

# **METHODOLOGY FOR PLM IMPLEMENTATIONS**

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## Summary

The large amount of information which is created during product development, the increasing products complexity, and globalization have lead to developing Product Lifecycle management (PLM) strategies. PLM allows managing information and processes developed and conducted through the product lifecycle, connecting all the stakeholders regardless their geographic location. This strategy is supported by technological platforms which provide the means for performing the engineering processes in a collaborative way. However, the platform implementation depends on a properly strategy definition and execution. PLM strategies are widely used in the global context, nevertheless, in developing countries such as Colombia this kind of implementations are not common due to the up-front costs and the lack of knowledge and experience in the implementation process. Due to that, the presented research describes a methodology for conducting PLM strategy implementations in Small and Medium Size Enterprises (SME) of local context, based in the use of an Open Source PLM system. This methodology, which was developed under an action research approach, is composed by five stages: I) Evaluation and diagnosis of processes and documentation standards, II) Introduction to PLM strategy, III) Definition of processes and documentation standards, IV) system configuration and V) Monitoring, evaluation and dissemination of results. Each stage, along with the system performance were finally evaluated through a case study which was conducted in a local company. The major conclusions from this research are: a) the open source system tested is properly for local context because it eliminates the up-front license costs and it meets most of the functions of traditional PLM systems, b) the PLM implementation methodology proposed provides a detailed process which includes the main social, technical and economical considerations C) the methods and tools proposed in the methodology are easy to perform and understand and D) Although PLM strategies can already be implemented in local context, it is required conducting a re-engineering process in the local companies which allows standardizing the main processes and making use of best practices. In this sense, this research seeks to provide the means for start implementing PLM in local context, considering as input the limitations and requirements of Colombian enterprises.

# Contents

<b>CHAPTER 1. INTRODUCTION.....</b>	<b>1</b>
1.1 BACKGROUND.....	1
1.2 RESEARCH JUSTIFICATION.....	1
1.3 OBJECTIVE AND RELEVANCE OF THE RESEARCH.....	3
1.3.1 <i>General objective</i> .....	3
1.3.2 <i>Specific objectives</i> .....	3
1.3.3 <i>Research questions</i> .....	3
1.4 RESEARCH SCOPE.....	3
1.5 THESIS ORGANIZATION.....	4
<b>CHAPTER 2. STATE OF THE ART .....</b>	<b>5</b>
2.1 LITERATURE REVIEW.....	5
2.1.1 <i>What is PLM</i> .....	5
2.1.1.1 PLM Systems Evolution.....	7
2.1.1.2 PLM definition analysis.....	9
2.1.1.3 PLM DEFINITION.....	11
2.1.1.4 Current Status.....	13
2.1.2 <i>PLM Seen as a Strategy</i> .....	13
2.1.3 <i>PLM seen as a Tool</i> .....	14
2.1.4 <i>Integration with Existing Systems</i> .....	16
2.1.5 <i>Analysis of PLM System Requirements</i> .....	17
2.1.6 <i>Application areas</i> .....	20
2.1.7 <i>PLM Challenges</i> .....	21
2.1.8 <i>Conclusion</i> .....	21
2.2 PLM TOOLS ANALYSIS.....	22
2.2.1 <i>Windchill™</i> .....	22
2.2.2 <i>Teamcenter™</i> .....	23
2.2.3 <i>ENOVIA™</i> .....	24
2.2.4 <i>Aras Innovator™</i> .....	26
2.3 LOCAL INDUSTRY SURVEY.....	27
<b>CHAPTER 3. RESEARCH APPROACH .....</b>	<b>36</b>
3.1 ACTION RESEARCH (AR) DEFINITION.....	36
3.1.1 <i>AR Cycles</i> .....	36
3.2 SOFTWARE FOR CASE STUDY.....	37
<b>CHAPTER 4. PLM METHODOLOGY CONSTRUCTION BY AR CYCLES.....</b>	<b>44</b>
4.1 CYCLE 1 (C1).....	44
4.1.1 <i>C1 - Planning</i> .....	45



4.1.2	C1 - Acting .....	46
4.1.3	C1 - Observing .....	46
4.1.4	C1 - Reflecting .....	46
4.2	CYCLE 2 (C2).....	47
4.2.1	C2 - Planning .....	48
4.2.2	C2 - Acting .....	48
4.2.3	C2 - Observing .....	53
4.2.4	C2 - Reflecting .....	54
4.3	CYCLE 3 (C3).....	55
4.3.1	C3 - Planning .....	56
4.3.2	C3 - Acting .....	56
4.3.3	C3 - Observing .....	60
4.3.4	C3 - Reflecting .....	61
4.4	CYCLE 4 (C4).....	62
4.4.1	C4 - Planning .....	62
4.4.2	C4 - Acting .....	64
4.4.3	C4 - Observing .....	66
4.4.4	C4 - Reflecting .....	69
4.5	CYCLES CONCLUSIONS.....	70
<b>CHAPTER 5. METHODOLOGY DESCRIPTION .....</b>		<b>74</b>
5.1	IMPLEMENTATION MODEL: STAGE 1 (IM-S1) .....	76
5.1.1	(IM-S1) Current processes analysis.....	76
5.1.1.1	(IM-S1) Analyzing the current company situation .....	77
5.1.1.2	(IM-S1) Defining the PLM implementation strategy.....	77
5.1.1.3	(IM-S1) Analyzing implementation priorities .....	77
5.1.1.4	(IM-S1) Identifying entities .....	80
5.1.1.5	(IM-S1) Identifying activities.....	81
5.1.1.6	(IM-S1) Identifying roles.....	81
5.1.1.7	(IM-S1) Identifying the resources related to the processes .....	81
5.1.1.8	(IM-S1) Analyzing processes' interactions.....	82
5.1.1.9	(IM-S1) Modeling processes .....	82
5.1.1.10	(IM-S1) Analyzing processes cost .....	82
5.1.1.11	(IM-S1) Identifying the process modifications required.....	83
5.1.2	(IM-S1) Defining KPI .....	83
5.1.3	(IM-S1) Reviewing formats currently used .....	83
5.1.4	(IM-S1) Reviewing the naming convention currently used .....	84
5.1.5	(IM-S1) Reviewing sequences and document version control currently used.....	84
5.1.6	(IM-S1) Identifying software currently used.....	84
5.2	IMPLEMENTATION MODEL: STAGE 2 (IM-S2) .....	84
5.2.1	(IM-S2) Installing and configuring the server for training purposes.....	85
5.2.2	(IM-S2) Introducing PLM concepts .....	85
5.2.3	(IM-S2) Enabling computers from which the system will be used (Client side) .....	85
5.2.4	(IM-S2) Creating tutorials and support materials .....	85

5.2.5	<i>(IM-S2) Starting training sessions</i>	85
5.3	IMPLEMENTATION MODEL: STAGE 3 (IM-S3)	86
5.3.1	<i>(IM-S3) Business Process Modeling and Definition or adaptation of currently used workflows</i>	86
5.3.1.1	<i>(IM-S3) Defining implementation goals and opportunities</i>	86
5.3.1.2	<i>(IM-S3) Defining priority in processes</i>	86
5.3.1.3	<i>(IM-S3) Modeling processes</i>	87
5.3.1.4	<i>(IM-S3) Analyzing changes implied for each role</i>	87
5.3.2	<i>(IM-S3) Defining new templates and documentation standards</i>	87
5.3.3	<i>(IM-S3) Defining or adapting naming convention (nomenclature) standards</i>	88
5.3.4	<i>(IM-S3) Defining or adapting document version control standards</i>	88
5.4	IMPLEMENTATION MODEL: STAGE 4 (IM-S4)	89
5.4.1	<i>(IM-S4) Selecting PLM tools and modules to be implemented</i>	89
5.4.2	<i>(IM-S4) Creating user's accounts and define roles and identities</i>	90
5.4.3	<i>(IM-S4) Defining and configuring suppliers and distributors on the system</i>	90
5.4.4	<i>(IM-S4) Configuring workflows to be automated in the system</i>	90
5.4.5	<i>(IM-S4) Creating libraries on the system</i>	91
5.4.6	<i>(IM-S4) Developing customized modules in the system</i>	91
5.4.7	<i>(IM-S4) Defining and configuring permissions on the system</i>	91
5.5	IMPLEMENTATION MODEL: STAGE 5 (IM-S5)	92
5.5.1	<i>(IM-S5) Monitoring processes and running projects</i>	92
5.5.2	<i>(IM-S5) Measuring KPI</i>	93
5.5.3	<i>(IM-S5) Comparing KPI measurement</i>	93
5.5.4	<i>(IM-S5) Planning corrective tasks</i>	93
5.5.5	<i>(IM-S5) Implementing corrective tasks</i>	94
<b>CHAPTER 6.</b>	<b>CASE STUDY</b>	<b>95</b>
6.1	STAGE1. EVALUATION AND DIAGNOSIS OF PROCESSES AND DOCUMENTATION STANDARDS	96
6.1.1	<i>Analysis of current processes and diagnosis of approval processes</i>	96
6.1.1.1	SWOT Analysis	96
6.1.1.2	Strategy definition	97
6.1.1.3	Effort – Benefit – Uncontrollable variables graphic	100
6.1.1.4	Entity table	102
6.1.1.5	Activity identification chart	103
6.1.1.6	Roles' characteristics chart	104
6.1.1.7	Resource chart	105
6.1.1.8	R-N-I Chart	106
6.1.1.9	Process modeling (AS-IS)	108
6.1.1.10	Analysis of labor cost	109
6.1.1.11	Process analysis chart	110
6.1.1.12	KPI definition	111
6.1.2	<i>Review of currently used forms</i>	113
6.1.3	<i>Review of currently used naming convention (nomenclature)</i>	115
6.1.4	<i>Review of sequences currently used for document version control</i>	117
6.1.5	<i>Identification of currently used software</i>	117

6.2	STAGE2. INTRODUCTION TO PLM STRATEGY .....	117
6.2.1	<i>Installation and configuration of the server</i> .....	117
6.2.2	<i>Presentation and concepts introduction</i> .....	117
6.2.3	<i>Tutorials and supportive material development</i> .....	118
6.3	STAGE 3. DEFINITION OF PROCESSES AND DOCUMENTATION STANDARDS.....	119
6.3.1	<i>Business Process Modeling and Definition or adaptation of currently used workflows</i> .....	119
6.3.1.1	Objectives, goals and opportunities chart.....	119
6.3.1.2	Priority process chart .....	120
6.3.1.3	Process modeling (TO-BE).....	123
6.3.1.4	Career plans design chart .....	124
6.3.2	<i>New forms definition</i> .....	126
6.3.3	<i>Naming convention (nomenclature) adaptation</i> .....	127
6.3.4	<i>Sequences and version management adaptation</i> .....	128
6.4	STAGE 4. SYSTEM CONFIGURATION .....	129
6.4.1	<i>Selection of methods and tools</i> .....	129
6.4.2	<i>User account creation, roles definition and identities</i> .....	130
6.4.3	<i>Definition and configuration of suppliers and distributors</i> .....	131
6.4.4	<i>Workflow configuration</i> .....	132
6.4.5	<i>Permissions definition</i> .....	133
6.4.6	<i>Library creation</i> .....	135
6.4.7	<i>Customized module developments</i> .....	136
6.5	STAGE 5. MONITORING, EVALUATION AND DISSEMINATION OF RESULTS .....	138
6.5.1	<i>Monitoring processes and running projects</i> .....	139
6.5.2	<i>Measuring and comparing KPI</i> .....	140
6.5.3	<i>Planning corrective tasks and implementing them</i> .....	148
6.6	CONCLUSIONS OF THE IMPLEMENTATION PROCESS .....	149
6.7	DIFFICULTIES RELATED TO THE SYSTEM IMPLEMENTATION .....	150
	<b>CHAPTER 7. CONCLUSIONS.....</b>	<b>152</b>
	<b>APPENDIX A.....</b>	<b>158</b>
	<b>APPENDIX B.....</b>	<b>162</b>
	<b>APPENDIX C.....</b>	<b>172</b>
	<b>APPENDIX D.....</b>	<b>181</b>

# List of Figures

Figure 1. Serial process (PLM Technology Guide, 2010) .....	7
Figure 2. Actual PLM Systems (PLM Technology Guide, 2010) .....	8
Figure 3. PLM as a tool .....	15
Figure 4. Interoperability .....	17
Figure 5. TeamCenter architecture .....	24
Figure 6. ENOVIA architecture .....	25
Table 4. Company's description .....	29
Figure 7. Companies rating .....	31
Figure 8. 11 Companies' Product Design Process .....	32
Figure 9. Action Research Cycles .....	37
Figure 10. "Project" module interface .....	38
Figure 11. Product structure browser explanation .....	39
Figure 12. Item types association .....	41
Figure 13. Version control code .....	42
Figure 14. Aras Innovator® interface .....	43
Figure 15. AR Cycles implemented .....	44
Figure 16. Implementation stages in Cycle 1 .....	47
Figure 17. Project Schedule in Aras Innovator for Cycle 2 .....	50
Figure 18. Project's permissions for Cycle 2 .....	50
Figure 19. Document's permissions for Cycle 2 .....	51
Figure 20. Meeting's permissions for Cycle 2 .....	51
Figure 21. Part's permissions for cycle 2 .....	52
Figure 22. Naming convention (nomenclature) for documents management in cycle 2 .....	52
Figure 23. Naming convention (nomenclature) for CAD management in Cycle 2 .....	53
Figure 24. Indicators measured in Cycle 2 and results obtained .....	54
Figure 25. Implementation stages for Cycle 2. ....	55
Figure 26. Project Schedule for packaging sub-project in Cycle 3 .....	58
Figure 27. Project Schedule for sewing sub-project in Cycle 3 .....	59
Figure 28. Naming convention (nomenclature) used for document management in Cycle 3 .....	59
Figure 29. PLM blog for training purposes .....	60
Figure 30. Indicators measured in Cycle 3 and results obtained .....	60
Figure 31. Implementation stages for Cycle 3 .....	62
Figure 32. Product Design process scheme for C4 .....	63
Figure 33. Lifecycle states for "Document", "part" and "project" functions in C4 .....	64
Figure 34. Document naming convention (nomenclature) definition for C4 .....	64
Figure 35. Instructive documents on the PLM system. ....	65
Figure 36. Stage definition for Project on Aras Innovator for C4 .....	66
Figure 37. Organizational chart used in Cycle 4. ....	66
Figure 38. Evolution of PLM implementation for Cycle 4 .....	68
Figure 39. Activity report performance for Stage 4 on Cycle 4 .....	69
Figure 40. Comparison of PDU, PDCN, PPUD and PART by Cycle .....	72

