2.5 Utilising DSS decision support instruments for forecasting

Having a system that consolidates data mixed with prediction capabilities is the right mix to accomplish efficient forecasting practices. For managers to leverage sales or expenditure data requires support of forecasting tools that come from a DSS analytical engine. Forecasting engines within DSSs are often implemented as addons using technologies such as Oracle Forecasting OLAP, or open source solutions that can be seamlessly added to the DSS like Apache Kylin.

Forecast addons allow better Cross Docking and WMS communication by using ARIMA to query data time series analysis. ARIMA follows a trial and error algorithms based on Gradient Boosting based on LSTM network architecture and is perfect for packing supply chain data coming from multiple directions (Wallot et al. 2016). This technology could be categorised as an algorithmic neural network that works as short-term memory for the DSS. The primary way this whole process should be rationalised is by placing its input layer sequence as its core component and the rest of the connections working as layers dependent to each other. For instance, the first layer creates a series of sequences that the neural network follows and the other layers are then connected to data sequences just like humans connect a thought based on another thought when there is chronology within the thought process.

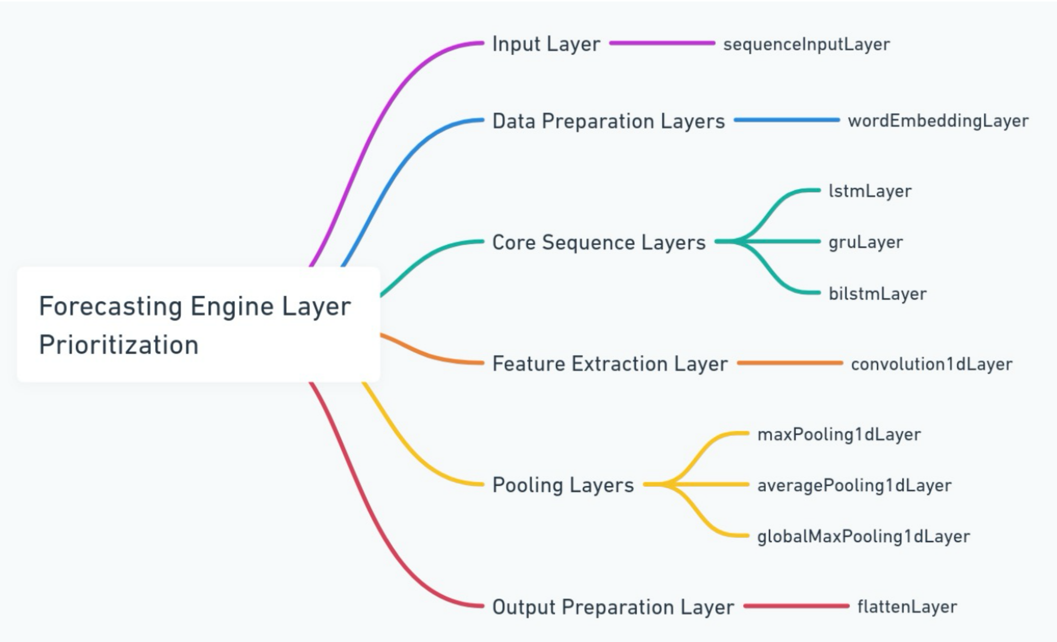


Figure 6. Forecasting engine layer prioritization (Wallot et al. 2016)

The add-on follows different routines depending on the forecast that the user is attempting to implement. For instance LSTM would use a Pad Sequence following a SequencePrediction option to engage with historical data based forecasting, so for instance sales forecasting, market trend forecasting and seasonal pattern forecasting. Forecasting production schedule or optimising inventory follows a different pattern however, since LSTM would use a Prune Sequence following the same SequencePadding option since the item pool is much higher (Wallot et al. 2016). The logic behind this is that the machine would simplify the sequence by homogenising items and attempt to solve it in a smaller batch. Data perceived as superfluous by the system is not applied either. Streamlining data sorting protocols is a very delicate process since automation is not always reliable. However managers can use these tools and empirically measure their level of reliability by comparing it with previous trends. It is worth mentioning that DSS systems often offer users benchmarks measured in degree of confidence for forecasts.

2.5.1 Alternative applications for forecasting

Forecasting technology can be easily applied to other undertakings of the company if data is sorted correctly. The procurement department of a company could for instance use LSTM forecasting to find anomalies within the classification itself of the data with the intention to predict which part of the sourcing process might bring about problems in the future. For instance Airbus has applied their forecasting tools to inspect their part replacement pipeline and was able to find inconsistencies coming from certain suppliers (Baumann et al 2020).

These inconsistencies were later predicted by their DSS system and the company changed suppliers afterwards. It can be therefore gathered that the tool could also be used to predict production ceilings during Sourcing activities so the company can rely on possessing a certain amount of units at set intervals. Using this tool the manager can recognise their sourcing needs given their current sourcing configuration. In general terms LSTM is quite apt to analyse current orders, production capacity, and inventory levels to forecast the optimal production schedule (Baumann et al 2020).

In the context of NTN we can infer that sourcing parts and having labour tightened to part availability must produce supply chain disruption prediction. By analysing data such as supplier performance and global availability trends this setup can forecast disruptions and display it with quantitative indicators for instance monetarily or time wise. This would only be possible if dependencies are set in a format that agrees with the particular supply chain pipeline of the company. Put more bluntly, a delay in receiving one specific critical component affects every other activity where that critical component required a predecessor.

2.6 Concluding the literature review, formulating central questions and developing a thesis statement.

Based in the literature review it can be gathered that the precision engineering industry benefits in different degrees from DSS support due to the complexity of the daily manufacturing process it faces on a daily basis and the need for data driven and up to date decision making tools which are almost exclusively available through setting a well integrated DSS. When this is the case the organisation should have market advantage compared to another that lacks the system. It therefore remains to be proven the statement that when implementing a customised Decision Support Systems and using it as Business Intelligence tool in particular manufacturing environments, said DSS is bound to enhance the decision-making processes within production planning, supply chain management, and quality control.

Now, to prove that effective integration of DSS is essential to retain organization's market position we will put the previous statement a test through a case study from a French company called NTN. The case study to be covered in the next section will be instrumental to objectively state the operational leverage of migrating from an old DSS to a new one since there is a clear lack of objective examples of how different DSS components integrate to other stakeholders within the industry. For instance, Section 2.1.1 lacks detailed a theoretical exploration of what those KPIs would look like within an information system of a company.

The section opens an academic debate about policies and operational environments but what could they objectively be. A case study is needed to contextualise the theory and to gather specific KPIs, be it production rate, defect rate, or supply chain lead times. It would also be interesting to see how these KPIs are aligned with more common production metrics such as machine uptime, defect rates, and supply chain efficiency. When the KPIs are well defined, the data required to measure them will be clearer. Another gap in the research is found on Section 2.1.2 as they talk about DSS Architecture, since it does not provide adequate insights into how modern DSS architectures can be adapted to handle the complexities of sudden changes within manufacturing environments like it is often the case in production lines. The current literature fails to address how cloud-based or hybrid systems can be integrated with legacy systems while maintaining real-time data processing capabilities.

The study does not mention how one goes about implementing such a change in terms of feasibility and does not offer a study protocol. The successful implementation of a DSS requires more than just technical infrastructure; it demands a feasibility study conducive to its adoption and use. This would be best observed through an objective example and that is why NTN's case study is ideal to portray the process. Section 2.3.1 talks about the approval process from internal users and auditors and this is a good insight to have some rudimentary notions of the feasibility process but lacks empirical information on how to foster this acceptance within manufacturing organizations.

Similarly, Section 2.3.2 on data provenance emphasizes the need for transparency when it comes to sourcing data but does not delve deeply enough into how this can be securely attained nor it mentions who holds the responsibility of its safekeeping. Moreover, Section 2.3.3 on AI integration touches upon automation but does not provide sufficient detail on how AI can be integrated into DSS systems, at first glance it seems counterintuitive since AI requires networks that the DSS inherently lacks. It is however possible to integrate AI to DSS and we will delve into that in the case study aswell. Finally we will delve in the DSS lifecycle based on its degree of acceptance. We already know that depending on the chosen system the experience and degree of acceptance will greatly change, it would be useful to contextualise it with a case study where we can observe the lifecycle of a DSS in a specific company, therefore this is the last area where we will dig to understand the timeline of such a project.

So far we have reviewed some central reasons for focusing on the implementation of advanced data and decision support systems in manufacturing environments. Trough the categorisation model we observe that operational efficiency and regulatory compliance are the most immediately observable and actionable aspects in this particular setting of micromachining, making this dynamic central to support preliminary this research hypothesis. These two dimensions evidently influence the ability to optimize processes but it remains for us to found out the degree to which it does so.

We have observed aswell though the Barnes & Noble study that operational efficiency directly impacts a company's ability to handle increased production, this is tightened to regulatory compliance, which is mandatory to uphold quality standards of operations by keeping manufacturers at bay when it comes to adjusting their processes to respect safety standards. These systems are impacted by constant change, change in the technology and change in the industries themselves, which translates in different needs for managers and users in general. Without efficient data management or decision support capabilities, even highly skilled professionals are bound to struggle to optimize production processes effectively. Therefore we can safely state that these dimensions are the main indicators when it comes to a proposition for a DSS to be implemented, This study so far has offered valuable insights to understand these indicators and are enough to build this work hypothesis and research questions:

Main Question:

1) How can the benefit of a particular advanced data system facilitate operational efficiency and regulatory compliance in manufacturing environments, specifically in the context of precision manufacturing?

Sub-questions:

1) To what extent does the process of implementing Decision Support Systems in precision manufacturing supply chain management affect operational efficiency, data reliability, and the general decision-making process?

2) What strategies can be applied to minimise operational costs and maximise transition efficiency when a DSS is being implemented in a department that leverages the maximisation of the professionals' ability to optimize the supply chain process across the pipeline?

Furthermore, these central hypotheses have been formulated based on the following grounds:

H1: The execution of Decision Support Systems is bound to an implementation cycle and each decision within the cycle impacts the efficiency of the system based on different criteria which directly influences its success rate, the measurement of that success rate might vary subject to the stakeholder (the user, the system administrator, clients, managers, database engineer, etc.)

H2: There is a positive relationship between efficiently implementing advanced data systems and operational efficiency within the environment to which the system operates environments.

H3: The implementation of an integrated DSS with third party functionalities such as Cross Docking and WMS significantly improves procurement efficiency by optimizing the capabilities the system has to optimise operational efficiency through harnessing better communication and data management.

3 METHODOLOGY AND CORE OF RESEARCH

A theoretical framework will be built based on the findings from this particular case study. At the same time, these results will be contrasted with the information gathered in the literary review. This particular case study examines NTN Europe's bearing manufacturing department and the core of the research employs a mixed methodology research approach that will be thoroughly explained in section 3.1. The goal of the study is to investigate the level of leverage an updated Decision Support Systems brings about the NTN Cage Assembly Department when it comes to addressing scaling challenges. Following we outline the methodology, scope and holistic data collection processes of the case study.