Figure 41. Comparison of PDD, PDNU and PARM by Cycle.....	72
Figure 42. Stages of PLM implementation methodology .....	74
Figure 43. Scheme of the Benefit-Effort-Uncontrollable Variables graphic.....	80
Figure 44. Organizational chart of the company.....	95
Figure 45. Effort – Benefit – Uncontrollable variables graphic.....	102
Figure 46. Revision (preventive maintenance) process.....	108
Figure 47. Preventive and corrective maintenance form fields identification .....	113
Figure 48. Company’s document pyramid .....	115
Figure 49. AS-IS company’s documents naming convention (nomenclature).....	116
Figure 50. Support material for training processes .....	119
Figure 51. Changes defined for “revision” process .....	124
Figure 52. Instructive document form .....	127
Figure 53. Naming convention (nomenclature) automation .....	127
Figure 54. Example of “Version Control” in Aras® .....	128
Figure 55. Users and identities definition in ARAS Innovator® .....	130
Figure 56. Suppliers list in Aras innovator® .....	131
Figure 57. Life-cycle developed for “Suppliers” in Aras innovator® .....	132
Figure 58. Lifecycle definition based on the entity chart .....	133
Figure 59. Machines and areas list .....	135
Figure 60. Suppliers form developed in PLM system .....	136
Figure 61. Customized module developed in Aras Innovator® (Test version) .....	137
Figure 62. Code developed for “Failure rates graph” in a test version .....	137
Figure 63. Preventive maintenance schedule in execution in Aras Innovator® .....	139
Figure 65. Percentage of activities reported in the preventive maintenance form measured by maintenance member .....	141
Figure 66. Activity completion report measured by maintenance member .....	142
Figure 67. Percentage of errors in preventive maintenance filling out per maintenance member ..	142
Figure 68. Evolution of the activity report process of the preventive maintenance format .....	143
Figure 69. Evolution of the activity completion report process (PART indicator) .....	143
Figure 70. Evolution of the percentage of errors in preventive maintenance filling out process per week .....	144
Figure 71. Evolution in the percentage of activities reported in the preventive maintenance form per maintenance member .....	144
Figure 72. Evolution of activity completion report (PART indicator) per maintenance members ....	145
Figure 73. Evolution of the amount of errors in the preventive maintenance’s form filling out process per week .....	145
Figure 74. Comparison of average failure rate before and after implementation .....	146
Figure 75. Comparison of the total average time among failures before and after implementation .....	146
Figure 76. Comparison of the total average time in repairing before and after implementation ....	147
Figure 77. Comparison of the total average of the percentage of cost invested in corrective maintenance before and after implementation. ....	147

<i>Figure 78. Comparison between the total average of percentage of cost invested in preventive maintenance before and after implementation. ....</i>	<i>148</i>
<i>Figure 79. Blue screen in the “Methods editor” .....</i>	<i>151</i>
<i>Figure 80. Company 1’s Design process.....</i>	<i>162</i>
<i>Figure 81. Company 2’s Design process.....</i>	<i>163</i>
<i>Figure 82. Company 3’s Design process.....</i>	<i>164</i>
<i>Figure 83. Company 4’s Design Process.....</i>	<i>165</i>
<i>Figure 84. Company 5’s Design Process.....</i>	<i>166</i>
<i>Figure 85. Company 6’s Design Process.....</i>	<i>167</i>
<i>Figure 86. Company 7’s Design Process.....</i>	<i>168</i>
<i>Figure 87. Company 8’s Design Process.....</i>	<i>169</i>
<i>Figure 88. Company 9’s Design Process.....</i>	<i>170</i>
<i>Figure 89. Company 11’s Design Process.....</i>	<i>171</i>

# List of Tables

<i>Table 1. Analysis of PLM definitions .....</i>	<i>11</i>
<i>Table 2. Classification tools (Mejía et al., 2008) .....</i>	<i>14</i>
<i>Table 3. Summary of systems analysis requirements .....</i>	<i>19</i>
<i>Table 5. Survey items analyzed .....</i>	<i>30</i>
<i>Table 6. Results of the comparison of product design activities in companies .....</i>	<i>32</i>
<i>Table 7. Decision making process in product design and development process .....</i>	<i>33</i>
<i>Table 8. Detail design activities per company .....</i>	<i>35</i>
<i>Table 9. Number of participants per group .....</i>	<i>63</i>
<i>Table 10. Indicators measured for Cycle 4 .....</i>	<i>67</i>
<i>Table 11. Evolution of indicators for Cycle 4 .....</i>	<i>68</i>
<i>Table 12. Comparison of indicators by Cycle. ....</i>	<i>70</i>
<i>Table 13. Descriptive information for “permission definition table” .....</i>	<i>92</i>
<i>Table 14. Proposed indicators for measuring the “level of use” of the PLM tool .....</i>	<i>93</i>
<i>Table 15. Implementation team .....</i>	<i>96</i>
<i>Table 16. SWOT Analysis table example .....</i>	<i>97</i>
<i>Table 17. Definition of objectives and activities for the PLM implementation .....</i>	<i>98</i>
<i>Table 18. Effort estimation table for objective 1 .....</i>	<i>100</i>
<i>Table 19. Benefit estimation table .....</i>	<i>101</i>
<i>Table 20. Uncontrollable variables estimation .....</i>	<i>101</i>
<i>Table 21. Entity table for “Revision” entity .....</i>	<i>103</i>
<i>Table 22. Activity identification chart for “revision” entity .....</i>	<i>104</i>
<i>Table 23. Roles’ characteristics chart .....</i>	<i>105</i>
<i>Table 24. Resource chart example .....</i>	<i>106</i>
<i>Table 25. R-N-I chart for “Revision” entity .....</i>	<i>107</i>
<i>Table 26. AS IS: Revision process .....</i>	<i>109</i>
<i>Table 28. Process analysis chart fragment for “revision” entity .....</i>	<i>111</i>
<i>Table 29. KPI for diagnosis processes .....</i>	<i>112</i>
<i>Table 30. Corrective maintenance form analysis chart .....</i>	<i>114</i>
<i>Table 31. Preventive maintenance form analysis chart .....</i>	<i>114</i>
<i>Table 32. Goals and opportunities .....</i>	<i>120</i>
<i>Table 33. Process benefit estimation .....</i>	<i>121</i>
<i>Table 34. Nomenclature for Table 33 .....</i>	<i>121</i>
<i>Table 35. Process priority table .....</i>	<i>122</i>
<i>Table 36. Nomenclature and definition of items for Table 35 .....</i>	<i>122</i>
<i>Table 39. Permissions defined for “Instructive documents function” .....</i>	<i>134</i>
<i>Table 40. Corrective actions conducted during the monitoring process .....</i>	<i>140</i>
<i>Table 41. Data base Engine requirements .....</i>	<i>158</i>
<i>Table 42. Operating system server side requirements .....</i>	<i>159</i>
<i>Table 43. Software requirements .....</i>	<i>160</i>

<i>Table 44. Additional requirements .....</i>	<i>161</i>
<i>Table 45. SWOT Analisis table .....</i>	<i>172</i>
<i>Table 46. Strategy definition table .....</i>	<i>172</i>
<i>Table 47. Effort estimation table .....</i>	<i>173</i>
<i>Table 48. Rating scale based on percentage table .....</i>	<i>173</i>
<i>Table 49. Benefit estimation table.....</i>	<i>174</i>
<i>Table 50. Uncontrollable variable estimation.....</i>	<i>174</i>
<i>Table 51. Entities table .....</i>	<i>174</i>
<i>Table 52. Activity identification table .....</i>	<i>175</i>
<i>Table 53. Roles' characteristic table .....</i>	<i>175</i>
<i>Table 54. Resources table .....</i>	<i>176</i>
<i>Table 55. R-N-I table .....</i>	<i>176</i>
<i>Table 56. Resources correlation table.....</i>	<i>177</i>
<i>Table 57. Process analysis table .....</i>	<i>177</i>
<i>Table 58. Form analysis table .....</i>	<i>177</i>
<i>Table 59. Objectives, goals and opportunities .....</i>	<i>178</i>
<i>Table 60. Process benefit estimation table.....</i>	<i>178</i>
<i>Table 61. Process priority estimation table .....</i>	<i>178</i>
<i>Table 63. Permission definition table .....</i>	<i>180</i>



# Chapter 1. Introduction

## 1.1 Background

PLM implementations in manufacturing companies are widely common throughout the world, especially in developed and industrialized countries. Even companies from other industries such as services, fashion, healthcare, among others, have started to implement PLM philosophy. This expansion has reached Small and Medium Size Enterprises (SME), forcing developers of these kinds of systems to generate light software versions in order to serve this large market. However, this kind of implementations requires formulating a clear strategy and a working methodology that will assure meeting the needed protocols and achieving success.

In developing countries, such as Colombia, most of the enterprises are SME and this kind of implementations are not very common due to license costs, lack of a properly working methodology in engineering companies, low educational level of many of the company's members and a short term culture in the company's management. According to this and also because of the lack of literature (describing the implementation process strategy on the mentioned cases), a necessity of defining an implementation methodology has been detected to suit local needs.

## 1.2 Research justification

PLM strategies are widely implemented around the world, due to the benefits that PLM provides to the companies which implements it. Some benefits reported in the literature are automation and process acceleration (Sääksvuori and Immonen, 2008), avoiding documents duplication (Grieves, 2006), supporting decision making processes, reducing information search time, centralizing management information, facilitating simultaneous work throughout the product life cycle regardless of the location of the people involved, among others.

These benefits increase the competitiveness of enterprises as in the case of aeronautic sector (Van Wijk et al., 2009), (Lee et al., 2008) and automotive industry (Trappey and Hsiao, 2008), (Tang and Qian, 2008). For these areas, an increase in competitiveness can be reflected not just in costs reduction, but also in the reduction in time to market (which strongly benefits any company in a global environment and enhances its innovation capacity).

However, the implementation of these kinds of strategies implies high costs due to the price of the system's licenses, the long term of the strategy formulation and execution, the training process, among others. Due to this, some companies such as ARAS Corp have developed Open source systems which can be used without paying license cost and the developers of the commercial PLM systems have also started to provide lighter solutions focused on SMEs, in order to offer lower costs; nevertheless its prices are still high.

Although the license cost of this kind of systems is usually very high, the biggest investments which must be carried out by any company that implements them is in the strategy definition &

execution (which are usually conducted by external consultant firms). This process includes integrating Concurrent Engineering (CE) principles and best practices in the working method, as well as training employees on the system use, among others. However, there is still scarce literature available on this implementation process.

Even though there are some authors (Grieves, 2006), (Stark, 2005), (Sääksvuori and Immonen, 2008) who describe certain steps for the implementation of a PLM strategy, few of them such as Schuh et al (Schuh et al., 2008) provide an in depth explanation of the steps which should be conducted. This situation, together with the fact that not all the software sellers of these kinds of systems includes any kind of assessment for configuring, installing and using process making it even harder to obtain a low-cost implementation.

This situation, along with the short term culture of local industry management, the lack of a proper working methodology in engineering companies and the low educational level of many of the company's members, hinders the implementation of PLM in the local engineering industry which is mostly composed by SMEs. In the long term, this could entail a loss of competitiveness of the local industry against international companies which provide similar products.

Based on all the assumptions previously exposed, defining a PLM implementation methodology focused on the local industry is vital in order to allow the use of this kind of strategies in developing countries such as Colombia, considering the economical limitations and cultural variations in working methods. This project proposes a methodology based in the use of low cost methods and tools and supported in the use of open source PLM systems.

This project is the backbone of a macro project developed in the Design Engineering Research Group (GRID) of EAFIT University which has included the development of projects such as:

- “PLM tools implementation for engineering projects development” (Mejía-Gutierrez and Ruiz-Arenas, 2010) : Which was developed in order to define the main aspects of the PLM strategy and system configuration for its implementation at EAFIT University.
- “Documentation and implementation of concept design phase under a PLM approach” (Beuth, 2011): Which was developed as an undergraduate project in order to define all the documentation standards related with the Product Design Process defined (Mejía-Gutierrez and Ruiz-Arenas, 2010) for implementation at EAFIT University.
- “Integration of DFMA throughout an academic product design and development process supported by a PLM strategy” (Osorio-Gómez and Ruiz-Arenas, 2011): Which was developed in order to integrate DFMA issues in an efficient manner in the Product Design Process and supporting them with a PLM system.
- The development of several academic projects and courses in EAFIT University which used PLM for its management such as “Machine Design course”.

These projects showed the strong interest in this kind of strategies that is permeating the local context, and the consequent necessity of available implementation strategies that could enable meeting local needs.

## **1.3 Objective and relevance of the research**

### **1.3.1 General objective**

Define a methodology that meets the Colombian industry needs and requirements to implement the PLM approach in a local context.

### **1.3.2 Specific objectives**

- Analyze how engineering processes are conducted in local industry, in order to identify needs, requirements and weaknesses, to contextualize the implementation methodology.
- Analyze the available PLM tools vendors and select the most proper one for this particular implementation.
- Define the activities, information flow, tools, methods and resources which will contribute to the implementation methodology.
- Test the proposed methodology by performing a pilot project to get feedback and determine its effectiveness in local context.

### **1.3.3 Research questions**

- Is the local market ready for PLM strategy implementation?
- Are the available Open source tools suitable for meeting the local industry requirements?
- Could a PLM implementation methodology ease an effective PLM strategy implementation?

## **1.4 Research Scope**

At the end of the project an implementation methodology will be delivered:

- A methodology map which includes activities, role responsible of each activity, information flow through the process and events which determine the process conditionals.
- A report that explains the whole process conducted for achieving the PLM implementation methodology and a thorough explanation of this methodology.

## **1.5 Thesis organization**

This research work is organized in seven chapters. After describing the research proposal in the current chapter, a literature review of PLM is presented in Chapter 2, establishing a distinction between the “strategy” and the “Software”. This review also includes an analysis of the available supply of PLM tools and a local industry survey report which presents the main conclusions of the requirements, needs and weaknesses of the local industry.

Chapter 3 describes the research methodology used in the project. “Action Research” (AR) is briefly explained and its use is justified in this chapter.

Chapter 4 describes the process of defining the PLM implementation methodology through the execution of 4 Action Research cycles.

Chapter 5 describes the proposed PLM implementation methodology.

Chapter 6 presents the pilot project conducted in a local company and its results. Finally, Chapter 6 summarizes the conclusions of the execution of the proposed methodology.

## Chapter 2. State of the art

### 2.1 Literature review

#### 2.1.1 What is PLM

Major industrial sectors such as the automotive and aerospace, have stimulated the growth of new strategies and technological solutions through investment in market sectors related with business, such as: Mechanical Computer-Aided Design (MCAD), Comprehensive Collaborative Product Definition Management (CPDM), Digital Manufacturing, Simulation and Analysis, among others. The maturity level reached by technological advances achieved in these markets, has created the need in industries to associate the processes related to these developments in a synchronous way, through the product life cycle, promoting thus the emergence of new strategies such as PLM which aim to solve this need within a collaborative engineering framework.

The different stages through which a product undergoes from its conception until its disposal are known as the Product Lifecycle. According to Kusiak (Kusiak, 1993) the phases of the cycle are:

- Necessity
- Design and development
- Production
- Distribution
- Use
- Disposal

The most critical phases of product development are the first two, because all the subsequent phases should be considered to accomplish them and achieve an optimal product. For this reason, it is important to consider the concepts of Concurrent Engineering and Collaborative Engineering and differentiate them.

Capuz (CAPUZ, 1999) has defined Concurrent Engineering (CE) as an organizational approach that seeks all actors who are working on a project to collaborate and work simultaneously throughout the product life cycle. This approach emphasizes the importance of product planning from the initial stages of development, considering New Product Development (NPD) and all aspects and restrictions related to the product in any stage, such as functional requirements, geometry, specifications, features, manufacturing processes and limitations, among others (Grieves, 2006).