3.1 Case Study Methodology

The core of the research follows an easily extrapolated single-case design based on NTN Europe's Industrial Bearings department in Alès, France, as the primary unit of analysis. This methodology allows an in-depth exploration of how DSS implementation would influence operational outcomes during the 2022–2023 production surge of the Sentinel One bearing line. Phone interviews were conducted with Dr. Jafet Francois Chedid, former cage assembly oversight lead at NTN's Alès subsidiary. These interviews focused on his first hand experiences during the DSS transition from ECC to S4 CORE106, operational challenges, and system-driven improvements.

Being the primary investigator, I coordinated interviews with Dr. Chedid, formulated question protocols that focused of acquiring a clear idea of the DSS transition process experienced through a managerial perspective keeping in mind the possibility of discrepancies given the intrinsic setting of the precision manufacturing milieu. During interactions I consistently cross-referenced Dr. Chedid's accounts with archival data to minimize recall bias. Regarding this archival data, the data used is based on an account of internal public NTN company reports and public production logs including: Annual production figures (specifically the Sentinel One demand surge from 350k to 600k units). General DSS performance metrics based in real-time monitoring capabilities post-upgrade, compliance documentation related to the European Green Pact, among others. These documents provided quantitative benchmarks to validate qualitative insights from interviews.

In terms of scope limitations, the study's focus on short-term achievements invites further exploration of potential long-term consequences of the particular DSS integration. It is also a fact that the case focuses on a single department of the company secluding the holistic idea of NTN as a multi-layered corporation. Future research could examine long-term consequences of the transition and extrapolate them across NTN's multiple subsidiaries with the intention to assess system adaptability in a more holistic level.

3.2 Case Study: NTN Europe's pursuit of handling increased demand

We will follow up the questions stated in section 2.6 through a case study about NTN Europe, a key player in the global precision engineering and motion technology industry that has several products, these span across three main sectors: Automotive, Industry, and Aerospace, with a particular focus on bearings, rollers, linear motion products, CV joints, sensors, and spare parts (Özcan 2024). NTN Europe possesses four major strategic focuses: supporting the enhancement of precision manufacturing practices, intensifying technology to adapt to changing markets, aligning with the European Green Pact, and adapting to European market characteristics (Özcan 2024). The company's portfolio in 2023 had a yearly yield of 500 bearing units, 200 million roller units, 50 million linear motion products, 100 million CV joints, 30 million sensors, and 150 million spare parts (Özcan 4). In this case study we will focus on a specific European bearing-manufacturing department within the company.

On 2023 NTN produced 500 million units, that number represents a 67% increase from 2022 production, which was 300 million units (Özcan 2024). This case study however will focus on a specific department within NTN, which is in charge of producing a small portion of the bearing product line called Sentinel One, which has a yearly demand of 350 thousand units.

An insider tells us that the department could have only handled the drastic increase in units by revamping the DSS from a generic ECC version, which was installed only 4 years ago (2018) to S4 CORE106 that very same year. The insider's name is Jafet Francois Chedid and he actively used DSS solutions provided by SAS Institute when he worked for 3 years in NTN doing cage assembly oversight to a series of central products the company offers and he has pointed for this research the fundamental arguments of why DSSs are valuable to track manufacturing operations.

Chedid's branch is located within NTN France Alès subsidiary within the department des Solutions Industrielles of SRN Sévennes. He is responsible of cage assembly oversight of the Industrial Bearings manufacturing process. The cage assembly department where Chedid works is in charge of fulfilling orders that pertains to engineering small circumference items, which are mostly bearings. The department designs customised bearing shafts for different intents using uniform arrangement protocols.

This department is a central branch for NTN since it permits the company to create other products like pistons aswell as selling the manufactured output on its own to third-party partners. To handle operations the company uses two DSS systems, SAP and Minitab. This particular department is responsible of fulfilling data concerning oversight of bearing seal protocols, alignment compensation required for customizing piece shafts, carry capacity measurement and loading limits, needle bearing customisation specifications, ratio of thermal speed limit and ratio of kinematic speed limit among others.

Chedid's department was in charge of the manufacturing of a particular bearing model launched by CREA LABS, the research and development subsidiary of NTN in Annecy. This particular model was the SENTINEL ONE, a type of bearing which was made with state of the art micromachining technology, thermoplastic technology in the coating and the whole bearing is made of stainless steel so they would be eligible to be used for food processing in water exposure prone environments such as conveyor belts, brushing machinery and kitchen fillers. This increased Sentinel One bearings demand from 350k to 600k in one year represented a staggering 71% premium to which the manufacturing pipeline was responsible of handling. Not only that but Chedid's unit was partially responsible of manufacturing a surplus of other parts from other product lines such as parts for the firm's semiconductors and industrial pumps.

Chedid witnessed the whole process of the department's 2022-2023 transition and had access to the Alpha and Beta of the new system. He assures that the transition was necessary for the survival of the department which was facing manufacturing overhaul and the following are his preliminary statements of why the updated DSS was instrumental to track manufacturing operations:

1. I believe the new system greatly enhanced our capability to reach target units through insight core manufacturing data offers in the form of BI.

2. The transition period helped measure the degree to which NTN is able to adopt the system across departments.

3. Transitioning helped categorise data better so each entry is validated more efficiently.

4. It helped us expand as the more knowledge the company has about production the better it can assess the viability of expansion

So the main objective of migrating to this new DSS was to handle the upscale in production within streamlining workflows cohesively so each stakeholder is aware how they should be positioned throughout this process. However, in general terms implementation is set with the intentionality of improving general accuracy within across the board (macro) decision-making process since the system removes biases as it works with homogenised sets of rules (Tao et al. 2012). Historic data depict that DSS implementation has helped NTN handle higher production and keep up deadlines and expectations across the board when the company has expanded. So it is commonly established that the need of updating a DSS comes from data necessities, for NTN, however the transition took place primarily from a need to fulfil an increase in product demand.

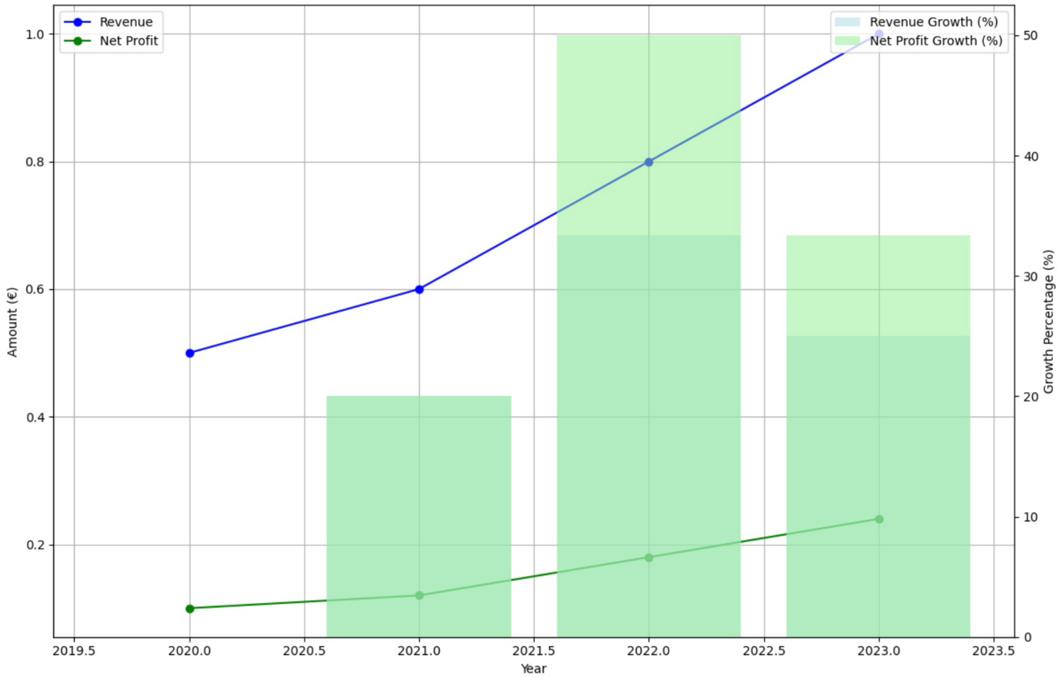


Figure 7. NTN's Recorded Growth from 2019 to 2023 (NTN Global 2023)

Another aspect of DSS that ought to be discussed is its ability to automate decision-making processes aswell as repeatable tasks within production since, once the instrument has enough data to act reliably, it can automate scheduling of machine work times, inventory level management, order processing, material categorising and its better at deciding whether specific materials meet production requirements by comparing measurements of alloys against specific tolerances (Fish & Taylor 2012). Since DSS updates in real time, it can analyse live data from product lines and automatically flag or reject altogether any entry that does not meet set standards. Furthermore, managers can automate corrective actions whenever these irregularities are detected. For all these reasons, the asset brought to the table by an efficient DSS brings great empirical value to companies.

3.3 NTN's Difficulties during DSS transition

Chedid gives secondary statements about the transition which he categorises as statements gathered when the system was up and running after some months, he states that it was hard to get the system functional to reach this level and that it took some time, but it was well worth it since after some months of managing data to make the system functional the DSS was suited to fulfil auditing operations. At later stages, most of the data could be filtered to meet audit requirements.

At NTN most of the data is objectively available to internal audits, whereas external audits get a more limited access. He also states that the system could be used to establish data cleansing protocols since the more data is collected and used the better the understanding of what is useful and what is vestigial. He also said that practicality was a central reason aswell since before DSSs were implemented a great deal of data would be stored in local computers and even in physical form, now this data can be accessed even outside the company through intranet, while travelling for example.

Once the system was fully set, users had a more visually appealing interface and were able to make reports faster.

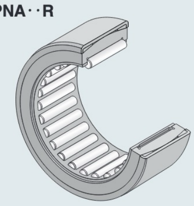
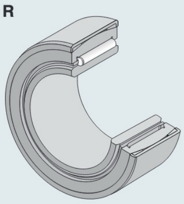
Bearing type	Applicable shaft diameter (mm)	Composition of bearing number	Remarks
Type RPNA··R 	ϕ15– ϕ45	RPNA 20 / 35 R Suffix Outer diameter Roller set bore diameter Type code [Suffix] R: Ribbed type	Maximum permissible temperature is limited to 100˚C because the bearing uses a resin-made support ring.
Type PNA··R 	ϕ12– ϕ40		

Figure 8. Example of NTN's interface setup post 2023 (NTN Global 2023)

Since we include NTN's supply chain necessities to the direction of this study aswell, let us dwell on the possible negative effects of the transitioning process in regard to supply chain pipeline automation: First let us tackle the potentiality of tracking manufacturing operations across departments giving incongruent data. When a company transitions for one resource management system to another, it is often the case that manufacturing and expenditure data might end up being located in multiple places within the database making it unreliable (Tao 25). A simple example of this would be when the procurement department has a bill stored within their e-sourcing system and within the department's credit card.

Such data inconsistencies can lead to disruptions in the department's activities, including errors in inventory controlling and delays in manufacturing schedules. When different departments operate on datasets that are ultimately incongruent, there would inevitably be challenges when it comes to maintaining accurate insights into elements of operations such as knowing the true cyphers of inventory levels. This lack of cohesion can be very detrimental for multiple stakeholders, ranging from managers to mid tier workers.

3.4 Further Challenges Faced

Updating a DSS can bring about many challenges. A clear negative effect coming from installing a new DSS is a potential flawed set up of the database in the early stages of adoption. Old data usually takes time to be transferred and new data might not be enough for the system to be used reliably. When doing reports and analysing datasets pragmatically the manager needs extensive and reliable data (Allen 2024). For instance if the attribute of a part is not fully documented then it might be ordered, only to realise that the part does not meet its purpose. Same if the entries have query errors or missing specific query fields, for instance product codes on the wrong format, then the user might oversight it. Another common effect is nomenclature conventions, particularly their potential lack of congruency (Allen 2024). An example for this would be code number written as RPNAR instead of RPNA.R which in plain sight might seem like subtleties but for the program it might be the difference between grouping an entry correctly or making a new one from scratch.

Let us understand the labour requirements to efficiently implement a DSS in place and keep it up and running: The early stages of implementing a DSS is the most laborious and takes 3 to 6 months to complete, it is a multi-layered procedure that requires calculated planning and having access to all previous databases and data sources. 60% of the system engineer's time will be spent in homogenizing old data into usable and transferable data. The 40% of the rest of the time will be spent analysing the best way to customise the DSS to meet the department's current processes and decision-making needs (Boyle 8-10).

3.5 Preliminary Lessons

Based on the depiction of those challenges and how they are tackled, the primary indication of a solution revolves around improved management of poor data quality during DSS integration. Legacy databases often contain out-dated, incomplete, or inconsistently formatted information, which can compromise decision-making accuracy. For instance, the aforementioned missing product attributes or incorrectly formatted codes leading to procurement errors or misrouted inventory, as these subtle discrepancies disrupt the data adoption process.

Systems analysts work closely with department managers to define the specific requirements for the backend, ensuring that the outline of the software aligns with what the company actually needs. Once the requirements are well established, a database engineer with DBMS knowledge (DB Management System) will set up the software structure considering factors such as what type of manufacturing takes place, how does the procurement department communicates with the production department, etc. (Boyle 2011).

Nomenclature inconsistencies further exacerbate these issues as NTN falls into the pitfall of utilizing different naming conventions across information lines, creating fragmented storage entries. Particularly the previously mentioned label disorders, which in one database might appear as “bearing_seal_v2” and “bs_v2_seal” in another, complicating integration. Resolving these discrepancies is not merely technical but requires cross-functional collaboration to establish protocols with a single format for each element that ought to be grouped.

The goal of all this is to create a robust database structure to read data attributes efficiently since the system is to handle vast quantities of data. Many companies fail in putting Database Engineers to handle data classification and data cleaning when that is not actually their job, resulting in loss of important data. Statistically a tad less than half of spending data is lost or badly categorised for this reason (Allen 2024). The crucial role Data Engineers play in this process is in creating a relationship with the line manager through developing the most sophisticated analytical model possible from the core of the capabilities they are able to offer.

Given the current DSS technology available, which is very sophisticated and given that we are entering in the era of state of the art support systems, there is vast room for that. The implementation phase also involves creating the best front-end interface for the managers. If there are tasks to be done daily, then it better be centric in the UI interface. Implementing these DSSs are costly indeed but at least the company can rest assured that there will be support all along the way from the part of the company they are choosing to make the transition.

3.6 How NTN leverages their Revamped DSS for Procurement Budgeting

Within NTN's transition, the integration of DSS into the procurement processes has proven invaluable in optimizing budgeting and improving overall efficiency. To contextualise this let analyse the various drivers used to optimise procurement budgeting through DSSs. When NTN learned the bearing product line was expanding, managers immediately attempted to reduce cost by modifying the purchasing mix, reducing waste, and reducing ordering surplus. This is done with the intention to leverage procurement data by connecting the DSS of choice with a localised WMS (warehouse management system), which supports RFID technology through efficient classification (Brazeal 2009). NTN did precisely this and this dual setup provided the data and functionality necessary to better track daily procurement operations all around the cage assembly branch. As we break down the stages of interaction and data management within the system it can be gathered that during the data extraction stage there is a myriad of inputs coming from different locations.

The most discernible ones would evidently be the ones requited the most, such as supplier information data, production order data, production scheduling data. Then we have deeper levels of raw material data such as derived replacement part data, historical data, production floor IoT data and metadata (Brazeal 147-148). When those drivers are set correctly the extracted data can be enriched with additional addons such as setting order divers which commonly are *buy limit, sell* *limit, buy stop and sell stop*. Additionally the order status can be added aswell in the form of *pending order, market order, cancelled order, retracted order*.

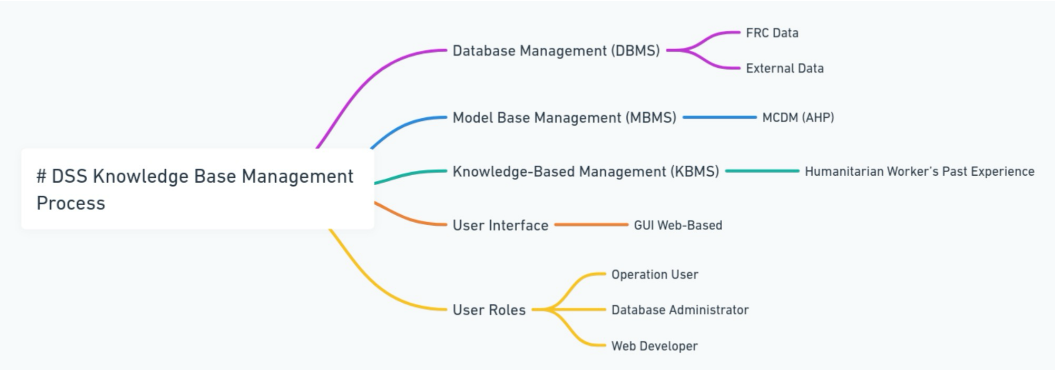


Figure 9. DSS Knowledge Base Management Process (Rudd 2000)

The process of setting the addons is comparable to WMS validation rules, which are built in to guarantee accuracy in order counts, and to red flag missing information. The part of the database, which is shared with the supplier, is set in a way that enables automatic rationalization of common ground data (Rudd 2000). There are multiple reasons why this is useful, for instance these addons can be set to respect the extent of the contract that the company conducts with the suppliers. Performance data can also be extracted from this whole process and used in a managerial level to enable the creation of purchasing and expenditure data maps, which are quite useful during decision-making processes.

3.7 DSS Structure and NTN's protocol to set its prioritisation

The implementation of a DSS structural framework often involves navigating complex constraints to ensure the system operates effectively within the defined parameters. A critical step in this process is determining how the system should optimize conflicting variables based on particular set of rules specified by the administrator. For instance, constraints such as maintaining minimum stock levels while simultaneously minimizing costs can create contradictions that the support system is bound to process on one way or another. Often before the system is fully operational, administrators are required to resolve these conflicts manually by setting manual protocols (Rudd 345-346).

Let us understand all this through external examples of the way administrators choose how the system would optimise given constraints. Let us go about this process through a particular illustration where a set of constraints are given on minimum stock levels for certain products and the system is prompted to optimize conflicting variables such as cost reduction algorithms, in this case the DSS will flag the command as contradictory and the administrator must manually set the protocol. This must be done with all the contradictions of the system before it launches (Rudd 2000).

Chedid gives us an objective example about this since on the new DSS system, their administrator did indeed set a rule that required a user to flag the row when a part is out of stock. The written protocol says that a replacement part must always have at least 50 units available in each pertinent product range of the warehouse, then the system would distribute inventory to meet this constraint while minimizing overall holding costs and, if it conflicts, the system has to point out an error. If the error is not pointed out then the DSS must be finessed and tested again.

Furthermore, when the system performs a Cross-docking function the protocol pertains to the DSS functionality that attempts to give the user a purchasing mix preventing the warehouse to have order overhead. In other words use as we order. The manager is responsible to set the parameters of the software with the intention of leveraging spending and usage (Rudd 2000). For this there has to be deep knowledge in the procurement flow by rationalizing the supply base. Cross-docking greatly helps accessing volume breakdowns and the cage assembly department of NTN Europe uses it daily.

Another instance where the administrator ought to set a command is when the system requires action criteria based on amount shipped: This focuses on using data to create a JIT (Just in Time) optimisation framework. This part of the software requires synergy with trader associates and partnerships so when users set constraints on shipping costs or delivery times, the DSS could optimize the selection of transportation lanes (Rudd 2000). To contextualise, whenever the cage assembly department of NTN is communicating with any stakeholder that handles logistics, the user must set constraints to keep shipping costs below a certain threshold while ensuring delivery within a set amount of days and a set amount of price, the DSS would ideally be set by the user to select the most cost-effective transportation lanes that meet the criteria. From this process managers can accrue data about the communication between the logistics adoption system in the form of transportation and expenditure data across the process. If this is not met then an automatic cancel-order protocol can be set within the DSS.

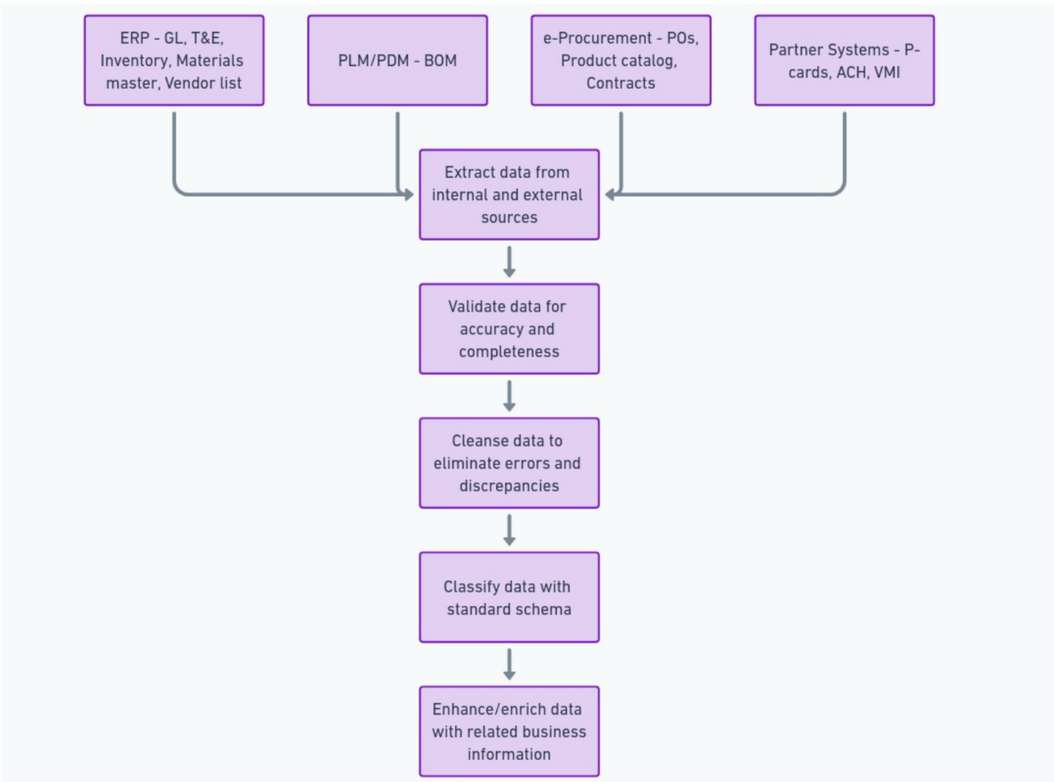


Figure 10. DSS Data Processing Workflow Logic and Process Breakdown (Rudd 2000)

Lastly, when the system sets pickup routes and purchase batching: Basically setting the DSS to estimate the order interval. This process follows Lean Six Sigma principles to reduce order redundancy and cut expenditures coming from wasted orders. The software uses quantitative data and Lean qualitative principles to set constraints pertaining order processing efficiency. For the order interval estimation the DSS system follows a MIN protocol to optimize order batching to meet these constraints (Rudd 2000). For instance, if a constraint were set to process when a part is running out, the system would then optimize order batching and picking routes to meet these targets.