On the other hand, Collaborative Engineering implies the participation of different people, working around the development of a same product. However, due to geographic dispersion implied by current developments that seek to maximize regional advantages in certain areas,

"Collaborative Engineering Environments" have been developed, whose main function is to enable the interaction between these people (Shen, 2003).

PLM integrates both concepts, since its implementation as working methodology and strategy involves the application of Concurrent Engineering; and as a tool it facilitates the development of collaborative engineering, since it allows experts located in different places to "communicate" and share information through a common virtual environment.

Some systems such as Product Data Management (PDM), Engineering Resource Management (ERP), Supply Chain Management (SCM), Customer Relationship Management (CRM), among others, have similarities with PLM concerning their role within organizations. However, they vary in approach, as specified by their definitions presented below:

- Product Data Management (PDM), is an application to organize different CAD formats (Grieves, 2006), storing and allowing the access of all people to information related solely with the product within the organization.
- Enterprise Resource Planning (ERP) are systems that automate activities such as manufacturing, human resources, finance and supply and which in turn support the decision making process within the company (Razmi et al., 2009).
- Supply Chain Management (SCM) is a management information tool that integrates supply and logistics processes (Kovács and Paganelli, 2003), i.e., focusing on the supply operations.
- Customer Relationship Management (CRM) is a strategy through which the company seeks to understand its customers and use the knowledge gained through them to improve the profitability of the company (Stringfellow et al., 2004).

Analyzing in depth each of these definitions, it appears that all systems have in common the basic function of managing information. However, their difference lies in the type of information they manage and the number of processes and areas of the company who are concerned with that information.

PLM has a great similarity with PDM systems, because both of them focus on information associated with product development. This is because PLM is an evolution of PDM systems, which also involves a work associated methodology and incorporates other areas of the company (not just engineering) that contribute or require information related to the product. Additionally, PLM includes within its operation, the information generated throughout the entire product life cycle.

It is important to note that during each phase of the life cycle, the authors involved in the product can vary and therefore also vary the nature of the information generated for each of them. This situation is highly problematic because the information associated with the product is dispersed and the other authors involved will not be able to access it easily.

PLM is born of the need to properly manage all information associated with the product throughout its life cycle, properly integrating work methodologies such as Concurrent Engineering and enabling collaborative work, regardless of the geographic location of the actors, and involving not only the engineers who design the product, but also all company departments, suppliers, distributors, among others that are related to information associated with the product.

Throughout this document, PLM will be analyzed in depth both as strategy and as technological tool. The definitions proposed by different authors in the area will be analyzed and a suitable definition will be proposed as a result of this analysis, also considering broadly the characteristics of PLM systems (technology tools) that currently exist.

### 2.1.1.1 PLM Systems Evolution

Previously, organizations oriented to product design were characterized by a division between all areas that in one way or another were involved in the life cycle. This division was generated from the limits imposed by the implemented enterprise architecture, which structured each area as an island, where each one represented a lifecycle stage, and in which internal processes in each of them were a black box for any other area of the organization. This approach is known as “Over the wall” (Anumba et al., 1997).

The architecture provided a database for each area, where all the information resulting from their processes was stored and any other area could not have access to it. The interaction between them occurred only in a unilateral way (similar to a factory with mass production) where part of a process could not occur without the completion of the previous process (view Figure 1). This organizational structure caused that the companies which implemented it could not respond on time to market needs, thus becoming slow, expensive and uncompetitive organizations.

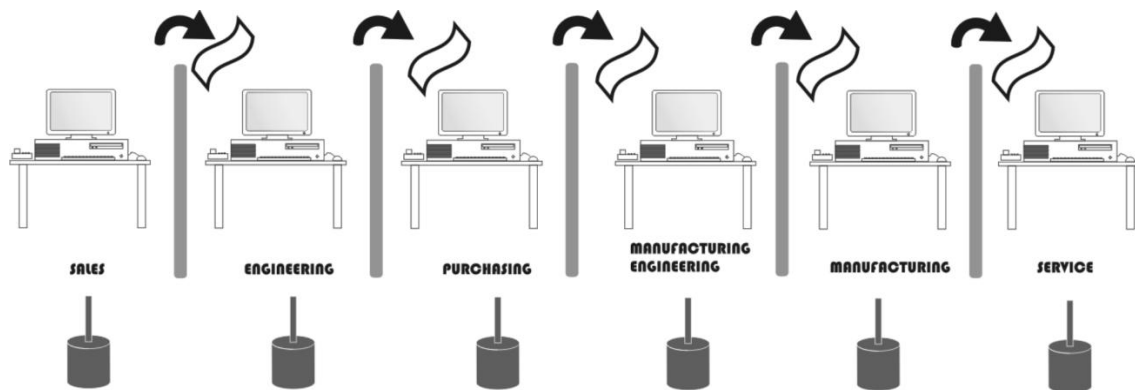


Figure 1. Serial process (PLM Technology Guide, 2010)

The problems generated by this work methodology resulted on the development of Concurrent Engineering, which allowed more planning in product development. However, information management was still deficient.

Problems such as duplication of documents, bad file regeneration, and misunderstandings in sending information, shipping of incomplete or incorrect information, missing information and availability of "garbage" information were very common during the development of engineering projects.

This fact, together with an increase in product complexity, due to the increase in parts and components and the incorporation of complex systems, resulted in the birth of PDM, which has been implemented successfully in many organizations. However, its application area was exclusively for engineering departments within companies, thus excluding other departments, suppliers and distributors that interact with the engineering department to develop their functions, receiving information from them and generating information for them.

Therefore, it was necessary to create a system that allowed sharing information between all members of the organization and even with external actors working on a specific project. PLM was born as a solution that allows all members of the company, distributors and suppliers to interact and also integrates concurrent and collaborative work methodologies that enable better performance during product development. This system stores information in a common database that allows real time access for all project stakeholders, so it avoids problems due to inconsistent information. View Figure 2.



*Figure 2. Actual PLM Systems (PLM Technology Guide, 2010)*



PLM brings benefits to companies that implement it for:

- Standardization, automation and process acceleration (Sääksvuori and Immonen, 2008).
- Considering from NPD all requirements, specifications and restrictions that will affect the product's design.
- Centralizing management of information and avoiding duplication of documents (Grieves, 2006).
- Connecting users scattered in different locations.
- Efficient re-use of information and reduced information search time.
- Support to the decision-making process.

These benefits are reflected in the organizations in significant reductions of time, during the NPD of the product, as this is evidenced by the results obtained in industries such as aeronautics (Lee et al., 2008). These reductions have a direct impact on the costs associated with the product development, because in this field reductions are also achieved.

Over time, different companies have been working on solutions that support the PLM concept, thus achieving: definition of product data standards and metadata, development of robust platforms for data exchange from increase in processing capacity, better broadband and storage capacity and use of Service Oriented Architecture (Srinivasan, 2008), thus facilitating access to all stakeholders and allowing further evolution of PLM systems. However, because of its short history, PLM technologies have not reached yet a sufficient level of maturity like CAD or ERP systems have (Stark, 2005).

Even so, the global investment in PLM platforms for 2009 was about \$ 14.03 billion dollars (CIMdata, 2010), which not only was made by areas of design and product development, but also for industrial areas for which these technologies were not originally designed for but can nonetheless benefit from the advantages they offer.

#### **2.1.1.2 PLM definition analysis**

Because of the importance and wide acceptance of PLM systems, many authors have generated different definitions about this topic. Grieves, (Grieves, 2006) focuses his definition as an approach to integrated information, where people, processes and technology are associated throughout the product lifecycle. According to Grieves PLM achieves its main benefits through proper management of information in all stages of the product lifecycle. Other definitions consider PLM as a business activity with a holistic character (Sääksvuori and Immonen, 2008) i.e. that focuses on PLM, as a leading activity of the process within the company, considering all the components that comprise it.

CIMdata (CIMdata., 2002) defines PLM as a business strategy to support the collaborative work around the product information and considers the concept of enterprise as extended, which includes all organizations and individuals involved in the product development. Under the term

"strategy" upon which many authors base their definition of PLM, some emphasize on the development of collaborative work distinguishing between PLM as methodology and PLM as a software solution (Mahdjoub et al., 2010), others emphasize on product lifecycle management (Thimm et al., 2006) and others also allude to the processing of information, including: creating, managing, distributing and use (Dohrman, 2007).

Ameri, F. & Dutta, D, (Ameri and Dutta, 2005), within their definition of PLM as a strategy, say that the management of the product lifecycle creates an environment focused on the product, and further considers all the stakeholders involved in the process development. In addition to this, they propose a definition of PLM as a technological solution, which, through a shared platform, provides a set of tools for information flow.

Danesi, et al, (Danesi et al., 2008) define PLM under the concept of collaborative work, focused on product design processes, and like many of the authors described above, they write about data integration, resources and knowledge during the design of a product. However, it does not consider the remaining phases of the life cycle. The word "concept" is also used to define PLM, (Sääksvuori and Immonen, 2008) which considers the integrated management of a product with information related to this product throughout its life cycle.

Likewise, other approaches focus on the management of product lifecycle (Sharma, 2005), others define it as a management technique that focuses on the flow of information related to the product (Takehi et al., 2009). Some definitions even, instead of using the word information, use the term intellectual capital (Datamation Limited, 2002), (Sudarsan et al., 2005).

Table 1 is a summary of the definitions given above, which presents a comparison of the concepts covered by each author. For this comparison the key words that gave meaning to each definition were considered, identifying the main focus of each one.

Table 1. Analysis of PLM definitions

DEFINICIONES PLM	Capital/Requirement						Action		Managed resources			Key Word					Others
	Extended Enterprise	Stakeholders	People	Process	Technology	Resources	Manages (generate, distribute, use)	collaborative working	Information	Knowledge	Intellectual capital	Software solutions	Methodology	Concept	Technique	Strategy	Life cycle
(Grieves, 2006)			X	X	X		X		X								X
(CIMdata Inc 2002)	X		X	X			X	X	X							X	X
(Sharma 2005)	X			X			X										X
(Kakehi, Yamada et al. 2009)							X		X						X		X
(Datamation Limited 2002)							X			X	X					X	
(Mahdjoub et al., 2010)				X			X	X	X			X	X			X	X
(Danesi et al., 2008)		X				X		X		X							
(Sääksvuori and Immonen, 2008)							X		X					X			X
(Thimm et al., 2006)		X					X		X							X	X
(Dohrman, 2007)							X	X	X							X	X
(Ameri and Dutta, 2005)		X						X	X			X				X	X

### 2.1.1.3 PLM DEFINITION

Considering the analysis carried out on different definitions, and knowing the functionality of PLM systems, it is important to emphasize the use of words such as:

- Strategy
- Administration and / or management
- Product Lifecycle
- Intellectual Capital

- Processes
- People Resources
- Extended Enterprise

The words “Strategy”, “Management” and “Lifecycle” were selected because of their frequent use during the definitions analyzed. “Intellectual Capital”, for its part, will be used because it globally encompasses the knowledge associated with each lifecycle stage, without limiting it to the concept of “information”; “people”, “processes” and “resources” are also considered, because they generate directly or indirectly the associated intellectual capital; and “Extended Enterprise” because the concept of PLM considers within its operation all stakeholders involved in product development, regardless if they are internal or external to the organization, including, for example, both clients and suppliers.

The word strategy is defined as the way to achieve objectives by managing resources and the creation of rules governing the use of them (Stark, 2005). That implies planning processes prior to development of any activity and the existence of a specific goal, which will be achieved through the implementation of it.

Due to this, the integration of a properly working methodology and the use of PLM systems, form a business strategy that must be supported by a proper planning process and an organizational culture that ensures its implementation.

Thus, and trying to bring together the main concepts, in this project is proposed the following definition:

***Definition 2-1. “Product Lifecycle Management (PLM): PLM is a strategy developed to manage the product life cycle, through the management of intellectual capital that is generated around it, in the extended enterprise, by integrating people, processes and resources supported by an organizational culture that can be supported on a technological platform”.***

With this definition it was sought to express the concept of PLM in a versatile way, considering the definitions proposed by other authors and including terms that the authors of this thesis consider important, in a way that they suit to a marked tendency of increasing functionalities, and emphasizing that it manages knowledge rather than just information generated during product development.

#### **2.1.1.4 Current Status**

In order to cover and analyze PLM, it is necessary to differentiate between PLM seen as strategy and as a technological tool. This document describes the management of the product life cycle as a strategy that relies on technological tools for the development of its function.

#### **2.1.2 PLM Seen as a Strategy**

To achieve all the benefits offered by an appropriate implementation of PLM, it is necessary to consider it as a strategy that encompasses all three levels: strategic, tactical and operational (Stark, 2005). The strategic level includes a long-term plan, and involves the entire organization, the tactical level is a medium-term plan and focuses on improving the performance of a specific area and the operational level has a short term range and focuses on individual activities.

To realize a strategy for developing products based on PLM, it is necessary to consider, from the moment that it will be defined, the guidelines established by the company's corporate strategy, to ensure that it is consistent with it. Many authors propose certain steps for the development of a PLM strategy (Stark, 2005), (Grieves, 2006), (Sääksvuori and Immonen, 2008), due to the impact that an appropriate definition can generate within the company.

However, it is not possible to speak of a standard strategy that can be successfully implemented in all organizations indifferently, since its approach varies depending on the needs, requirements and business model that the company handles as well as its corporate strategy and area of action.

Within the product strategy generated, product lifecycle management, due to its definition, and supported by software systems available on the market, offers benefits associated with a work methodology based on Concurrent Engineering, which establishes guidelines related to the design and development process which can predict, from the early stages of NPD, all requirements and limitations, including multidisciplinary working groups and the appropriate distribution of tasks and activities among the actors involved in the process.

All this must be supported by an organizational culture that generates awareness, among all members of the organization, of the importance of the implementation. This is to ensure that all people involved will act according to established guidelines, and make proper use of the software tool. For this purpose it is necessary that the strategy to be implemented in each company is built on consensus among the members of the organization, considering their views and opinions.

In order to define this strategy it is important to apply Business Process Management (BPM). BPM allows finding the "Most efficient way to bring all resources together in an end-to-end cross departmental process that add value to the customer" (Davis and Brabänder, 2007). It entails analyzing the existing processes of the company (also known as "AS-IS") aiming to define the improved new processes ("TO-BE"). "AS-IS" and "TO-BE" concepts are widely used in the "Re-engineering" field.

### 2.1.3 PLM seen as a Tool

PLM tools are information technologies developed to support and assist the PLM strategy. Its main function is to put the associated information on the hands of everyone involved in the design process, allowing to re-use it. Additionally, this type of system provides tools to coordinate and support the decision-making processes, which facilitate and expedite the product design process.

Some authors have classified PLM systems as an information management tool (Mejía et al., 2008), because it manages the information that is documented throughout the product lifecycle (CAD / CAM / CAE files, blueprints, assembly and process tables, among others) in a central database to which all stakeholders have access to. See Table 2.