Alternatively, when the system is set to define the labour costs in function to the operational costs the administrator is entitled to create a function that sets process requirements where all the subtleties of costs are reflected. Most of these subtleties are adopted by creating a time/salary data map. When managers set the labour function as a constraint on for instance storage capacity or spatial product allocation, the system could optimize warehouse space utilization (Rudd 2000). For example, if a constraint is set that certain products must be stored together for efficient picking, the system would optimize the storage layout to meet this requirement while maximizing overall space utilization.

3.8 Managerial Benchmarks and Regulations Expected from DSS

As a manager there are certain key benchmarks strived for the successful implementation of a tailored data system and these can be extrapolated to this particular case study in the following manner: During NTN's DSS update there were cost reduction KPIs which were more easily monitored by utilizing Infor WMS's advanced algorithms for inventory optimization across all production sites. As a general rule, as managers leverage their knowledge against the DSS cross-docking strategies, they are able to make more educated decisions throughout the transportation management pipeline. From this, better shipping routes and shipment consolidation protocols can be expected.

Other types of cost reduction can be inferred from the fact that managers have a real-time tracking capability tool at their whim (Riegler 2017). This enables them to monitor KPIs such as delivery efficiency, delivery deadlines, production quotas, delivery overhead and material usage given set contractual terms. Managers can count on these tools to ensure regulations are being complied within the department. Through this, managers can track elements such as item quality, laboral procedures, serial numbers, machinery protocols and expiration dates for each component in the assembly process (Riegler 2017). This detailed tracking enables NTN's cage assembly auditors to study processes and scrutinise them against regulatory laws pertinent to the process, some general laws that apply to all manufacturing syndicates in Europe are the following:

Health and Safety at Work (HSW Act) Particularly the Section 6 has a myriad of articles that restrains the use of certain substances in the manufacturing environments (Riegler 2017). The law covers general health obligations on the department.

European 2008 Machine Safety Regulations and Supply, which covers standard guidelines of safe machine operation and design. Mandates technical file compiling and conformity for each machine marking. This regulation requires machines to have comprehensive instructions in English, German and French. Enforces CE marking on product (or UKCA marking post-Brexit) when the products are placed on EU markets (Riegler 2017).

Directive 2006/42/EC (now repealed by the 2024/1230 revision), which is an electrical equipment health and service conformity procedure (Riegler 2017). It applies to electricity-supported equipment and gives a depiction on the voltage and intensity limit per hour based on machine size.

ISO 9001 Quality Management System standards instruct certain conformity assessment procedures to be followed by manufacturers. For certain categories of machinery, this regulatory procedure may involve third-party assessment (Riegler 204). It provides assembly standards for construction management.

ISO 45001 Occupational Health and Safety standards, which places general occupational health obligations pertaining to the work environment. Managers must carry out assiduous risk assessments for all active machinery. Machinery must be serviced taking into account the results of the assessment (Riegler 2017).

UKCA & EU Environmental Conformity Assessment Act. These are regulations required for products placed on the market in Europe and Great Britain. Regulations include Environmental conventions including waste control and emissions limits. REACH protocols (Registration, Evaluation, Authorisation and Restriction of Chemicals) if any part of the manufacturing process involves chemical substances. RoHS Directive (Restriction of Hazardous Substances), which pertains to products containing electrical hazardous substances or unstable electronic components. In terms of waste processing regulations it includes the Waste Electrical and Electronic Equipment (WEEE) Directive (Riegler 2017). This directive is applicable to the final stages of electrical manufacturing waste.

Chedid describes the regulatory rules followed at NTN's cage assembly department as standardised. They use Infor WMS's traceability features to comply with regulations like the French laws of *Prévention des pollutions, des risques et des nuisances* (Articles L501-1 à L597-46). The department has sequential data repositories set to track processes, part batches, serial numbers, and quality quotient for components they use in the cage assembly process. This detailed tracking enables managers to perform mock recalls in under 4 hours (Riegler 2017).

Lastly, Chedid contrast this to previous operational manual processes that used to take days. He points the significant improvement coming from having adopted the update as he compares both approaches. He further states that the department now integrates WMS with their existing DSS system using an API, which updates through intranet so they get real-time security threats involving machinery and processes. The live-feed aspect of this setup greatly improves health and safety across the board. Chedid also points that these analytics tools have one particular feature called ABC inventory analysis, which identifies slow moving machinery.

How it works is that the current process time is compared with historical process times and the ABC analysis will report any incongruence. So if this is applied to the assembly pipeline, process managers can detect suboptimal machinery protocols.

3.9 Research Findings

This case study has revealed how the implementation of a tailored Decision Support System has had positive and negative impacts in Chedid's department. We firstly observed how by integrating Infor Warehouse Management System (WMS) algorithms with real-time tracking capabilities, NTN streamlined inventory optimization, enhanced decision-making, and adhered to stringent European manufacturing regulations, making the updated application useful in this respect. We also witnessed the transformative potential of data-driven systems in industrial operations within the micro machining context when aligned with strategic benchmarks and regulatory frameworks in the following manners:

NTN did achieve noticeable cost savings at the moment of integrating Infor WMS's advanced algorithms within their new DSS. Inventory optimization became a key driver of efficiency and was thoroughly scrutinised, as real time tracking reduced data discrepancies. Additionally, the use of cross-docking strategies set by the updated DSS improved shipment analysis consolidation and optimized transportation pipelines, and this was verifiable through NTN's public data.

Another improvement came through the updated ABC inventory analysis, which identified setups within machinery and enriched them using NTN's current and historical process times. This allowed the cage assembly department to proactively address inefficiencies in the department's assembly pipeline. So we can set as finding that these measures collectively enhanced the NTN's ability to manage procurement budgets while maintaining operational dexterity.

The integration of DSS with Infor WMS was also instrumental to carry departmental operations in adherence with the increased demand they experienced.

Particularly, the system's traceability features allowed NTN to track part batches, serial numbers, and quality quotients in manufacturing components apprehended on a per order basis within the cage assembly process. This enabled the company to perform mock recalls in less than four hours as Chedid states. This is a significant and measurable improvement compared to the days it previously took with the old system.

Also, the updated function set to monitor operation protocols holds compliance with health and safety regulations coming from the previously mentioned Health and Safety at Work Act (HSW Act). We observed how the new system is set to facilitate adherence to environmental directives like REACH and RoHS by tracking chemical usage and hazardous substances throughout the manufacturing process (Riegler 2017). This automated approach not only is bound to reduce faulty operations that would go against compliance violations but also helps to minimize administrative burden altogether because the information is more widely available to managers and auditors to scrutinise.

All this proves that integration of multiple analytics tools brought about by an updated DSS into NTN's operations enhances efficiency across multiple domains. Thank to this, managers got to harness very specific key performance indicators such as distribution goals, general deadlines, quotas from the quarter, machining procedures, among others. For example, the system automated technical file compilation and ensured multilingual instructions for machine safety compliance under EU Machine Safety Regulations. It also embedded quality management protocols aligned with ISO 9001 standards into its workflows, helping auditors be more involved in the daily flow of operations within the cage assembly department.

Finally, the new DSS contributed in the process of aligning order obligations with the departmental operational force. Particularly the system's API driven intranet integration set in place to optimise machining response times. Additionally, the updated Infor WMS's capacity to compare historical and current process times allowed process engineers to detect suboptimal machinery protocols almost automatically and address inefficiencies before they escalated into larger issues. These improvements provide real proof of the importance of setting an advanced data system on a department that is faced with a demand spike.

4 RESULTS, RESOLUTIONS AND THEORETICAL DERIVATIONS

We have contextualised the consequences and concerns of implementing a DSS through NTN's case study and from it we can gather particular decisions, which will benefit NTN through the 2022/2023-transition context.

Firstly, in Chapter 3 we have reviewed in detail how exactly Chedid's branch was challenged with rapid growth due to the increase of demand of SENTINEL ONE. We saw how the company upgraded its DSS in that environment with the hope of handling the operations overhaul and the hardships brought about by their sudden increased demand in production. From what was observable throughout this transition and scrutinised in Chapter 3, we gather the following inferences.

4.1 Case Study Core: NTN's operational challenges during DSS Transition process

(A) The new DSS improved data categorization and validation efficiency on its late stage of operation. This enhancement in data management directly contributed to the 71% operational increase experienced in Chedid's department by ensuring that the system could handle the surplus. Transitioning helped categorise data and this statement is backed by a general consensus of users, which was thoroughly settled in the previous chapter, the premises hold that data was simply managed more efficiently. The consensus indicated that user improved data quality and accessibility played a significant role in enabling them to handle increased demand for SENTINEL ONE bearings aswell as the production of additional parts for other product lines.

The implementation of the new DSS also facilitated better assessment of expansion viability. Chedid states that the system "helped expand operations as the more knowledge the company has about production, the better it can assess the viability of expansion." This corroborates *H2: There is a positive relationship between efficiently implementing advanced data systems and operational efficiency* *within the environment to which the system operates*. This further suggests that the new DSS provided value that is directly traced to the department’s ability to engage in better operation practice when it comes to scaling up production. This must of course be leveraged against the expenses of setting up the system in the first place.

Furthermore, the transition period gauges NTN's ability to adopt the system across departments. It also indicates that the implementation process was carefully managed to ensure optimal integration and efficiency gains. For these reasons it can be stated that in this case, this systematic implementation approach likely contributed to the significant improvements in operational efficiency.

(B) The case made it clear that the main challenge of implementing a new DSS is to make it reach a certain level of functionality. This observation is backed by the cyclical nature of DSS implementation and gives good ground to deem the Implementation Cycle as relevant. We first observed in Chapter 3 that the early stages of implementing a DSS are the most laborious ones and it takes up to 6 months to complete. We gathered from our theoretical framework that for system engineers, the effective homogenization and transfer of data measures success. We also gathered that 60% of the system engineer's time would be spent in normalizing data into usable and transferable data. Through this we can safely state that there is indeed a wide gap within operations where the new system remains idle and suboptimal.

These premises lead us to infer that for system engineers, success is tightened to timeframes, the efficiency of the transition process, compatibility of the data storage protocol and its alignment with the user needs. This supports *H1: The execution of Decision Support Systems is bound to an implementation cycle and each decision within the cycle impacts the efficiency of the system based on different criteria which will directly influence its success rate, the measurement of that success rate is subject to the stakeholder (the user, the system administrator, clients, managers, database engineer, etc.).* It is pivotal that we also point the distinction of different stakeholder's points of view since for department managers and users, success would be measured by their personal needs, how well is the system aligned with their daily activities and ease of use, but for auditors success is measured by data accessibility and transparency.

The point of view of each stakeholder when it comes to benchmarking the implementation cycle is further stressed by the way the department allocates resources to build their data management network. We now have a clear understanding how failing to do so lead to significant information mismatches and reduced system efficiency. From these premises we can state that the success of the creation of a resourceful data network based on the needs of the department directly affects design usability and user experience.

(C) We further examine the WMS (Warehouse Management Systems) i.e. systems set specifically set in place for warehousing operations & DSS integration process to corroborate that *(H3): The implementation of an integrated DSS with third party functionalities such as Cross Docking and WMS significantly improves procurement efficiency by optimizing the capabilities the system has to optimise operational efficiency through harnessing better communication and data management.* At the time NTN's bearing product line expanded, managers leveraged the old system with WMS to create a new DSS and optimize their procurement process. This was done as explained in the previous chapter by connecting the DSS with a localized WMS that supports RFID (Radio-frequency identification) technology, which is quite a common approach to classify inventory. By achieving this, NTN created a powerful tool for tracking daily procurement operations in their cage assembly branch that was easy to query for any user, including customers. This was a great choice because RFID is a universal language, which is very compatible.

The integration itself allowed efficient classification and management of a wide range of data inputs, including query of supplier information, third party production orders, general scheduling, raw material levels and general IoT data from the production floor. The system's ability to enrich extracted data with additional addons, such as order drivers can further be treated to make a case that WMS validation greatly ensures accuracy in processing orders, thereby improving overall across the board data reliability (Hompel et al 2007).

The theoretical framework gave good grounding to ensure that cross docking within DSSs holds a crucial role in optimizing the purchasing mix and preventing warehouse order overhead, as it allows managers to leverage resources effectively. The theoretical framework demonstrated aswell how the integration of Cross Docking with DSS can significantly enhance procurement efficiency. It is worth adding that the system's ability to optimize JIT operations further supports the hypothesis since, by setting constraints on shipping costs and delivery times, the DSS can optimize the selection of transportation lanes. These 4 inferences all validate H3.

(D) We can set the WMS implementation dynamics exposed on chapter three to support H2 aswell since it corroborated a direct link between enhancing the data system and usage improvement. The case demonstrates this by pointing the advantages of integrating the DSS with cross docking strategies to make more educated decisions within the transportation management pipeline. The case study made it observable that this has had positive results in choosing better shipping routes through shipment consolidation protocols, directly improving NTN’s logistics and transportation pipeline in terms of data communication.

Furthermore, real time tracking capabilities provided by Infor has enabled managers to monitor performance indicators such as delivery-time, production quotas reached, and target usage of materials. Therefore it can be established with a moderate level of confidence that in cases related to this industry and perhaps others, Infor WMS visibility significantly improves a department’s ability to manage operations better and oversight compliance of third parties (Hompel 2007). The detailed tracking capabilities of the implemented systems clearly allowed NTN to monitor operations more efficiently.

The case further reports that the integration of Infor WMS with NTN's API enabled a consistent security threat monitoring that is updated in real time. This level of control and visibility supports H2 since directly contributes to improved operational efficiency. It also enables NTN to have agency on system security. Its ABC inventory analysis feature further helps identify slow moving machinery since it is applied not just to inventory type, but to performance as well (Hompel et al 2007).

As Chedid points out, this analytical tool has a particular feature that identifies machinery that is functioning sub-optimally. This application of ABC analysis to machinery performance further supports H2 aswell since NTN can prioritize its maintenance and optimization efforts through it. Processes categorized within “A ranking” would be those critical to the production process and even small inefficiencies could have a significant impact on the overall yield of the process. These would receive the most attention and resources. Subsequent rankings within the system imply that the process might be important but less critical. Lastly, the use of Infor WMS's traceability features to comply with French environmental laws and the ability to perform mock recalls in under 4 hours (compared to days with previous manual processes) further backs H2.

4.2 Objective Resolutions: enhancing DSS layout through SCOR modelling in Chedid's Team's 2022-2023 Transition

Given that Chedid’s team faced operations overhaul from the increase in process demand in 2023, their department embarked on a diligent mission of improving their DSS layout. This process can be scrutinised through building a SCOR model (Supply Chain Operations Reference), a common benchmark framework for supply chain management, within their DSS framework that works as a methodology to scrutinize problems and project constraints based on specific set problem statements. To withstand these challenges, the following measures are advisable for the 2022-2023 transition:

(1) During transition the system specialist should focus on integrating old DSS processes to their DSS mapping since their department started to communicate with 15 new suppliers and 10 new manufacturing partners at the time, the ideal undertaking was to create a single data resource for all suppliers and manufacturing companies. This was easy for the most part if the suppliers were using SAP or SAP compatible software, which they were. Having individual information on procedures helped optimise negotiations and check contracts across business units. This was instrumental not only to track expenditure analysis, but also to compare manufacturing policies between partners to assess risk.

(2) Managers should focus on the mapping, tracing, development, building, delivering, controlling process described in Chapter 3 and enable driver installation permissions to the current DSS layout. In here the SCOR framework can be used as a guide to follow when setting the requirements of expanding the DSS structure (Ozbiltekin-Pala et al. 2023). This part must define each element of the expansion in detail, it must identify the amended points of input and output for each variable and link processes internally in the department supply chain pipeline.

Chedid states that in this stage of their expansion process they did require a systems engineer who took the role of advising since this sort of integration, specifically in the procurement side of operation is very delicate when it comes to integrating internal procurement data collections. He added that the system engineer set a test pilot system after he aided with the integration of the updated elements, so the department was getting consistent internal feedback from the consultant. The test pilot review lasted 3 months.

(3) Managers must set performance metrics to fulfil 2021 challenges' requirements. These are objective metrics of what needs to change to withstand the intensification of operations. These metrics are for instance machine-hours metrics, order fulfilment cycles, inventory days metrics, overhead metrics, set-up costs metrics and other capacity metrics concerning the department itself. When the

DSS is updated it will provide a database standard measurement of the new metrics through data analysis tools (Ozbiltekin-Pala et al. 2023).

This measurement is key to the department's ability to handle manufacturing execution requirements aswell as warehouse management requirements while keeping quality management protocols in line. It also helps the user objectively understand what suppliers are bringing to the table and how contracts will actually be reflected in operations. Most application of these metrics can be integrated through automation using ETL (which stands for Extract, Transform & Load) processing (Tao et al. 2012). This is a generalised term used to depict the process of adding new data into the data warehouse of the DSS through its repository lines. This integration is conducted through APIs (Application Programming Interface) within SAP REST Field-Grass API and it either can be set as inbound data or outbound data (Tao et al. 2012). An API is basically any software set in place for a specific purpose and interface is the front end of that application. In this context of API, the user has to specify the database where the inbound/outbound data is coming from and the software will unpack it.

(4) The system specialist should sync databases with old and new suppliers though Minitab. The integration process that NTN should use is fairly straightforward: the department has a storage server in the cloud and another in premise. To integrate with new suppliers, NTN should engage only with the Cloud EDGE computing protocols to share information with the supplier separate from their core backend. In other words there is no risk of data leakage through this process. Minitab can be embedded in any SAP S4 HANA stack (Hardy et al. 2004).

The advantage of this solution is that integration does not compromise the company's database because the output is extracted as an ABAP amenity (Advance Business Application Programming) and exposed as REST API through Representational State Transfer (Hardy et al. 2004). Operationally speaking, this is the best way to conduct automated integration while keeping drill up data requisition capabilities and it can be applied to legacy systems, databases, ERPs and CRMs.

4.2.1 Feasibility study prior updating their DSS from ECC to S/4 HANA. Layout of implementation

The particular SAP version NTN transitioned to is S4 CORE106. In light of NTN’s cage assembly department expansion in 2021, it is clear that new manufacturing needs brought forth parallel lines of business as the new demand required new provision. These LOBs (Lines of Business) were a requisite to compete on an operational level and attain decision-making improvement. The cage assembly division is a high-priority branch of NTN's production line since other departments depend on their operations. Hence the requirement to fit new LOBs coming from other departments to this expansion. The main intention for transitioning to S4 CORE106 is to update the operation flow and include new LOBs while harnessing the need for real-time system asset update. Prior to executing the DSS, NTN's management department tested it.

We start by analysing the stakeholders affected by the transition, aswell as the changes within the specific areas of decision-making in the department from the perspective of the managers and the general users (Ozbiltekin-Pala 2023). Primary users include production managers, assembly line workers, precision manufacturing engineers, industrial engineers, lean specialists, quality control personnel, and supply chain experts. Next, technical feasibility was conducted by checking if InforWMS is compatible with its predecessor. There is a need to assess the best system for data transferability but since ECC and S4 CORE106 are both from SAP there is automatic green light there (Hompel et al 2007).

After that, the Enterprise Server should be able to entertain the needs of any middle-sized production department and be fully compatible with its internal port. If these measures are followed it can be safely stated that the projected ROI, boasted by better system efficiencies in the cage assembly operations should be positive. The efficient application of these measures is therefore directly reflected in the cost benefits from inventory management and production planning.

When assessing the efficiency of the new DSS the main benchmarks to take into consideration are the system's reach, its compatibility and its accuracy. This can be quantitatively measured through comparing operation flows before and after implementation (Douglass & Euske 2008). Since this happened in 2021 we have enough feedback to draw that after implementation there was optimized data management and more resource allocation efficiency. The implementation can also be qualitatively measured since there was visible improved production efficiency, enhanced departmental ability to respond to market demands and greater ability to respond to supply chain disruptions.

These variables can be linked to indirect drivers such as user adaptation protocols and project implementation methodology. More specifically, the project implementation methodology will shape elements such as user adaptability and user approval, both key considerations when replacing an old DSS system with a new one (Ozbiltekin-Pala 2023). Chedid explained that NTN's technique for users to comply with the proposed system update involved a transition program, which encompassed managers, systems engineers and the users. The mission statement of the transition project was to attain a smooth shift that involved all stakeholders and prioritised the synchronization of data and comfort of users.

Furthermore, it was also stated in chapter 3 that to ensure the updated DSS will actually suit the needs of a department, there were weekly surveys and interviews tethered to the update. This leads us to believe that the user perspective was important in shaping the DSS structure. It also backs the idea that the record of revamping the DSS is instrumental for keeping track of adoption rate, which is useful when guiding the project through the timeline.

4.2.2 Establishing a project timeline through Lifecycle to enhance NTN's decision-making process

Chapter 3 gave a clear understanding that the lifecycle of NTN's old ECC system was fairly short since their old DSS only lasted 4 years, this is a good starting point to set the premise that DSSs evolve fairly fast, however many elements of old versions persist through updates, specially within special purpose manufacturing industries since operations are tightened to standardised protocols. These protocols are tightened to standard operating procedures since industry policies rest in old building blocks.

To give more context to this let us set some concrete examples how this is applicable to operation management at NTN. To oversight operations in the cage assembly department, the company implemented a system that handles technical processes remotely so line workers and engineers can assist with troubleshooting and provide support to tasks even if they are not present. It also helps override a task that is set automatically but should not be performed in a specific scenario.