*Table 2. Classification tools (Mejía et al., 2008)*

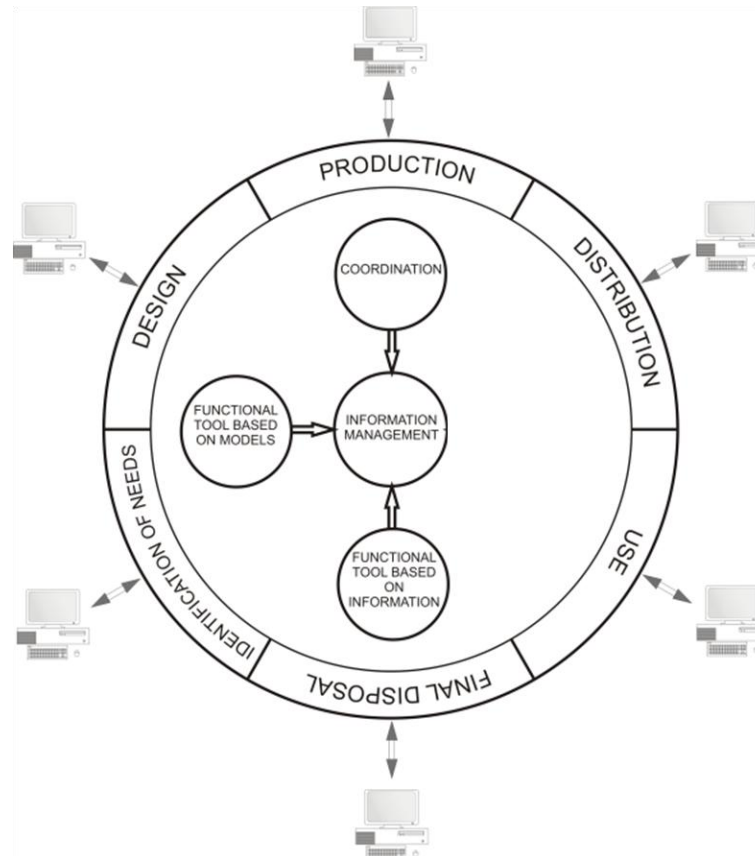
FUNCTIONALS		KNOWLEDGE AND INFORMATION	COORDINATION	COMUNICATION
INFORMATION	MODELS			
-QFD -FMEA -IDEF-0	-CAD -CAM -CAE -ECAD	-Databases -ECM -Repositories -PDM -PLM	-Project Management -Workflow -Groupware -e-management -e-project	-Videoconference -Skype -Forums -Chat -E-mail -CSW

This would imply that PLM can be considered as a coding strategy (Hansen et al., 2005), i.e. a tool that focuses on re-use of information within the company.

Coding tools are highly useful because they increase efficiency by allowing the availability of information, generated not only during an ongoing project, but also during previous projects for its reuse. Current PLM solutions are oriented to transmission and storage of explicit knowledge, which only covers a small percentage of total knowledge; the “top of the Iceberg” (Haldin-Herrgard, 2000).

However, this classification severely limits the scope of PLM solutions, and to categorize it solely as an administrative tool of information would leave out functional tools that are integrated into the platform, such as coordination, which together allow operation of the system.

Because of this, a model in which PLM is composed of a set of coordination and functional tools (based on information and models) that complement its main function of managing information in a centralized database is proposed (view Figure 3). In this way, information that is generated throughout the product lifecycle is managed and stored by PLM, and while using complementary tools, all stakeholders have full access. Throughout this approach, all the tools that conform PLM are included and this makes PLM different from other technology solutions such as PDM systems.



*Figure 3. PLM as a tool*

Most of the current PLM commercial systems on the market, manage product development from a modular approach. It entails the tool can be configured by each company based on their needs and requirements allowing configuration by modules and libraries. This feature allows PLM system to adapt to any strategy which could be defined in any company.

These modules are usually distributed in three broad areas:

- Project management: is done through portfolio management; tools like Project management, management reports and deliverables and performance analysis processes.
- Management and quality control: consider the application of methodologies such as Failure Mode Effect Analysis (FMEA) for product development, analysis of toxic substances and management of libraries associated with rules and regulations.
- Management of engineering processes: It includes CAD file management and similar, its approval flows related, Request for proposal (RFP) / Request for Quotation (RFQ) / Request for information processes and sourcing and production process design.

To realize all these processes and activities, PLM uses BPM methodologies, which allow to plan and manage processes related to each of the three areas and that in turn facilitate the management of permissions, constraints, allocating roles and responsibilities and therefore providing traceability throughout the development of a project.

Additionally, PLM solutions have a series of preconfigured templates that are widely used in the industry, such as FMEA reports, Gantt charts for project management, assembly and process blueprints, among others. These templates are associated with other functions of the system, allowing instant updating in case of carrying out any changes, allowing updated information management and achieving major reductions in development time.

The use of Bill of Materials BOM / BOP and the processes chart are also associated with different PLM action areas, because engineering process management activities are carried out in it, such as CAD / CAM / CAE integration and Sourcing; management activities and quality control including libraries such as toxic substances and regulation.

Currently, the Bill of Materials (BOM), together with workflows, are fundamental to the operation of PLM systems and as mentioned above, many of its features are based on their use. However, other tools are increasingly common in software solutions for managing the product lifecycle. This kind of tools can be included in the PLM platform or may occur through interaction with existing tools such as Microsoft Share point, thus showing a strong trend toward the integration of new tools that complement and extend the scope of PLM.

#### **2.1.4 Integration with Existing Systems**

In the business world, there are other solutions similar to PLM which are responsible for the management of information throughout the different processes that take place in a company, but with a particular approach. Such is the case of ERP, SCM and CRM, to name a few.

PLM interacts with these systems within companies; sharing with them some of its features. For example, PLM and SCM have modules for development of RFP<sup>1</sup>, RFI<sup>2</sup> and RFQ<sup>3</sup> for the selection process and allocation of suppliers. PLM and ERP make use of tools such as Bill of Materials for developing some its processes and PLM and CRM work with client's portfolios associated with projects. See Figure 4.

Although there are common features among these systems, the implementation of any of these information technologies does not exclude the other. Each of these systems has its own approach and it determine the differences in the management of the information between the functions that are shared with other systems. In this case, the focus of PLM is the information

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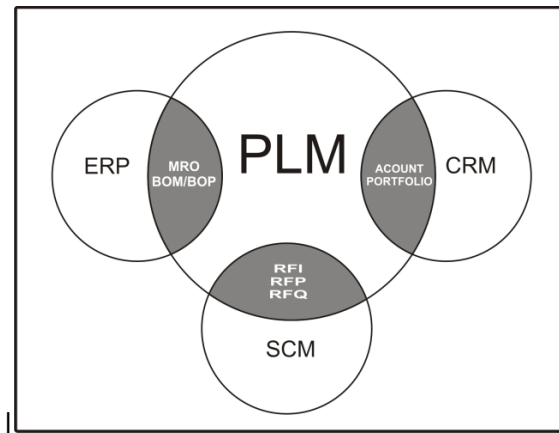
<sup>1</sup>Request for Proposal

<sup>2</sup>Request for Information

<sup>3</sup>Request for Quotation



associated with product development, while CRM is information related to customer management, to establish a baseline.



*Figure 4. Interoperability*

Thus all systems can be used in parallel within an organization, since neither replaces the other, but instead, complements it, covering the totality of the processes that take place in the company.

Because of this, and with the goal of getting a full interoperability, technologies have been developed based on markup language, such as XML to represent data and metadata, allowing them to be interpreted by all other systems; so information as Bill of Materials, assembly structure, or management of versions and change history are compatible among all of them (Srinivasan, 2008).

Thus, PLM not only ensures a wide coverage within organizations because of their inherent functions, but also allows interoperability with similar systems, so that all business processes may be covered from the focus or emphasis associated with each of the implemented information technologies. This facilitates the automation processes in companies and adequate management of information allowing greater flexibility in its daily operation.

After analyzing PLM as a system, it is important to consider the implementation requirements needed for commercial solutions currently available. The following sub-section (§2.1.5) presents an analysis of the technological requirements.

### **2.1.5 Analysis of PLM System Requirements**

As it has been exposed, PLM has undergone a major transformation since its conception as a necessity, to become a robust strategy, which, according to the size of projects and organizations who adopt them, is supported by a software tool.

This software tool must be able to support interdisciplinary teams distributed in different geographical locations and allow them connecting simultaneously to a single source of

information. This information source should have the capacity to transact large volumes of data and assign roles to manage it.

Additionally, PLM systems should allow scalability, as well as facilitate interaction with the other systems that will also be implemented by the company.

The technological development has currently allowed software vendors to develop PLM systems according to market requirements, achieving with them, the benefits expected by the industry.

However, given the complexity of PLM software architectures, organizations must incur in high investments to acquire information technologies. Often, these technologies are offered by large companies because the investment is not limited to licenses (which are expensive), but also to the acquisition of technological infrastructure (e.g. servers, database engines and technical support), plus the costs related to the implementation process and the strategy assimilation (Change management).

In order to serve all markets, PLM vendors offer versatile solutions to suit different company sizes through scalable products that support less complex architectures and therefore do not provide full functionality. This needs have been unattended at the point that some software companies have developed Open Source PLM solutions. These open solutions enabled SMEs to access the technology needed to support a strategy for managing product lifecycle.

Therefore, the implementation of PLM in organizations is a decision that requires consideration of different points, including requirements such as:

- Data Base Engine
- Operating systems (from the server and from the client)
- Architecture
- Technology
- Additional Software

Because of all of the above, four commercial PLM solutions where considered for analysis:

- “ENOVIA V6”™ from Dassault Systems<sup>4</sup>.
- “Windchill”™, from PTC<sup>5</sup>.
- “Teamcenter”™ from Siemens<sup>6</sup>
- “Aras Innovator”™ from Aras Corp<sup>7</sup>.

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<sup>4</sup> <http://www.3ds.com/products/enovia/products/enovia-v6/overview/>

<sup>5</sup> <http://www.ptc.com/products/windchill/>

<sup>6</sup> [http://www.plm.automation.siemens.com/en\\_us/products/teamcenter/](http://www.plm.automation.siemens.com/en_us/products/teamcenter/)

<sup>7</sup> <http://www.aras.com/>

From these solutions, the first three represent the most commercial and recognized in the market due to their sturdiness and wide implementation. The fourth is a relatively recent Open Source solution, whose business model is based on the assessment and technical support service associated with the implementation of the platform. This system presents almost the same functionality as commercial systems; however, it has deficiencies in connection with CAD systems, which is supplied through the installation of commercial connectors, and compatibility with different technologies.

It is important to clarify that all applications support Web access and the vast majority allow connectivity with other solutions, usually of the same parent company. The technological requirements of selected PLM systems are detailed in Table 41, to Table 44 of Appendix B. A summary of the system requirements analysis can be seen in Table 3.

*Table 3. Summary of systems analysis requirements*

<b>Database Engine</b>	<b>Operating system Server side</b>	<b>Software requirements</b>
The only PLM system which can operate with all database engines analyzed (IBM DB2, Oracle, MySQL and SQL server) is Enovia V6. PTC Windcill and Teamcenter can operate just with Oracle and SQL server; Aras Innovator only works with SQL server.	Enovia V6 can be used with AIX, HP-UX, Macintosh, Linux, Sun Solaris and Microsoft Windows. PTC Windchill also works in these systems except by Macintosh and Sun Solaris and Aras Innovator can only work with Microsoft Windows.	Teamcenter can work properly in all analyzed Web Browsers (Internet Explorer, Safari and Firefox); Enovia V6 and PTC Windchill only works on Internet Explorer and Firefox ; Aras Innovator only can be used in Internet Explorer.

Such considerations are essential when selecting the software to be implemented within a company, in terms of technological characteristics. However, it is also important to consider other aspects such as costs, suppliers and tools that they have, and applicability of the tool to the business which the company performs.

In the next section (§ 2.1.6), the action areas in which PLM operates and some applications of which there is a bibliographic record associated with PLM are presented.

### 2.1.6 Application areas

Some PLM solutions have added to their basic functions, modules designed to answer specific needs in development areas different to those that it traditionally attended. Thus, sectors such as fashion design, healthcare, packaging, and others have begun to be covered with their solutions by different software providers.

There is documentation on the use and implementation of PLM in different industries such as: manufacturing of digital components (Chiang and Trappey, 2007), thermonuclear (Muhammad et al., 2009); fashion design, which has specific solutions such as Lectra Fashion PLM (CIMdata, 2009); packaging (CPF Consumer Package Foods), through modules such as Packaging and Artwork Management of Siemens, which also considers the administration of the brand within this module (CIMdata Inc, 2009c); food, through solutions such as PLM Vivo developed by the Kalypso company (Cimdata Inc, 2009b); chemical, construction, oil and mining, which are covered by solutions provided by different companies, including SAP (CiMdata Inc, 2010); and even in the medical and pharmaceutical industry (CIMdata Inc, 2009a).

This situation shows the great reception PLM systems have had in several areas and helps to measure the growth and importance achieved in different industrial sectors. As well as there are a lot of modules and applications developed for this kind of systems, there is also literature that includes many scientific publications about PLM from different perspectives or models trying to resolve certain failures related to the management of the product lifecycle.

That is the case of Srinivasan (Srinivasan, 2008) that mentions the factors that encouraged the development of an integration system based on open standards and service oriented architecture for PLM. On the other hand, Ni (Ni et al., 2008) has focused on developing a model of flexible product structure for product families in PLM. Sharma (Sharma, 2005) proposes a system that integrates product development, collaborative work and innovation throughout the PLM platform, in order to get the benefits of each of the items integrated. Xiao (Xiao et al., 2009) presents a system model that supports aspects of modeling and simulation of virtual products. Jun (Jun et al., 2007) proposes the integration of RFID to products, so that it can capture product information generated during after-sale phases. Kakehi (Kakehi et al., 2009) develops a curriculum designed for PLM education and Alemanni (Alemanni et al., 2008) proposes a series of indicators to measure the efficiency after the implementation of PLM in companies.

All cases previously exposed allow estimating the importance of managing the product lifecycle and show the number of fields from which it can be addressed. During the last decade there has been intense research and development in the field of PLM, which enabled the existence of robust platforms. These platforms assist the strategy and, instead of becoming a constraint, offer an effective solution that is successful in the business market.

According to this literature review, no documentation of the implementations of PLM systems made in Latin America could be found, including statistics about this that could enable determining its application level.

### **2.1.7 PLM Challenges**

By analyzing several PLM tools and literature outlined on the previous pages, some of the difficulties that PLM systems have, that remain to this date, were identified:

- Connectivity and conservation of parameters between CAD systems created by software providers different from that of the PLM software.
- Information management during the after-sale phases. This is due to the distributed nature of information, together with the difficulty of establishing an effective strategy to ensure the storage of information. Technological shortcomings also play an important role as connection has to be ensured with the centralized database (even if the product is being used in areas of difficult geographical access) (Jun et al., 2007).
- The high costs involved in its proper implementation, which hinders their use in small and medium enterprises in developing countries.

This last difficulty begins to be mitigated due to the emergence of open source software in the market. However, these solutions have major shortcomings in terms of connectivity as mentioned above and may involve costs associated with the acquisition of software connectors for its implementation. Additionally, the cost of implementation is not limited to costs associated with licensing, but also with the services relating to planning and execution as strategy, and technical support associated with the system's physical infrastructure.

### **2.1.8 Conclusion**

It is clear that PLM should be considered as a strategy, which must be supported by an organizational culture that ensures a proper implementation. It uses PLM software applications as supporting tools to carry out this business strategy. Also PLM (viewed as a system) interacts with different applications such as CAD, SCM, and CRM systems, among others. It should allow new modules integration to enable communication with these systems. From this, it is possible to infer that PLM systems are in a continuous development process, and its role has changed from being just an information management platform to become a director of intellectual capital.

Accordingly, PLM has successfully integrated and used functional tools, which shows the growth of PLM and reflects the trend of trying to cover processes that were not previously covered by such systems. However, it still has not reached the sufficient level of maturity to allow PLM to fully support the last stages of the product's lifecycle, such as use, maintenance and disposal, thus leaving space for new developments.

Finally, the emergence of Open Source systems opens the door for PLM to permeate the small and medium sized business markets, which were previously unable to access its benefits due to high costs. However, there is still much to accomplish in terms of portability.

## 2.2 PLM tools analysis

For the development of PLM tools analysis four systems were considered:

- “Windchill”™ from *PTC*
- “Teamcenter”™ from *Siemens*
- “Enovia/Smarteam”™ from *Dassault Systems*
- “Aras Innovator”™ from *ARAS Corp*

The first three systems were selected because their wide recognition in the industrial environment. The last one was chosen because is an Open Source system which is also broadly known and can be used without incurring in high license costs. This last characteristic is very important, being a big opportunity for the local industry to access to these modern technologies. In the following paragraphs each system is going to be described.

### 2.2.1 Windchill™

This system is developed by *PTC* which is the same company that makes Pro Engineering and Creo CAD/CAM/CAE software. Due to this, Windchill has a direct connection with these software solutions, which means that all parameters and relationships defined during 3D modeling are directly imported from/to the PLM system automatically. It is important to note that this system also includes connectors for other CAD software.

Windchill works through a web interface developed in Java and its multilevel architecture enables different configurations, from a single server, as well as multiple servers with complex configurations. This feature is very important because it allows it to be adapted to any kind of company, regardless of its size.

This software includes some modules for manufacturing process management, CAD files management and project management through MPMLink<sup>8</sup>, PDMLink<sup>9</sup> and ProjectLink<sup>10</sup>. These modules are integrated in the system and allow managing integrally the information related to product development; conception and planning process with projectLink, detailed design with PDMLink and manufacturing through the use of MPMLink.

In order to test Windchill a three month courtesy license provided by PTC to EAFIT University was used. A team of eight members was conformed and a project which was being carried out as an academic assignment was selected to be managed with the PLM system.

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<sup>8</sup> <http://www.ptc.com/products/windchill/mpmlink/>

<sup>9</sup> <http://es.ptc.com/products/windchill/pdmlink/>

<sup>10</sup> <http://www.ptc.com/products/windchill/projectlink/>

The project started with a training process which was performed with PTC's Learning Management System named "Precision LMS<sup>11</sup>". This process meant a guided self-learning process group in which each member of the team was in charge of studying a particular assignment. Then, each member had to share all obtained knowledge with the rest of the group. Although most of the simulation exercises were performed, the project could not be executed in the system because its installation process was not successfully accomplished in the time period in which the license was available.

The main problems found during the installation process were:

- Nobody with at least half time dedication was assigned to the project for the installation process. This person was required to study the manuals and handbook provided by PTC for installation and system tests.
- An assistance or advice service for the platform installation was not available.
- EAFIT's IT Department has no knowledge or previous training in PLM system installation.
- A network infrastructure analysis at EAFIT University was not performed. This analysis was necessary to evaluate if the network had the capacity required for the number of users which would access the system.
- A dedicated server for Windchill was not available. It was therefore installed at "Pluton"<sup>12</sup>; where some other PLM software was also installed.
- The installation protocols suggested by PTC were not performed because of the lack of dedicated personnel for this task.

The Windchill test suggested for the project was not accomplished due to the problems mentioned above and the short time the license was available. Therefore it was not possible to identify its main benefits and limitations during the use stage.

### **2.2.2 Teamcenter™**

Teamcenter is considered as one of the most robust PLM solutions in the market. It has two types of architecture: Two Tier or Four Tier. These architectures are shown in Figure 5.

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<sup>11</sup> <http://www.ptc.com/company/community/education/products/precision-lms/>

<sup>12</sup> Name of the server where Aras Innovator is installed at EAFIT University.

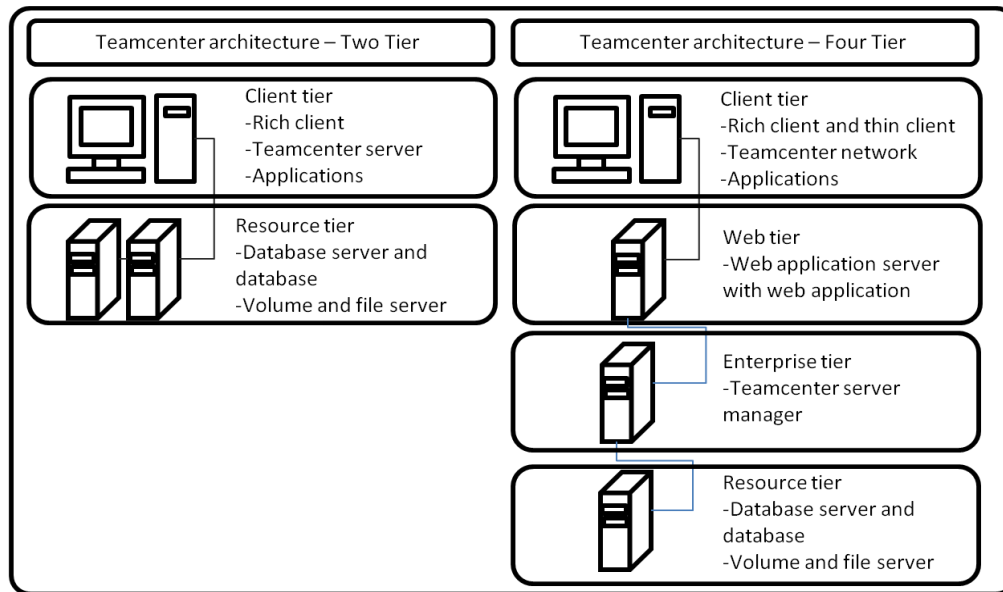


Figure 5. TeamCenter architecture

Depending on the architecture selected for PLM implementations the client can be a “Rich Client” or “Thin Client”. Each of these configurations is explained below:

- Rich client has an interface installed in each client computer. It allows to store some files and to synchronize them with the server making it easier to upload large files such as CAD, CAM and CAE.
- Thin client uses web browsers and does not require installing any interface in each client computer. Due to this only lightweight files can be uploaded or downloaded from the system.

The architecture also depends on the Teamcenter version to be installed, namely: Teamcenter or Teamcenter express. Teamcenter is the robust version of the system and Teamcenter express is the light PLM version which was developed for SMEs.

Teamcenter integrates several software developed by Siemens to manage manufacturing plant design, CAD files management, project management, among others. These operations are done through systems such as Solid Edge™, and NX™.

### 2.2.3 ENOVIA™

ENOVIA is the PLM system developed by Dassault Systems which is also the creator of CATIA™ and SOLIDWORKS™. This PLM solution is one of the most recognized and robust platforms available in the market which works via an HTTP connection, and has connectors for the main CAD software and integration tools for related systems such as SAP (Dassault systems).

The main solutions of the system are classified by “Governance user” which includes functions such as project management, product portfolio management, materials compliance and regulatory



compliance; “Engineer/Designer” which includes design functions such as Bill of materials management, change management, system engineering and Multi-CAx management and “Supply chain user” which includes the supplier and sourcing management (Dassault systemes).

Its architecture is built on a MatrixOne architecture which allows creating modular and scalable environments. It enables dynamically configuring processes and application objects, extending it when new functions are added and thus allowing optimal use of databases. The ENOVIA’s architecture makes use of a centralized database with distributed file storage (Dassault systemes) which allow storing and loading large files in order to reduce the loading time; a web server communicates the stations with the Application Servers which allows the connection between the database and the web client View Figure 6.

ENOVIA also makes use of a basic architecture in which the client is connected to a server manager which is also linked to a vault manager and a database (Wichita State University).

Testing this platform was not possible because it was not available for the development of this project. Due to this, the information exposed here comes from commercial or academic sources.

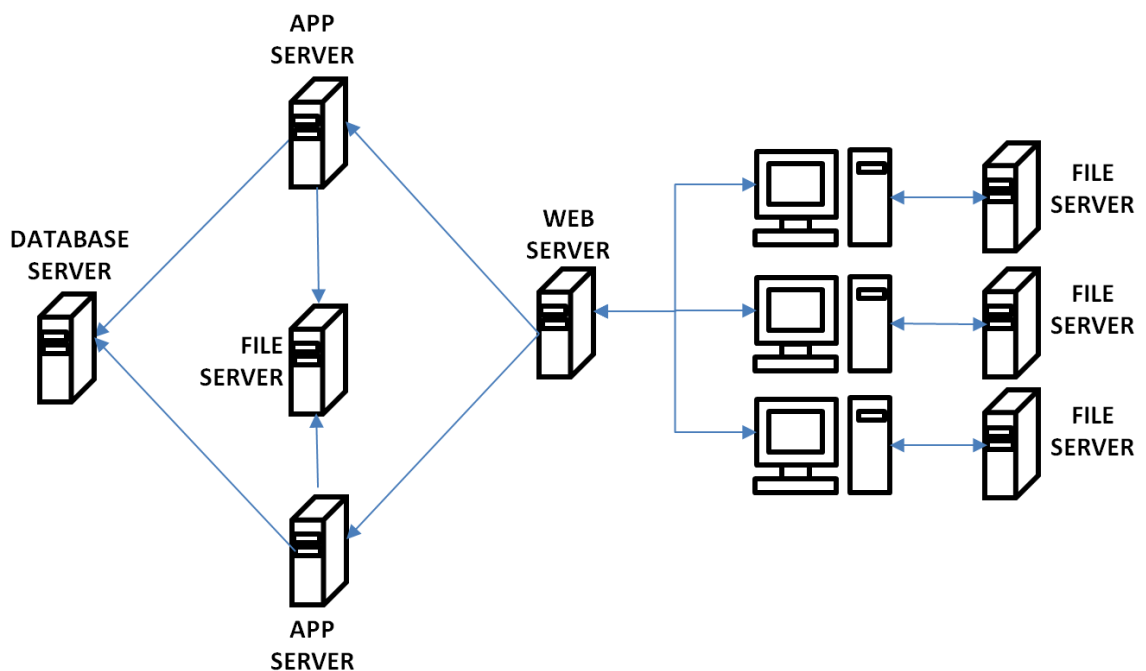


Figure 6. ENOVIA architecture

#### **2.2.4 Aras Innovator™**

Aras Innovator Is an Open-source system which can be accessed by a web browser. This is an easy to use system which includes most of the functionalities of conventional PLM systems, such as document management, project management, change management, supply management, etc.

For educational purposes it is quite useful because of its ease of use and because it can be installed without incurring in license costs (although subscriptions with additional services are also available). Due to this it can be very attractive for SMEs in Colombia.

In order to test the system, a pilot lab was established at EAFIT University during six months. In this period of time a training process was executed through the study of the Aras Innovator help tool called “Just Ask Innovator” in order to learn how to create new users, define permissions, upload documents and schedule new projects. This process was executed through the definition of a simulated project into the lab.

Once concluded that pilot experience (based on a LAN network with restricted access) the system was installed in an operational server located at the university informatics facilities. This server could be accessed through an external web address, being able to be accessed by Internet.

The established server protocols allowed accessing the system from inside and outside the University campus, making it possible to use it in several projects, as well as to test the network capacity to support the access of multiple users at the same time. The system was explored with the participation of Product Design Engineers, Computer Science Engineers and undergraduate students of Product Design Engineering.

Once the analysis was finished the main conclusions obtained were:

- Aras Innovator has most of the functionalities that conventional PLM systems have.
- Aras Innovator is an easy to install and use platform. The “help” tool is very complete and clear for new users.
- There are a lot of forums at the company’s official website which can help to solve questions related to the installation and operation of Aras.
- Because Aras Innovator is an Open source system, it allows developing new modules and functionalities which can be customized depending on each company’s specific needs.
- CAD file management is not straightforward in Aras Innovator due to the lack of free connectors between the platform and the most popular CAD systems. Due to this, the management of a CAD assembly requires manually uploading

each CAD file which composes the assembly, filling out all the metadata<sup>13</sup> related to each file, creating the BOM relationships manually and then downloading and updating all the files of the assembly when one of the pieces suffers a modification.

- Some of the system's messages are not easily understood by common users (not Computer Science Engineers) because these are coded in complex programming languages.
- The Aras Corp CEO has a close relationship with Aras Innovator users and often participates in the forum of the official website of the system. It makes it easier to solve questions related to the platform.

Considering all the benefits and limitations of the system, Aras PLM is easy to use and install and have a low cost and good performance. However, it is important to analyze how important CAD management is for the company, because it would imply an investment in additional automatic connectors.

In conclusion, although Aras Innovator has some limitations compared with conventional systems, its low cost and ease of use could make it a good option for local SMEs. In order to identify the main requirements of local environment in terms of a further PLM implementation, a local industry survey was conducted. It can be seen in section 2.3.

## 2.3 Local Industry Survey

In order to identify the local industry context in engineering projects, a survey was conducted in order to identify the current situation of the local companies, based on a set of criteria, including:

- Product Design Process Standardization
- Decision and approval processes
- Organizational chart
- Informatics tools used in the design process

This information allows identifying the implementation phase that requires the biggest effort in the performance of the methodology and the goals that must be achieved through its development in a local company. For the development of the analysis, 11 companies from the discrete product manufacturing sector were randomly selected. A short description of each company is shown below in Table 4. However, it is important to note that the real names of each company have been omitted due to confidentiality reasons.

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<sup>13</sup> Data about the file uploaded in the system. Metadata can consider information such as name of the file, type of file, version and creator, among others.

The surveys were conducted personally in each Company's headquarters and the questions were requested to different members of the design department (or equivalents). The type of survey carried out was qualitative and it was composed of open questions that were defined to analyze the level of accomplishment of the items listed in Table 5. Once obtained the information required from each company, each of the items described in Table 5 were rated in a scale from zero to five, been five the best possible qualification. See Figure 7.