This system requires a set of protocols that must be developed from scratch; a central issue arises concerning how much a company should commit on implementing a specific support system. In this particular case the company made a decision to connect the updated DSS with this function and include this integration within the project timeline. Needless to say, the particular integration required the department to expand its project timeline and acquire a greater knowledge base through hardware.

This gives us insight that an important metric to measure relevance of implemented lifecycle liabilities is whether the company will establish a set up from scratch or buy one already built. When a company decides to implement manufactured hardware or elements for the back end servers, it is usually where most of the capital will be allocated. For NTN's case the end justified the means.

Concerning the software itself, which in the case study is S4 CORE106, the advantages of this particular packaged application can be traced through distinct decisions the company took: NTN bought a customizable prebuilt solution from vendors and thus saved the cost of in house development. Secondly, the installation only took a month and an implementation that occurs very rapidly is quite attractive for precision manufacturing departments. This is so since time required fulfilling orders and providing value is crucial. Also, settling for a package solution can lessen the risks when other stakeholders face opposition for IT deployment orders (Blokdijk 2002). In the event of any hardships during setup, managers should be able to exercise their agency as long as the scrutiny does not affect development activities and there is consensus in how the software is being customised.

At the same time, the appeal of pre-packed solutions should be digested with caution since there are intrinsic disadvantages pre programmed packages posses: a major consideration is whether a pre-built package can handle the specificity a cage assembly department requires. Bearing production is highly complex and sometimes a solution that meets the problems of high engineering supply chain comes a high level of customisation (Sharma et al. 2014). This however was not the case in this specific package update since Chedid assures that there was not a great amount of customising required. He confesses that software engineers spend a much higher portion of their time in connecting the API of S4 CORE106 with participants outside the company such as suppliers and customers.

Another factor that contributed in making implementation successful during transition was the fact that the old DSS was compatible with Microsoft Cloud. When companies have access to the same software, they might miss competitive edge but they gain advantage when it comes to communication channels (Richards & Grinsted 2013). It can be gathered that choosing S4 CORE106 as software model posed a great benefit to NTN since they acquired a system that was highly compatible and moderately flexible on the custom development flank.

The core106 version had a layout which was close to being a perfect fit for expanding cage production operations, their edge over other setups relied on the nature of the decision of implementing this update because it increased productivity across the board. This DSS can thus be framed as an update conceived to handle NTN's future growth through creating solutions that focus on satisfying scalability and flexibility needs. The series of decisions made in the year 2021 following the increase of demand for the department were set to satisfy the short term, mostly because this was a medium scale software development project.

4.2.3 Creating a desired Customisation protocol given Chedid’s department condition in 2022

Let us now find the best customisation mix for S4 CORE106 to maximise the program yield during the transition process based on the set case study. It is already established that this particular DSS application is packaged and only a certain amount of customisation can take place within the confines of the software. This stance relies on the tested framework SAP is so famous for and NTN doubtlessly rejoiced of its cost effective nature. This is a software package ready for commercial use while allowing catering of particular components specific to NTN's special conditions.

The customization itself adds specificity for a department’s production scheduling within the MRP module, for the way the department communicates with other stakeholders within the DSS ecosystem and for engineering protocols within manufacturing execution. This setup allows operations to be conducted following three data pipelines depending on their data management need, namely intranet, cloud storage and a mixed setup (Richards & Grinsted 2013). Intranet development allows NTN to have a more personalized control over operations and be able to handle the knowledge of its own operations locally. Cloud storage offers increased efficiency because data sharing is held real time and communication is experienced through the lenses of scalability.

There are also some disadvantages that come with a partially customised solution such as security and privacy risks. With this particular S4 CORE106 setup NTN has less control over their data since the company is not fully capable of managing system security locally, however the company would be saving money since the hybrid setup requires only a certain degree of internal expertise along with SAP outsourced activities.

This setup delivers a mix of localised and cloud technology. Going for this choice gives NTN a relatively inexpensive solution with a well edited framework based and developed by expert SAP designers. This choice reflects a strategic decision to leverage a commercially ready software package while still allowing for some degree of internal customization from the front end that meets the department's specific requirements.

Let us call this setup "hybrid" and, as observed in Chapter 3, this approach comes with potential security and privacy risks. NTN's reduced control over data in the cloud environment sets a limit on the DSS's ability to manage system security locally. This is a common concern with cloud-based solutions. The hybrid setup, combines internal protocols with outsourcing SAAS solutions and mix localized and cloud technology. This combination comes from the protocol of hybrid multicloud data storage, which aims to combine the attributes of on-premise and external cloud resources (Richards & Grinsted 2013). The hybrid setup allows NTN to leverage the benefits of both local and cloud-based systems while mitigating some of the risks associated with a purely cloud-based solution. We must keep in mind that the implementation of a hybrid cloud solution can introduce complexity in terms of keeping the integrity of important data and making the system compatible within itself and externally.

4.2.4 Setting an SDLC to oversight NTN's system transition

Transitioning to a managerial outlook, the decision of NTN to do this upgrade requires that management within the department is sure the new software is actually instrumental to make better assessments. For this they must gauge whether S4 CORE106 delivers reliable data analysis post implementation and this can be scrutinised by finding discrepancies between data predictions. Specifically whether the standard deviation of return increases or decreases. If it decreases it means the update gives more reliable analysis. The data is curated by with setting a SDLC benchmark in the department, which will be explained later in this subsection.

In principle, the update is set to increase the computing power of the department so managers can perform better data analysis. Managers and therefore other workers can use their time more efficiently pursuing relevant tasks. Along with a well-structured chain of commands within the department, the enhanced handling of direct provision the software brings to the table is a primary leverage point for meeting KPIs. The most reliable waterfall model to analyse feasibility in this particular scenario is to develop a Software Development Life Cycle, SDLC in short. This is a benchmark method that divides the development process in the following stages: enterprise goal requirements, systems analysis, system design, core programming, core implementation, usage, testing protocols and evaluation protocols (Burtonshaw-Gunn 2019). After finishing a step, the manager can subsequently deploy the next.

The first stages are divided into a series of quantitative protocols: scrutinising user requirements, system design, programming conventions, test plans, input and output element analysis (Burtonshaw-Gunn 2019). We will not dwell in the specific of each protocol since it would be more useful to focus this section on the technical stages. It can however be said that these series of evaluations are implemented in a structured manner and are validated by both prospective end users and the developer of the system.

Pertaining the more advanced stages, implementing technical SDLC stages to the particular case of NTN's cage assembly department consists in going through a thorough process of testing each required element and documenting results. For system requirements, S4 CORE106 uses the ABAP RESTFUL programming model while the company’s old support system (ECC) used ABAP Traditional. S4 CORE106 also requires a working Data frame for backend functions while ECC does not. Also, S4 CORE106 requires CDS (Core Data Service) while ECC does not (Zaidi 2019).

By putting this method into practice we gather necessary information about the back end requirements and tether our decision-making from it. Furthermore S4 CORE106 has specific front-end requirements that every computer must meet in the department, specifically that S4 CORE106 needs much more memory (32+ GB vs 6 GB for ECC), S4 CORE106 typically requires terabytes of Disk Space vs. gigabytes for ECC, in terms of processor, S4 CORE106 needs a more powerful multi core processor and finally S4 CORE106 runs on fewer operating systems so some workers might need to update their OS (Zaidi 2019). ECC was good enough for the amount of data the department was processing prior 2021 but as production increased and there where process bottlenecks, investing in a more robust system made perfect sense. The value proposition of implementing the new system outweighed the software and hardware expenditure by a considerable amount.

Measuring requirements entails counting on the participation of all possible users, from production managers to line workers. This process is comparable to the Pure-Power PW1000G testing protocol from Airbus and follows a comprehensive examination of the department's demands on a micro level and engages all potential users through active communication. This sort of scrutiny is held to identify particular problems raised during project execution and reporting it when they do not align to the department’s operational objectives (Perra 2008). In NTN's case, this should be conducive to a regulated and more predictable development process with clear milestones and deliverables.

The project manager has the duty of requiring documentation and approval at each stage, specially within the project milestones tightened to their formal contractual constraints. Chedid states that in the case of NTN’s particular project, they signed a standard outsourcing project with a third party software implementation company where some elements of the SDLS were already stipulated within the contract. This led the implementation to rely on a functioning reference that arbitrates any sort of dispute. Chedid confesses that some of the contractual restrictions did present problems during the DSS development; the project however was successfully completed after bending some transient parts of the contract. This was possible since all parties involved in contractual disputes concluded the priority was to implement a support system that enhances department processes, communication with suppliers and their relationship with customers through technology.

The case study made it clear that, after project implementation was conducted, there was a general impression drawn by Chedid, which ensured that improving the reach of the department's DSS opens the possibility of revamping the entire development cycle. At that point, NTN's mid tier management was in the process of refreshing some operational structures right from the start.

The timing was perfect since the new DSS brought about incremental development across the board as lines of communication were more powerful in terms of meeting needs and processes. S4 CORE106 welcomed a more flexible approach to communication through automation and its impact has been corroborated company wide. For instance, one of the hands-on requirements one would expect from such systems is that it allows users to give feedback concerning permissions available or unavailable to them within their interface (Schwabish 2021).

From all these premises, we can settle that migrating from ECC shed light upon the impossibility of mid tier employees to effectively query data or to even adjust to changes in the manufacturing processes based on their level of clearance. A full system overhaul was ultimately what was needed to address that issue. It can be therefore stated that this approach was perfect to facilitate closer collaboration between managers and the rest of the team, proving that real life interaction is required to ensure the final product actually works as intended.

4.2.5 Setting advanced prototyping techniques to support implementation

Another function imperative to benchmark adaptability is through prototyping. To implement an appropriate condition testing prototype through internal flow control statement protocols in NTN's particular precision manufacturing environment the following tickers need to be checked: the system's engineer must install Eclipse IDE parallel to the previous DSS, then they can construct the series of ABAP development tools plugins as a mirror and make a scape-goat HANA system within it. Through this technique the engineer can set up Cloud Connector for Core106 for secure connectivity between on-premise systems and the cloud platform without disrupting the ECC version running in the foreground (Keller et al. 2014).

Eclipse IDE is the layout of the entire prototype system for NTN, system engineers can use Eclipse IDE to manage holistically the information flow behind the upgrade since it is a modern network design for the sort of architectural model the department is trying to implement, one based in machine learning training. The Eclipse Modelling layout makes it possible to design how the DSS will look like in terms of domain model. This canvass will become the cage assembly department's DSS working software.

This sort of prototyping helps the engineer understand the project requirements and challenges by actually developing and testing the system through an initial DSS prototype. It then goes on to iterate the prototype itself through changing the prototype framework until a working version is apparent. The prototype is finessed through pilot testing and implementation which can be done in phases or full-scale (Pegiel 2021). This approach is very dynamic and its main advantage lies in its pragmatism.