In order to facilitate the analysis process and to make a comparison between the studied companies, the information obtained was classified in the main stages of the Product Development Process proposed by Pugh (Pugh, 1990): i) Market, ii) Specification, iii) Concept Design, iv) Detail design, v) Manufacture and vi) Sell. It is important to note that the Sell stage was not considered in the analysis and the name of the stages was modified for equivalent labels:

- Fuzzy Front End
- Requirement definition
- Concept development
- Detail design and
- Manufacturing

*Table 4. Company's description*

<b>Company</b>	<b>Description</b>	<b>Some Products</b>	<b>Size</b>
Company 1	Rotationally molded plastic product development.	Water storage tanks, manholes, road barriers, animal feeders, kayaks, etc.	Medium
Company 2	Injected plastic product development (Mostly packaging and house ware).	Clothing hangers, food packaging, POP, etc	Medium
Company 3	Product development for home and industrial applications.	Kitchen recipients, cleaning utensils, plastic tableware, plastic trays, feeding systems, etc.	Large
Company 4	Doors, boards and modular furniture development.	Modular furniture, doors, boards, etc	Medium
Company 5	Modular furniture development for home and offices	Cabinets, shelves, closets, libraries, desks, tables, etc	Medium
Company 6	Office furniture design and development.	Office furniture.	Medium
Company 7	Design and development of components for lighting systems, telephone, electrical, communication and telephony equipment	Public telephones, telephones, public lighting lamps, insulators, lightning rods, payment devices, etc.	Medium
Company 8	Development of engineering projects through the execution of studies, supervision, consultancy, design, etc.	Projects, studies, consultancy and design in engineering developments.	Medium
Company 9	Company dedicated to the design and development of parts and components made of aluminum alloy by injection molding.	Furniture accessories, structural elements, accessories for tents and events.	Medium
Company 10	Design, development and deployment of clean energy solutions	Power systems, water heaters, pumping systems, etc.	Small
Company 11	Designs, development and installation of escalators and elevators.	elevators and escalators	Large

*Table 5. Survey items analyzed*

<b>Number</b>	<b>Item</b>
1	The Design and Product Development process is carried out concurrently.
2	Decision-making processes are delegated
3	The company has standardized formats for process activities
4	The Design Process is documented properly
5	Activities related to FFE are carried out in a structured way.
6	A feasibility and risk analysis during the proposal selection process is included in the FFE.
7	Fieldwork is conducted for the definition of requirements
8	The definition of requirements is conducted by a multidisciplinary team
9	Structured activities are carried out for the formal design of the product (Industrial Design)
10	Structured activities are carried out for the functional design of the product or project (Systems and subsystems)
11	Activities are carried out in order to foster creativity during previous processes of proposal development.
12	Design concepts are developed by more than one person
13	Design concepts are developed by multidisciplinary teams
14	Focus groups or evaluation activities that include the end-user are carried out.
15	Engineering calculations are carried out.
16	3D models are developed by more than one person.
17	FEA Analysis and some other similar methods are carried out.
18	Detail design is carried out by a multidisciplinary team.
19	Detailed design takes into account the availability of manufacturing processes and manufacturing requirements.
20	Development and testing of prototypes is carried out
21	Intellectual property protection is considered
22	Environmental considerations are considered

The current design process of the companies was analyzed and modeled in order to synthesize the information obtained, and to have a better understanding of the processes conducted in each enterprise. These processes can be seen in Figure 8 and is presented in detail in Appendix B.

It is important to note that, in some companies, a documentation analysis was also conducted. This analysis included the examination of some forms, drawings, orders and even the Design Process Handbook if it was established in the company. This process was carried out in the enterprises that were willing to provide this kind of information (36% of the companies analyzed).

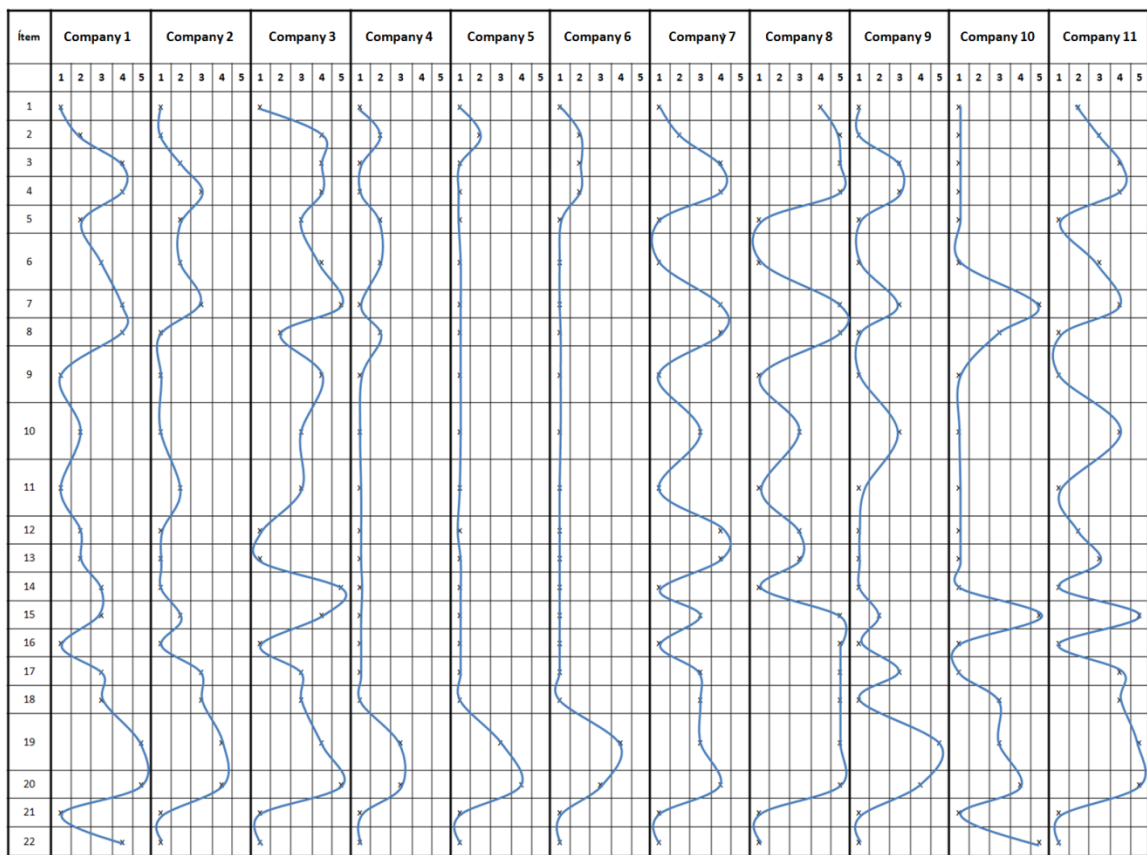


Figure 7. Companies rating

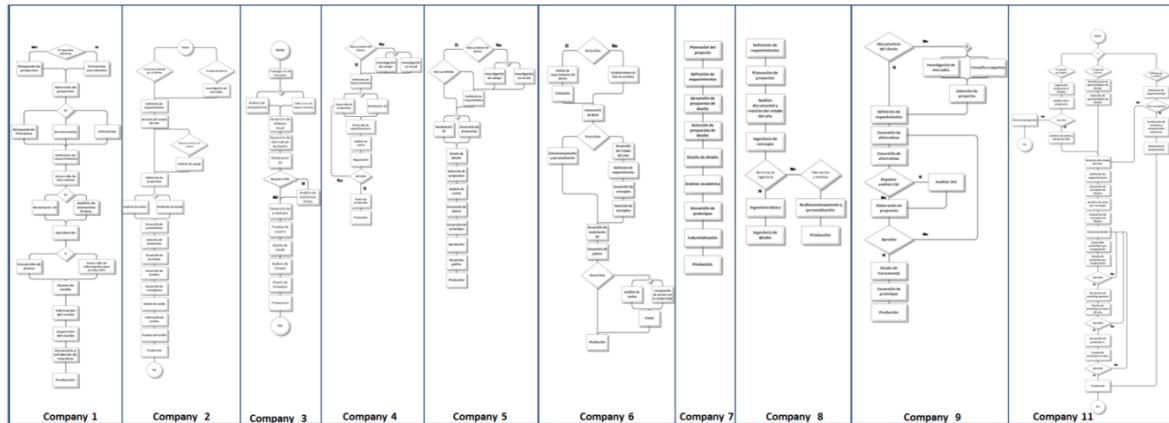


Figure 8. 11 Companies' Product Design Process

The main conclusions obtained from the survey analysis are:

Although most of the companies have certified their product design process by ISO 9001, such a process is limited to the standardization of some general activities (See Table 6). Due to that most of the stages depend on the designer's decisions and are not subjected to a methodological process. Thereby, the kind of documents created during the development of each project is different between them.

Table 6. Results of the comparison of product design activities in companies

Process	Number of companies who expressed to have established the process
Market Research	7
Project Planning	2
State of the Art Review	6
Requirements Definition	11
Development of design proposals	10
Prototype development	6
Detailed engineering	9
User Testing	4
Selection of proposals	6
Development of visual alphabet	1
Cost Analysis	6

Some companies like Company 4, Company 5 and Company 6 have not formalized their product design process, arguing that the execution of a standardized process would imply longer development times.



The “new project definition” phase is conducted by the marketing or management department in all the companies analyzed. These departments are in charge of the identification of new development opportunities or of transmitting the main requirements to the design department when the project is directly proposed by a client.

Management is in charge of the approval process of new project ideas in seven of the companies analyzed. In the remaining three this is carried out directly by the marketing department. Each company’s decision making process during product development is performed by the departments described in Table 7.

*Table 7. Decision making process in product design and development process*

<b>Company</b>	<b>Department in charge of the Decision-Making process</b>
Company 1	Management and Marketing
Company 2	Management and Marketing
Company 3	Product committee (Composed by members of marketing and design department)
Company 4	Marketing
Company 5	Marketing
Company 6	Management and Marketing
Company 7	Management committee
Company 8	Project manager and client
Company 9	Management and Marketing
Company 10	Management and client
Company 11	Management and technical experts

The definition of requirements is a process carried out in all analyzed companies. However, not all of them have a standardized format to do it. Although in eight of the companies this process is conducted by the design department, in companies where non advanced engineering processes are developed, this activity is performed by the marketing department.

In nine of the analyzed companies the “concept development” phase is performed by just one member of the design department. This implies that collaborative and Concurrent Engineering methods are not conducted. Six of the companies have not documented their conceptualization process in detail.

The “Detail Design” phase depends on the features of each product. However, ten evaluated companies perform 3D modeling during this stage. The activities conducted by each company are presented below in Table 8.

Most of the companies carry out their own manufacturing process. However there are some processes which are outsourced. The main reasons to outsource a process are that the company does not have the required infrastructure to accomplish it, or that it is more profitable to execute it outside.

In Company 4, Company 8, Company 10 and Company 11, assembling processes are also conducted.

Due to the conclusions which arose from the local industry survey, it is important to carry out a proper diagnosis and process definition willing to formalize and standardize the activities that are regularly performed in the local industry. This process must include the definition of templates, naming convention (nomenclature) and roles that will help to execute the tasks needed to achieve a successful design process. The decision making processes must also be standardized and the planning stage has to be reinforced in order to adopt a Concurrent Engineering approach.

It is also important to consider the cost of the PLM tool to be selected for the implementation because it is one of the most important factors that local companies consider when they are going to acquire these kinds of tools. Also, how easy to install and implement this kind of systems play an important role. Thus, the support service offered by these tools' suppliers is a key aspect for the companies to analyze and consider.

*Table 8.Detail design activities per company*

<b>Company</b>	<b>Activities defined</b>
Company 1	3D modeling
	FEA
	Engineering calculus
Company 2	3D modeling
	Mold filling analysis
Company 3	3D modeling
	FEA
	Mold filling analysis
Company 4	Component selection from catalog
	3D modeling
Company 5	3D modeling
Company 6	3D modeling
Company 7	3D modeling
	Concept redesign in order to adapt it to the manufacturing processes
	FEA
	Engineering calculus
	Development of prototypes and tests
Company 8	3D modeling
	Drawing
	Simulation
	Engineering calculus
Company 9	3D modeling
	FEA
Company 10	Component definition
Company 11	3D modeling
	Engineering calculus
	Mechanical simulation
	FEA
	Development of prototypes and tests

# Chapter 3. Research Approach

The research methodology used was Action Research (AR). This methodology, which is widely used in areas such as social, education, organization and administration (McNiff and Whitehead, 2002) allows acting and learning through reflecting about the action performed. This methodology which can be considered as a “collaborative approach”, enables people to solve problems through systematic action (Stringer, 2007).

## 3.1 Action Research (AR) Definition

Dick (Dick, 2002) defines AR as a “family of methodologies, each of which simultaneously pursues action and research”. This process can be achieved through the development of a series of cycles composed by three main steps (Stringer, 2007) namely: Look, Think and Act. The first step implies to collect information related to the problem to be solved and defining the situation; Thinking entails analyzing the situation and theorizing about it; and Acting means to implement and evaluate the items defined in the last stage.

Some of the main characteristics of AR are:

- It is a cyclic process.
- It is a systematic process.
- It involves action and reflection in each cycle which means that is a practical research methodology.
- The conclusions obtained from reflection feed the execution of the next cycle (if it is required).
- It can be conducted by individuals, professionals and educators(Costello, 2003)

Due to these characteristics, AR implies a deep critical analysis of the actions executed during each cycle and can be considered as a process of continuous improvement due to its cyclic nature.

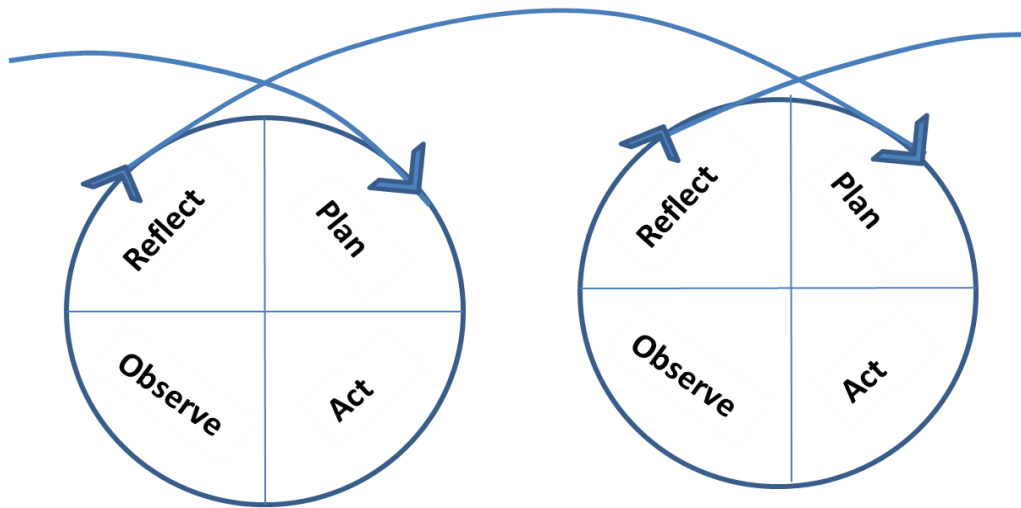
### 3.1.1 AR Cycles

Although AR was described as a process composed by three main steps which compose each research cycle (Look, Think and Act), some authors have an expanded definition of it, such as the model proposed by Kurt Lewin (Lewin, 1946), (See Figure 9) which is composed by 4 main steps:

- Plan
- Act
- Observe
- Reflect

These steps, which properly delimit each stage, allow to:

- Consider all the data required, making assumptions and defining the action to be executed through the “Planning stage”.
- Implement the actions defined in the previous phase in a practical implementation through the “Acting stage”.
- Monitor the performance of the Acting stage through the “Observing stage”.
- Analyze the situation based on the observed items and make conclusions about it through the “Reflecting stage”.



*Figure 9. Action Research Cycles*

According to Koshy (Koshy, 2005) the main advantages of AR are that it can be applied in specific situations, the researchers can play as participants, imply continuous evaluation, and theories can be formulated from the research.

Considering all the characteristics and advantages previously described, AR can be used for the development of the PLM implementation methodology, based on the plan, act, observe and reflect stages. Each cycle performed is described in this document in chapter 4.

### **3.2 Software for Case Study**

As it was mentioned in section 2.2, ARAS Innovator® is a good option for local SMEs, due to it does not require investing in license costs, it is easy to use and it includes most of the functionalities of conventional PLM systems. Thus, in the following paragraphs a deeper description of the software is presented.

Aras PLM integrates several modules such as “Quality Management”, “Supplier Management”, “Project Management”, “Process Management” and “Document Management”, among others. These modules are by default in the system and can work independently, however some others such as “project” and “parts” can integrate information which comes from the remaining modules. Due to its importance in any PLM implementation, a brief description of them is explained:

- **Project management:** Aras Innovator® integrates the activity planning, monitoring, and documents related through the project schedule. This module enables defining for each activity the execution date, role assigned, predecessor activities, and amount of hours estimated. Additionally, the system use a color code for indicating the status of the activity once the project is in execution.

The project execution control is conducted through “activity completion reports” which are filled out by the role assigned. This report is uploaded in the project schedule in order to inform to the manager the status of the activity. Additionally, the execution of the project is assisted by the use of automated notifications which inform to the role assigned when each activity should be conducted. All the information for monitoring the project can be delivered to the manager through a Gantt Chart report. A view of the module’s interface can be seen in Figure 10.

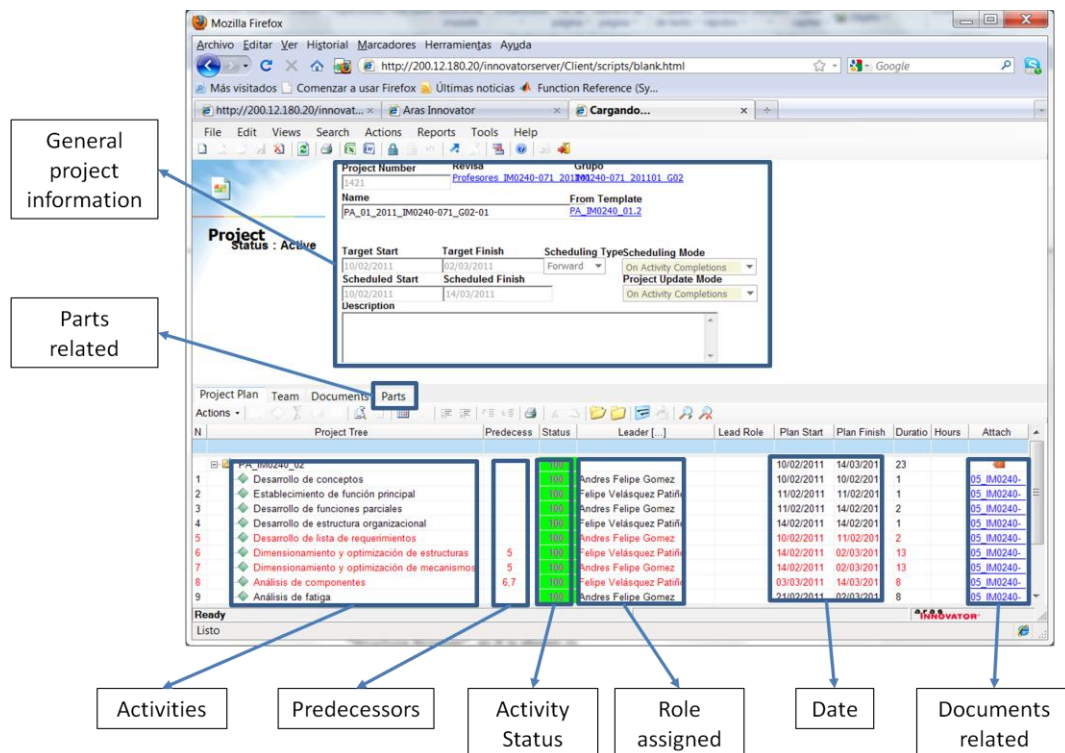


Figure 10. “Project” module interface

- **Parts (product structure):** This module integrates information which comes from other modules, using product’s component as classification criteria. In this sense all CAD/CAM/CAE files, documents, reports, and information related are put together through the BOM, as well as the manufacturing processes associated. Additionally, the system allows visualizing the information structure in a synthesized way through the “Structure Browser”, as it is shown in Figure 11.

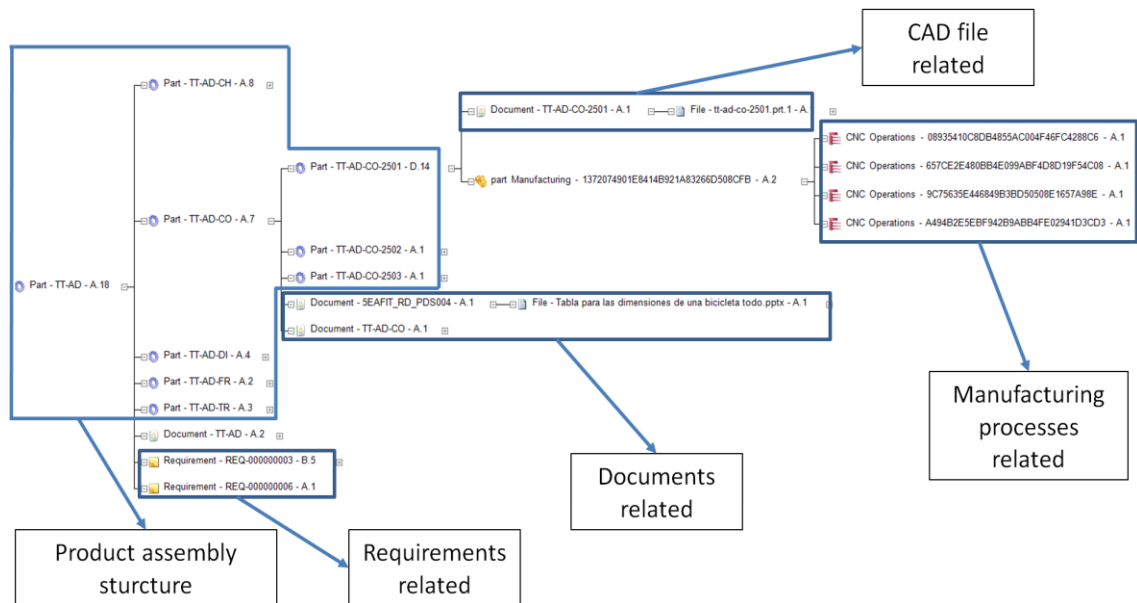


Figure 11. Product structure browser explanation

This integration is conducted through the use of “links” which allows accessing to any particular information stored in another module since the form of “Project” or “Parts”. In this sense, based on an operative perspective, CAD and project management can be considered as the backbone of the system.

This information management depends on the emphasis of any company. If their work way is based on projects, it could be useful to manage it through the “Project” module. However if it is based on products or product family it could be managed since the “Part” module. Both perspectives can also be used in parallel.

Although main operative procedures can be conducted through the “by default” modules, there is also possible to develop customized modules (which can also integrate information). These can be developed and shared by users, as Aras Innovator® is an Open Source System.

In order to ease the users to share this kind of developments, Aras provides the “Community”<sup>14</sup> which is an open space located in its web site. There, this kind of modules and developments can be uploaded and downloaded by users. Additionally there are also available forums where user’s questions can be answered by other users or Aras Corp members.

All modules which integrate the system are “Items-Types”. An “Item-Type” is a “business object” which defines all the properties and characteristics of each module. Any instantiation of an “Item-Type” is an “Item”. For example, the module “Document” is an “Item-Type” and there are defined all its properties and its way of working. Any particular document developed by a user in its daily work (such as purchase order) is an “Item”. There could be “n” “item” per “Item-Type”.

<sup>14</sup> <http://www.aras.com/aras-community/>

Some other concepts related to “Item-Type” are also important for understanding the system’s way of work:

1. User: Is any person who has a user account in the PLM system.
2. Identity: Can be considered as a “role” which is performed by any user. There can be defined “single Identities” and “group identities”. A “group identity can be integrated by other identities.
3. Permission: Defines all the access conditions for any “Item-Type”. There is established which identity can “add”, “edit” or “view” any “Item” from an “Item-Type”.
4. Lifecycle: Defines all the states in any particular “Item” could be. For example, a document could be in any of the following states: “Preliminary”, “In review” or “Released”. The permissions which govern an “Item-Type” could depend on the state in which any “Item” is.
5. Workflow: Allows automating any process in the system. It enables defining the activities, its task related and identities in charge of performing it. The system provides automatic notifications when any activity is active. This notification informs to the identity in charge when should perform the activity assigned.
6. Method: defines any particular action to be performed by system. It should be programmed in the system through the AML language. This language, which is an XML dialect, drives Aras Innovator®.

In this way, “Permission”, “Lifecycle”, “Workflow” and “Method” are also “Item-Types” and each instantiation of them are “Items”.

Any “Item-Type” integrates the instantiations of permissions, workflows, lifecycles and methods associated which describes its working way. This relation can be seen in Figure 12.



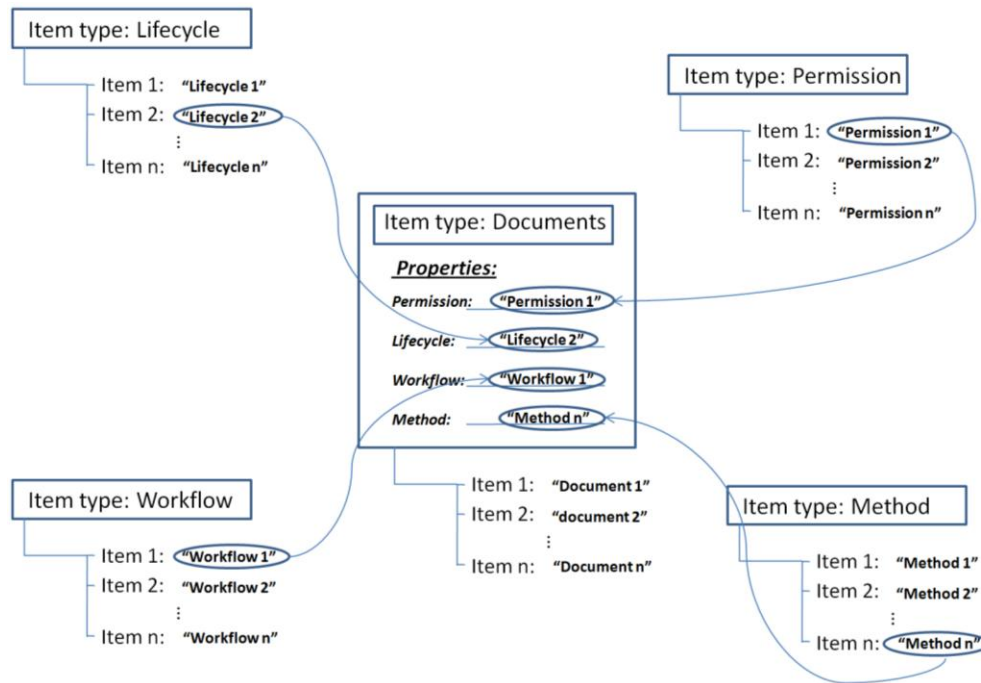
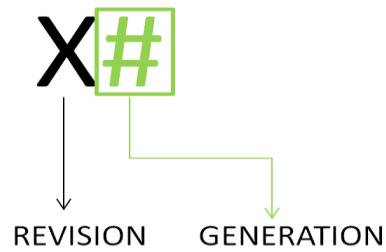


Figure 12. Item types association

Considering that PLM manages all the information related to the product lifecycle, Aras Innovator® has established “version control” and “history record” functions. “Version control” allows keeping record of different versions of any particular document or “item” in the system, while “History record” defines which versions and operations should be stored in the system. Both concepts are deeper explained below:

- Version control: Aras Innovator® has established a default “version control” for managing the modifications and eases the traceability of each “Item”. This “version control” is conducted through the “Lifecycle” of the document. Therefore the version control is performed through the use of a capital letter followed by a number as shown in Figure 13. The meaning of this code is explained below:
  - The letter is known as revision on the PLM system and it indicates the times in which the document has started a new cycle. This implies that if the document is in the first cycle, i.e, it has not been released yet, it will be labeled as A#; however if this document is in the second cycle, i.e, it have passed from released to preliminary once again, it will be labeled as B#. It will continue changing as revision cycles are performed.
  - The number is known as generation on the PLM system and it indicates the times in which the document has been edited during the cycle. This counter restarts when a new cycle starts.



*Figure 13. Version control code*

- History record: A default “History record” is also provided by the system. This process is defined as a default template on the PLM system. This template includes the recording of the amount of times in which any item on the PLM system is “added”, “updated” and “promoted”, i.e when an item is created, edited and promoted to any state of the lifecycle

Finally, once explained the main concepts which will be considered in this manuscript, a brief explanation of the Aras Innovator interface is shown in Figure 14 (for demonstrative purposes “Document” module is active in the figure)

Simple Search Page Size: 500 Max Results: Current As Of:

**Item search settings**

**Documents**

- Documents
- Ejemplos
- Formato
- Formatos de calificación
- Meetings

**Administration**

- My Innovator
- Change Management
- Dashboards
- Design
- Documents
- EAFFIT

**Table of content Modules configured (Item-types)**

**Document**

Created By: **Juan Felipe Quiceno Quintero**  
 Created On: **22/11/2011**  
 Modified By: **Juan Felipe Quiceno Quintero**  
 Modified On: **22/11/2011**  
 Locked By:  
 Major Rev: **A**  
 Release Date: **22/11/2011**  
 Effective Date: **22/11/2011**  
 Generation: **1**  
 State: **Preliminary**