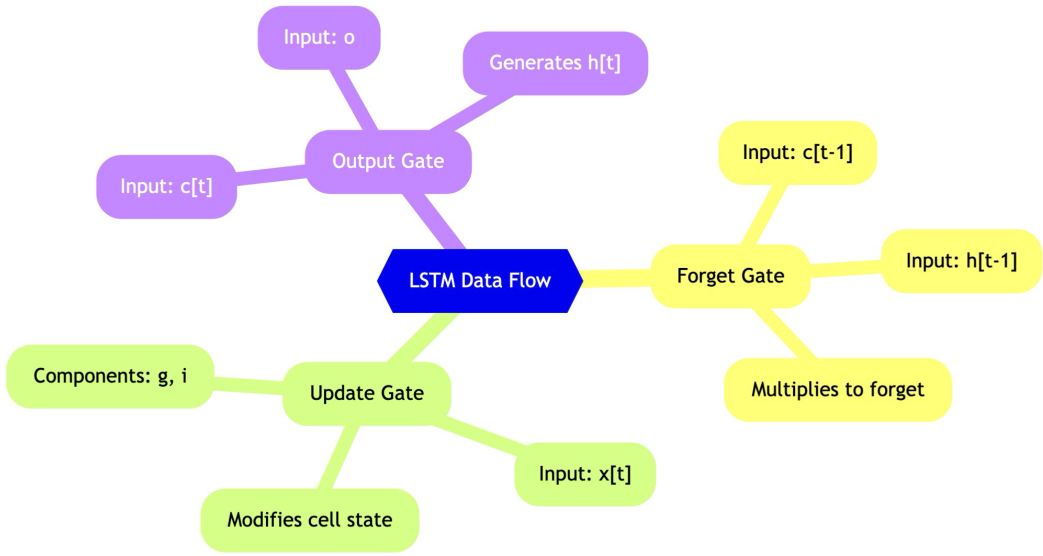


Figure 11. LSTM Data Flow Protocol and Data Categorization Breakdown (Pegiel 2021)

The prototype is confined within an LSTM model compilation, which permits both systems to share the embedding layer that process categorical data (Pegiel 2021). To define this term, Long Short-Term Memory (LSTM) is a type of recurrent neural network architecture which is created to model sequences that are short term and temporal in an accurate way. LSTM networks use memory cells and gating mechanisms based in input, output, and gate sequences to control the flow of information, this is done with the purpose of retaining relevant information over extended timeframes and address the vanishing gradient problem that limits standard methods of storing information (Sak 2014).

The point of all this is to rest the prototype on a sequential model that gathers data from a synced feeding mechanism. This should help the software engineer point out demonstrable features and scrutinise them. Although the first prototype may not directly deal with abstract problems like access to databases or mirror extensive systems, it would at least train and validate the future alpha of the software that will be implemented through interaction and feedback.

Objectively, LSTM aids the department analyse activity data which would include machine routines, decision system prioritisation and order processing by carefully making the selection of categorical details like product codes or machine IDs into numerical formats the prototype should intake, the rest is disposed as inconsequential data therefore saving capacity. the model identifies patterns in past orders. For example, it learns that certain machines require maintenance every 90 days or that specific bearing designs take longer to assemble during peak seasons. This allows the system to predict potential delays and give engineers a proactive tool to optimize schedules.

In the case of NTN, the hands-on experience accrued from following this protocol will be crucial to the company. It will give them a chance to develop an API to interface an LSTM model created and trained by them with NTN's existing DSS execution system. The prototype then will become an alpha, management will respond to the system, stakeholders will analyse its features, and eventually approve within a certain confidence interval. This should be standard operating procedure at the time of the transition. Skipping parts as well as responding to necessary adjustments are the bases for future inclusion of contingent elements.

The Rapid Application Prototyping (RAP) approach would seem to work particularly well on NTN’s cage assembly department since it correlates with precision manufacturing technical needs. This approach suggests fast and parallel step-by-step prototyping through minimal data handling, since it is not the data acquisition process we are testing, but the support system itself (Mathew 489-491). This approach is relevant presuming NTN's particular precision manufacturing department conducts operations through Line Base Mode, which they most likely do considering the department handles an extensive data network between numerous stakeholders, where suppliers, clients and production processes are deeply interconnected.

Positioning Rapid Application Prototyping under the light of this particular project allows the software engineer to test new specification components in a timely manner by ignoring some data protocols and focusing in the end user visualisation of the prototype, which is the driver affecting user experience the most. Updating a DSS implies the need to replace vestigial old specifications with simplified functions used in new technology. For example, receiving printing signal and prediction time series data can be improved by finessing the LSTM so it takes only relevant SequenceInput layers.

It can be stated that the process of Rapid App Prototyping enables a design to be shaped in real time after only a few minutes of designing. When the prototype has feedback from the user, the data engineer has a solid basis to move forward in the software design process (Tax et al. 2017). The prototype can be further pushed through the development cycle, or it could instantly replace the old DSS. In NTN's case the latter approach is a better choice not only because communication between the user and developer will keep shaping the DSS for a few weeks, but also since the later development steps are much more efficient when it is implemented. It would finally be worth to mention that NTN must be aware of pitfalls concerning implementation timeframes since rapid prototyping when improperly managed can lead to extended development schedules.

4.2.6 Directing the DSS transition process to give agency to the user

Based on NTN's contextualisation gathered from the previous points on this chapter, this last resolution takes the shape of a suggestion that presents an alternative approach to previously discussed traditional developer driven executions, since it focuses on end-user development. The End User Base resolution relies on setting up S4 CORE106 to give agency to people that worked with the previous DSS for years and know exactly what worked and what lacked from the previous system. This approach is relevant because the end user has innate ground experience of what the software brings, and what it lacks (Reji 2008).

Their input would be the main benchmark to harness a stronger DSS that has deep understanding of NTN's particular manufacturing processes and it would be reflected into the system's design. This method has an obvious advantage: the user who needs a particular functionality is the holder of the solution. This approach requires open channels between users and the engineering team and users have the right and duty to make immediate requests during the development process.

There evidently are disadvantages in this approach, namely that users, however literate they are in the field, are not experts in the best practices of software development, system testing, documentation, data security, and user interface design (Reji 2008). As DSS systems are quite complex, these shortcomings inevitably gain traction fast. In order to make the method of end-user DSS development implemented correctly and risks minimised, NTN should take a moderate approach. Ensuring collaboration between users and data engineers is an efficient way to keep vital procedures streamlining properly in terms of security, overall system's architecture and networking.

The goal is to let end users achieve what they propose while enforcing standardized protocols. The collaboration tool should be based in a workflow management SAAS addon for DSS migrating projects with a shared console specifically designed for cross functional communication. Either way there is no supreme approach to tackle a DSS transition, each approach is efficient in a case-by-case basis and, more often than not, a combination of approaches should be utilised to find the best path for the transition.

We can concretely state ways on how the user can benefit from this change. For instance, production line workers customising their own data dashboard to their own accord in a situation where the standard layout of the dashboard does not display useful input for him, such as machine downtime oversight for particular shifts. With the capabilities the updated DSS has, the production line worker can request and even configure himself a custom layout that tracks and visualizes whatever he requires in his every day processes. In terms of workflow automation gained through the system, changes can be made as well from the side of the end user. For instance, the warehouse staff realises that a pre-set function the DSS fails to automatically flag supply briefings that have been delayed by more than 15 hours. Through the new collaborative platform, they set an automation rule as follows: “If order status is marked as ‘pendant’ for >15 hours, send alert”. The rule would be automatically sent to moderation and accepted after review, all with minimal computing resources. All this to set straight that there is a great deal of agency gained from the new DSS.

Finally, it should be said that this community tool must include a way for users to suggest specific packages of data they would need to access in specific situations, for example if users are doing process mapping for supply chain orders then they should request access to the proposed tracked data through a build interface. This is a basic contribution procedure based workflow commonly used in departments and offices and is now extrapolated to DSS design. This design is specifically intended for system migration and improvement projects such as the one experienced in NTN. The platform would ideally include a shared interface for communication that is instated cross functionally. Making this possible would doubtlessly boost and better the potential for effective collaboration while finessing the system and make the department’s transition process more democratic.

5 FINAL THOUGHTS AND CONCLUSIONS

As a whole the direction of this work illustrated that a well thought out DSS implementation can give, as long as the right circumstances are set in place, particular advantages for departments that deal with precision manufacturing processes. Through our focal point based in NTN's case study we have been able to appreciate different real-life situations the cage assembly department was entangled with, when updating their new DSS to improve their data management and we have appreciated how these particular changes within the system were able to improve activities that require automation or have some level of repetition when integrating the new system with previous departmental set operational infrastructure.

We have also developed premises based on how these methodologies can be best applied to empower very specific dynamics set in place in the context of manufacturing and daily operations to respond effectively to set auditing regulatory requirements, increased demand in production and how to stay on top of the competition. The lessons drawn from NTN's experience offer valuable and applicable consulting advice which works and remain relevant in many contexts within the industry, for groups and individuals that want to use technology of this nature to enhance manufacturing operations.

5.1 Restating the Research Aim, Approach and Objectives

In terms of research aim we began the set of premises by situating the DSS framework within the bigger picture of the progression of manufacturing management, giving a historical context to the objectives to be pursued in an attempt to find the best possible uses of this technology to enhance activities within this very particular industry of precision machines and micro manufacturing. We also described how the manufacturing process for such an industry looks like in terms of its pipeline and its generic protocol based on regulation that is backed by industry wide ruling and legislation. We also did highlight how the advancement in terms of novelties originated within DSS technology has brought a clearer operational process to the way organizations handle and take advantage of data on a daily basis and make strategic decisions using the information accrued with help of the offered functions.

The insights gathered from the initial premises were then complemented in the project by giving it context with the installation process of the communication infrastructure brought by the Sentinel One bearing demand overhaul and their departmental needs to tighten operations in their production lines. We gave all the necessary arguments to state with confidence that the department's surge in demand led NTN's management to recognise the limitations of their legacy system, which was ECC, and we described their complex transition to the a advanced DSS, which in this case was the SAP S4 CORE106 platform. We set motives that lead us infer that this upgrade was technical change necessary to reach their scalability and data integration goals within their cage assembly timeline.

Taking a look at the transition process within this specific case study made us appreciate in a deeper level the conceptual groundwork of a semi-customised Decision Support System and setting the research objectives of this work. In terms of research objectives, we can state that they were set with the intention of giving a purpose to what these systems ought to accomplish in contemporaneity within this specific industry.

Specifically, the first objective aimed to compare the effectiveness of various DSS implementation approaches such as software development life cycle (SDLC), rapid prototyping, and end-user development to handle the changes and the requirements NTN was facing when optimizing their already complex cage assembly processes. Through this objective we evaluated and criticized the departmental decisions during the transition, measuring the impact of the new system on data categorization, validation, and the ability to meet increased production targets.

Another objective addressed in detail the dilemma of whether it is better to invest in pre-set DSS or customised DSS, for this we analysed all pertinent factors that influenced NTN's choice between developing a customized DSS and adopting a commercial solution. The thesis further aimed to benchmark the impact of the new DSS using key performance indicators such as equipment effectiveness, order fulfilment times, inventory optimization, and compliance with regulatory standards.

Based on these objectives the following questions had arisen: In what way do the operational challenges within a department ought to be studied to benchmark their data management needs? In what way should companies approach DSS development in terms of tailored customization? What is the aggregate impact of a company's ability to transition to a better DSS on both the short and long-term to improve their operational goals? And how can an implemented DSS be benchmarked to measure improvements across manufacturing, communication, supply chain, production parameter selection, and equipment scheduling? We then employed diverse techniques and methodologies to find answers to these questions, always finding context through real life applicable situations, which in our instance is through our detailed NTN's cage assembly department case study. The case study approach made it possible to have real life context through the objective exploration of these issues.

5.2 Summary of Key Findings

We answered each question stated previously through contextual analysis. The analysis demonstrated when read wholistically that the new DSS played a net positive role – when weighing the negatives with the positives, in enabling NTN to manage a 71% increase in output. We found that it was a good decision in the mid-term and the long term to upgrade the system because it was the only way the department could handle the data overhaul created by the situation they were facing.

The short-term stance did look dubious on paper and there was noice all around the department since such a big change brought about resistance from several stakeholders, but this was compensated by the enhanced accessibility to data that this new DSS provided to everybody, giving the department as a whole a tool that brought about more reliable communication and insights to operations.

Going for specifics, we deemed by answering the research question that the importance of a structured and stakeholder-centred implementation cycle was the way to go. The early stages of transition were complicated and tedious, since the new DSS required compatibility within the new system and external sources and a great deal of data cleaning, sorting and migrating. The research highlights that this departmental process brought about different measurements of conformity among different stakeholders: Mid-tier workers and engineers had a harder time integrating to the system before the first wave of customised updates were launched. Managers on the other hand adopted the system more smoothly since they saw the update as an enhanced data outlet that aligned with their operational needs. Then we have the auditor's perspective, for them adoption was also positive from the get-go since more data available means better auditing scrutiny for regulatory compliance.

Then we examined the nature of the integration of the DSS with Infor Warehouse Management System (WMS) and third-party functionalities such as RFID tracking. The premises of this section lead us to conclude that this integration positively improved procurement efficiency within NTN and external stakeholders. The main reason is that the new system enabled real-time tracking of materials and products by better integrating stakeholders, the key of this is that the new DSS homogenised the language and format of data across the streamline process. We saw this when we learned that the new system allowed NTN to perform mock recalls in under four hours, a significant improvement over the days required with the previous manual system.

Continuing with the DSS predictive analytics modality set for production enhancement. This tool emerged as one of the most pertinent features of the system and it enabled overall better resource allocation and procurement optimisation.

Having such a system set managerial alerts is a great way for managers to improve on their jobs by having more visibility in operations. We see this for instance when the new DSS was able to harness vibration and temperature data from CNC machines to predict particular defects in equipment even before they took place. We can state that this also was a financial success because such a tool would prevent delays within production.

It has to be said that despite these benefits, there were some downsides in embarking the transition. First off, there was the issue of incongruence within data pools, this brought about nomenclature inconsistencies making the new system unable to process information instantly. The initial months after implementation were marked by NTN's department having suboptimal system performance, the department required monetary and time resources to capture and handle the data. This aggravated the image of the system in the short term.

Our study then emphasised the critical role of data engineers in establishing robust database structures and protocols for data classification and cleaning. By describing this process, this lead us to conclude that the decision of adopting a hybrid DSS framework, which combined intranet and in the cloud solutions, greatly helped the department solve these issues. This was potentially the best approach for NTN since the hybrid solution optimised deployment and improved compatibility with other stakeholders, it also introduced solutions data access and security dilemmas.

Another key finding pointed that regulatory compliance and respecting external legislation given by auditors became easier when scrutinising daily operations through the new DSS. We saw this through the enhancement in serial number technology the new system brought about when handling tenders, this includes quality checks set for checking that operations follow safety and regulatory standards. Particularly we have the updated system's traceability feature supporting NTN's quest to adhere to the European Green Pact and other environmental initiatives.

5.3 Practical Implications

We have already stated some of the repercussions of altering a DSS within a department that handles intrinsic operations every day. To that we can add that that this work gave us reason to believe that, in general, early phases and the transition face of a DSS migration is indeed complex and requires various efforts and resources from stakeholders. Through this work we have learned the details of this process and this led us to accept that such a change requires meticulous data migration protocols.

Companies looking to replicate NTN’s success must recognize that the success of a DSS overhaul is not just a matter of software installation but of organizational change management. Enhancing the infrastructure of such a system requires all stakeholders to work together and communicate throughout the process to hold certainty on the premise that new systems ought to be tailored to actual operational necessities, user necessities, and compliance necessities. Our case study paradigms distinctly show that when users are involved in shaping protocols within a system, the results are infinitely more agreeable.

The integration of DSS with advanced warehouse management systems (WMS) and third-party functionalities, such as RFID tracking, is another lesson directly applicable to our purposes. NTN’s ability to streamline procurement, automate inventory management, and ensure traceability updated promptly was significantly enhanced by these integrations. For other precision manufacturing companies, this means that DSS upgrades should not be considered in isolation but as part of a broader digital ecosystem. The seamless flow of information between DSS, WMS, and supply chain partners enables faster, more informed decision-making, reduces lead times, and strengthens compliance with industry regulations.

To give more takeaways on the subject, it is clear that the advancement in DSS technology has had a considerable impact in automation of departmental processes. We see this reflected in this case study since it detailed how NTN’s new

DSS brought about front-end tools to be utilised to automate and predict certain processes. These tools not only minimized downtime and reduced costs, but also allowed the company to proactively manage supply chain risks and production bottlenecks. For other organizations similar to NTN, investing in DSS platforms that support the latest DSS technology might yield clear benefits depending on their goals and their current production requirements.

It would also be fair to state that regulatory compliance can be directly integrated to operations and even measured as a unit through DSS automation. By setting different Objectives and Key Results within the system, NTN was able to respond to auditorial protocols in a more efficient manner. For companies that require a great deal of scrutiny within their practices, this capability greatly aids in keeping control means on point.

Finally, the research blatantly suggests that the benefits of DSS upgrades extend beyond immediate operational gains. NTN’s experience shows that a modern and harmoniously integrated DSS is the best decision a department can take if it seeks to expand operations or launch a new product line. This work provided a roadmap for any precision manufacturing company aiming to leverage their data management infrastructure to attain managerial improvement. By following the recommendations and assertions of this work, organizations of a similar standing can not only improve their own DSS implementation outcomes but also position themselves at the forefront of the ongoing evolution in precision manufacturing activities.

5.4 Limitations of the Study

Continuing towards limitations and focusing these limitations within the context of NTN´s very specific organizational and production layout: we can say that at the heart of NTN’s success was the enhanced ability to handle vast datasets generated during micromachining and assembly processes through other variables independent to the DSS. These neo variables can be good upper management and good workforce synchronisation, for instance. Prior to the DSS upgrade, the company found constant data inconsistencies within the cage assembly department and within other stakeholders, this hindered the department’s ability to scale so management made the decision of investing in having consistent data formats across the board. This is a very specific practice and therefore the first limitation of the study lies here, since we cannot pretend that other companies have the same data infrastructure than NTN´s.

To give an example of these inconsistencies, bearing component specifications stored as “bearing_seal_v2” in one database and “bs_v2_seal” in another led to procurement delays and misrouted inventory. The SAP S4 CORE106 system introduced ways to homogenize data, this however did upset the whole communication infrastructure of the department since workers were already used to a certain form of data handling. This is just lay on the table that data management problems are prone to be very specific and inherent to the company setup, making it hard for other companies to find direct context in this work’s content.

Another limitation is that DSS adoption is not a technical upgrade accomplished in one go but rather a cyclical process requiring alignment across stakeholders. We have tried to give it a time frame and a structure but the truth is that companies face the detritus of such system overhaul for years. We observed how the phases we artificially set focused on labour intensive data migration and system customization, where engineers prioritized technical integration, while managers emphasized long term assessments, the NTN case study clearly suffers from inconsistencies within timeframes.

Another limitation lays within the Infor WMS and RFID tracking and its indirect relationship with procurement and inventory management. Real-time data from RFID tags enabled dynamic cross-docking strategies, reducing lead times by 18% in paper but ignoring other factors that might have affected that number. For instance, components arriving at the warehouse were immediately rerouted to assembly lines without storage, optimizing just-in-time workflows.

Lastly, DSS's machine learning modules have limitations as well since they are inherent to legacy data that may be outdated since it is coming from a previous system. For example, we know that sensitive operational data, such as proprietary alloy compositions remained on local servers, while cloud modules facilitated integration with third-party tools like Minitab for statistical analysis. This architecture limited the system since synchronizing data across platforms required a very intrinsic encryption protocol to prevent breaches.

5.5 Suggestions for Future Research

This work does provide solid foundation for other companies that practice precision manufacturing in big scales if they seek to understand how advanced data systems can transform operations in environments where accuracy is paramount. The first and clearest direction for future research is the development of a guide for companies similar to NTN to follow if they want to upgrade DSS and make it as adaptive as possible within the frame of their needs. The NTN case demonstrates how data processing can have an outstanding impact in operations so it would be interesting to find more objective measures of this idea.

Future studies should also explore how DSS architecture can be utilized to set CNC machines in an optimal way in terms of setup. For instance, how edge computing can be best utilized to gather data from CNC machines, specially within laser micromachining practices and allotment divisions. The goal would be to optimise the system's potentiality to recalibrate machining parameters on the fly, for instance adjusting feed rates or laser pulse durations to enhance operations, making it possible for managers to attain highest possible operational precision and minimizing mistakes and incidents.

Another interesting potential future study direction could be to dig on how DSSs ought to be integrated with artificial intelligence to enhance daily processes and relieve the workforce from repetitive activities. For instance, we have learned that tool degradation and poor maintenance can quickly lead to unacceptable surface finishes or dimensional errors (Zhang et al. 2019) therefore creating a layout that can automatically set maintenance protocols in place. It could also be interesting to set future research in the direction of developing machine learning models trained specifically on optimal vibrational signatures to optimise the lifecycle of the tools these machines utilize.

Given that the relationship within a DSS and its user is not so well documented, it would also be interesting to trace this direction in future DSS research to answer the question on how this relationship can be optimised. Future research should investigate the operator's workspace and the end user dynamics of these systems, perhaps with the intention of creating or enhancing training programs that help DSS end users to develop the skills needed to take advantage of this tool in its full potential. Understanding how to foster the complex dynamics between human experts and advanced decision systems will be vital as micromachining environments become more complex.

Sustainability in DSS is another area we did not profoundly touch and would benefit from investigation. Micromachining processes, given it has very high energy intensity and the potential for reducing material waste if optimally set, present very interesting challenges for manufacturing in a more conscious and environmentally friendly manner. Future studies could be based in cage assembly department's quest to improve their regulatory compliance and future work could touch upon the development of particular DSS modules that incorporate lifecycle assessment tools, track the carbon footprint and waste streams associated with microfeature production, and support circular economy initiatives such as micro-swarf recycling (Zhang et al. 2019). Having a framework that optimises and gives priority to environmental impact within every step of the production process could be a good research direction because a well contrived DSS can surely help manufacturers align with their environmental standards.

To end, it can be safely said that the lack of academic information regarding microfeature measurement and classification presents a barrier to cross-platform

DSS integration and this should be further investigated. As the NTN study showed, the company lost a great deal of time and resources in trying to homogenise data. Future research should focus on developing a way to keep data consistent and in par with the most current language and format available. Efforts to update old data perhaps automatically with modern data language models could help bridge the gap between older and newer systems, making it possible for DSSs software to be a technology that passively updates by itself like a phone or a computer.

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