**Item's historical information**

**Item's list**

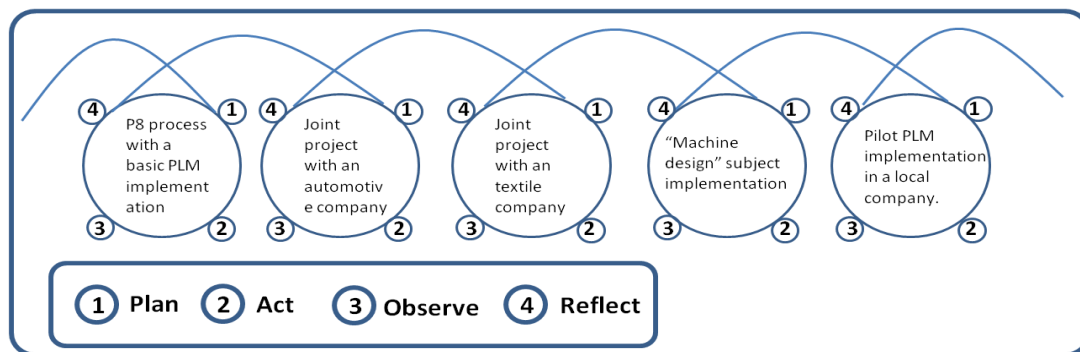
Item ID	Item Name	Item Type	Item Category	Item State	Item File
01_IP0283-160_2	TO BE ARIS	Document/Miscell	Preliminary	IP0283-160_20	
01_IP0283-160_2	01_IP0283-160_201102_PH03	Document/Miscell	Preliminary	IP0283-160_20	MESA_7.jpg
01_IP0283-160_2	01_IP0283-160_201102_PH04	Document/Miscell	Preliminary	IP0283-160_20	
01_IP0283-160_2	PLANOS	Document/Drawin	Preliminary	IP0283-160_20	
01_IP0283-160_2	RENDERS (POSTER)	Document/Miscell	Preliminary	IP0283-160_20	
01_IP0283-160_2	Design for manufacturing and a	Document/Miscell	Preliminary	IP0283-160_20	
01_IP0283-160_2	DFMA 2	Document/Miscell	Preliminary	IP0283-160_20	
01_IP0283-160_2	INFORME FINAL	Document/Miscell	Preliminary	IP0283-160_20	
01_IP0283-160_2	PRESENTACION FINAL	Document/Miscell	Preliminary	IP0283-160_20	
05_IM0240-071_1	PROPORCION TAMAÑA Y GE	Document/Miscell	Preliminary	IM0240-071_2	
05_1JN010_PH00	focalizado	Document/Miscell	Preliminary	grupo 1	Focalizacion.d
05_1JN010_PH01	PROTOCOLO DE REVISION D	Document/Miscell	Preliminary	Alumnos_Curs	
05_1JN010_PH01	Protocolo prueba FJ	Document/Miscell	Preliminary	Alumnos_Curs	3D.jpg
05_1JN010_PH01	PROTOCOLO PROCEDIMEN	Document/Miscell	Preliminary	Alumnos_Curs	
05_1JN0102_PH0	PRESENTACION ALVARO RO	Document/Miscell	Preliminary	Alumnos_Curs	corona.bmp
05_1JN0102_PH0	PRESENTACION DAVID RÍOS	Document/Miscell	Preliminary	Alumnos_Curs	Colinas azules
05_1JN0102_PH0	PRESENTACION IVAN	Document/Miscell	Preliminary	Alumnos_Curs	Colinas azules

Figure 14. Aras Innovator® interface

## Chapter 4. PLM methodology construction by AR cycles

The development of the PLM implementation process was carried out through the execution of five AR cycles. These cycles were executed making use of Aras Innovator, because it was the only PLM tool which was fully tested.

The process started with an academic implementation in order to test the behavior of Aras Innovator in real collaborative projects and to analyze reactions of people involved in the implementation (Cycle 1). The following two projects included the participation of some companies through the execution of joint projects (Cycle 2 and 3) making use of the same functions and tools tested during the first cycle. In the fourth cycle another academic implementation was conducted in order to test new functionalities in the system and finally in the fifth cycle a purely industrial implementation was executed as a pilot project. See Figure 15.



*Figure 15. AR Cycles implemented*

It is important to note that this process started with the analysis of an undergraduate final project (Sanin Perez, 2010). It consisted on implementing PLM in a design project course from the Product Design Engineering program at EAFIT University. This project compounds the two first AR Cycles.

Each cycle is described below in this chapter and the last cycle is described independently in Chapter 6.

### 4.1 Cycle 1 (C1)

This project was a pilot implementation of PLM in an Engineering Design Course named "Project-8" (P8) which is part of the Product Design Engineering program. As it was explained above, this project was part of an undergraduate final project and is fully documented at the EAFIT library where it is published (Sanin Perez, 2010).

This project can be divided in two main parts. The first one consisted in the “AS-IS” process analysis and the second one is the implementation of the “TO-BE” of the process. Both of them implied the execution of a project: the first one without the use of PLM tools and methodology and the second one with the implementation of Aras Innovator and the definition of a Design Process.

Once concluded the “AS-IS” process, the main conclusions were:

- The project schedule defined in MS Excel was not followed by the students during the project execution.
- The information managed through the email account was not well structured and much of the information created was not updated and was not well addressed.
- Tasks and Activities were not assigned properly.
- Good results in the product generated through the execution of the process not necessarily meant a proper execution of the process and some variables (such as individual member’s performance, time planning and organization) influenced the results of the product.
- Although everyone in the group was informed about their individual responsibilities, this did not mean that these people accomplished all the activities they were assigned.
- Interactions between roles had to be analyzed and planned carefully for a proper project performance.
- People involved in the Project were not aware that any delay in some activities would have repercussions in following tasks, due to the sequential nature of these projects.

Based on these conclusions Sanin defined the “TO-BE” strategy. This project included the implementation of Aras Innovator through the execution of a project developed by two teams composed by students of P8 during the first semester of 2010. This process is summarized through the following AR steps:

#### **4.1.1 C1 - Planning**

For this step the following activities were executed:

- Two student groups were selected to be followed through their project execution.
- A new Product Development Process was defined based on the problems found through the execution of the first cycle. This process included the definition of tools and methods for each activity based also on the state of the art of collaborative design and PLM.

- Aras Innovator was installed in a server from EAFIT University enabling web access for students.
- The “Project”, “Document”, “Parts” and “Meetings” modules from Aras Innovator were selected and configured to be used by the students during the project.

#### **4.1.2 C1 - Acting**

The “TO-BE” process was fully defined and modeled through the use of ARIS<sup>15</sup> Event-driven Process Chain (EPC) notation in order to be implemented in Aras Innovator. The training process was also conducted to ensure that all students involved were able to use the system. This process implied the development of several tutorials and a presentation in which the strategy and system were explained to the students. Then the project ran assisted by the PLM strategy and the software.

#### **4.1.3 C1 - Observing**

The monitoring process was conducted making use of Aras Innovator tools such a color scale (red/yellow/green). These indicators are used in the “project” module to indicate the progress reported by the students for each scheduled activity. Some performance indicators were defined in order to evaluate the effectiveness of the implementation. Indicators as enabled to compare “AS-IS” and “TO-BE” processes.

#### **4.1.4 C1 - Reflecting**

Based on measured results during the observing process, the following was concluded:

- The implementation of PLM tools for project management was successful and did not imply major difficulties for students. The feedback showed that proposed tools and work methods can be assimilated without any problems.
- Some of the problems identified during the “AS-IS” process can be solved through the implementation of the PLM tool. For example, following the project schedule, structuring information, distributing work between team members, among others.
- The Open Source software used to support the project, proved to be useful for this kind of implementations and worked correctly for a small amount of users. However, some problems related to the software implementation were identified, such as server connectivity, web browser compatibility, accessibility configuration, among others (especially with regular Operating System

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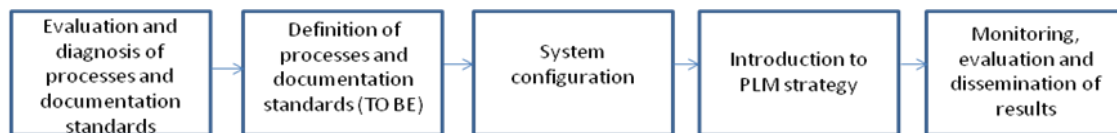
<sup>15</sup> From IDSScheer, which is a company that develops, markets, and supports Business Process Management software.

updates). These troubles were documented and most of them were also solved during the project's development.

Based on the process followed during the "TO-BE" scenario, and the implementation stages previously identified in the "AS-IS" process, the method can be interpreted as:

- Evaluation and diagnosis of current processes (AS-IS)
- Definition of processes and documentation standards (TO-BE)
- System configuration
- Introduction to the PLM strategy
- Monitoring, evaluation and dissemination of results.

The execution order of the stages can be seen in Figure 16.



*Figure 16. Implementation stages in Cycle 1*

Based on the process identified during the Cycle1 the further cycles were also defined and are explained below.

## 4.2 Cycle 2 (C2)

Considering the identified phases in the first cycle development, as well as the results obtained through the implementation of the Open-source PLM tool, a joint project with a car assembly company was set-up as a new testing scenario. The main objective with this project was to analyze the viability of conducting joint projects between the University and local industries.

The project was carried out in a course called "Special projects" from the Product Design Engineering program at EAFIT University. Considering that in the previous cycle, only one discipline<sup>16</sup> was involved, this time different disciplines were also included (mechanical and production engineering) for the execution of the second cycle. The team was composed by six students and it was directed by two University researchers and one engineer from the assembly area of the company.

The project consisted in the redesign of the two existing circuits of the engine assembly line in order to gain efficiency during the process. The project was carried out during one academic period (5 months) from EAFIT University.

Each step from the AR methodology for this cycle is described below:

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<sup>16</sup> Product Design Engineering students

#### **4.2.1 C2 - Planning**

In order to perform a fast implementation process (as required by the company) the team decides to change the sequential nature of the process identified during the first cycle. That is why the stages: “Definition of processes and documentation standards”, “system configuration” and “introduction to PLM strategy”, were proposed to be executed in parallel. The first stage (Evaluation and diagnosis of current processes - AS-IS) was not performed in the development of this cycle.

One of the course’s students was selected as system administrator in order to be in charge of the system configuration and another student was chosen as project manager.

The activities defined for the project were:

1. Analyze the current situation of the assembly line, considering the related times, activities, and tools. In order to perform this analysis the documentation provided by the company was studied.
2. Carry out and measure performance indicators in order to define:
  - Time and movements at the shop-floor
  - Components, devices and tools used in the workplace.
3. Create a virtual model of the current layout.
4. Define the design requirements for the re-design process.
5. Develop design proposals.
6. Analyze the economic feasibility.
7. Generate the documentation and virtual models for a further implementation in the company.

Based on these activities the project was divided in five phases:

1. Current processes analysis.
2. Product Design requirements
3. Design proposal development,
4. Detailed design
5. Final report.

#### **4.2.2 C2 - Acting**

Once project’s phases were clarified, the Work Breakdown Structure (WBS) was also set supported in a standard Design Process in order to define project schedule (view Figure 17).



User accounts were created in Aras innovator for each member of the team. To organize these accounts, PLM systems usually have a classification for user accounts through the definition of roles and groups<sup>17</sup> in order to simplify permissions assignments. In this manner, a “role” could represent a duty or function to be performed in the company without having to use the person’s name. This enables the definition of generic templates, processes and permissions allowing that such a function operates over all the people who are labeled by this role or group. Additionally, the group’s definition enables that each user that composes a group inherits the permissions defined for such group.

For this project, four main groups were defined:

- Project management: Role in charge of monitoring the project’s development
- Workteam: Composed by all students who were involved in the project. This group was defined in the system through the identity “Manager”. This identity allows to the members of the team visualizing the project schedule.
- Reviewers or professors: Professors from EAFIT University who directed the project. This group was defined in the system through the identity “Owner”. The system defines this identity for the “project manager” role in the “Project” module, enabling to define the permissions for this identity.
- Engineers: The engineers of the company who were involved in the project.

Considering the activities to be executed and the users and groups previously defined, the modules “Project”, “document”, “Meeting” and “part” were selected to be implemented in the project and permissions were defined for each module. The project schedule can be seen in Figure 17 and the permissions are shown in Figure 18, Figure 19, Figure 20 and Figure 21.

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<sup>17</sup> For Aras Innovator, “users” are defined in the system as well as the “identities” related to each user. The “user” is the person which can access to the system through the use of a username and a password. An “identity” can be a role which can be assumed by any user or can also be a “group”, depending on the number of users that compose such identity.

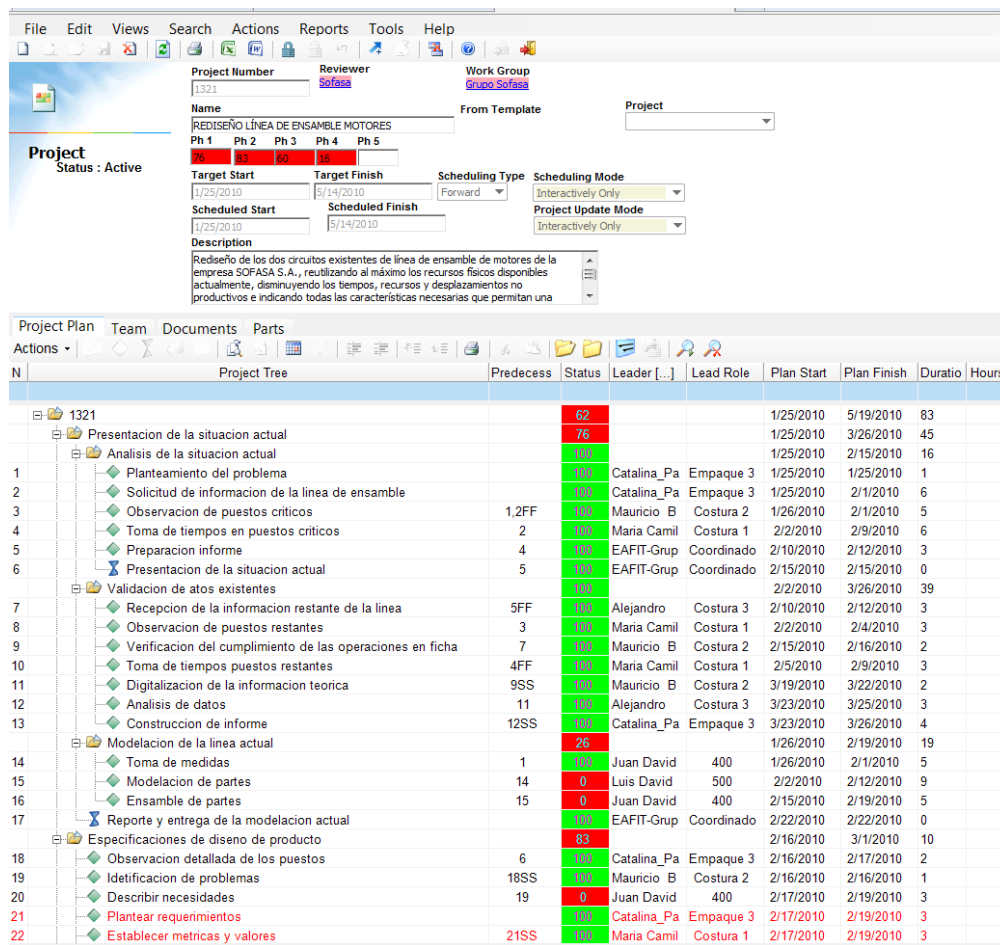


Figure 17. Project Schedule in Aras Innovator for Cycle 2

**Permission Access:**

Name	Get	Update	Delete	Can Discover	Show Permissi	Can change ac
Owner	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Project Manageme	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Profesores	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Innovator Admin	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Manager	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ingenieros	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Creator	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 18. Project's permissions for Cycle 2

http://200.12.180.20/innovat... x Aras Innovator x Cargando..

File Edit Views Search Actions Reports Tools Help

Name  
New Document

**Permission**

Access

Actions ▾ Pick Related ▾ Simple Search

Name	Get	Update	Delete	Can Discover	Show Permissi	Can change ac
Aras PLM	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Creator	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Innovator Admin	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Manager	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Profesores	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Owner	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ingenieros	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 19. Document's permissions for Cycle 2

http://200.12.180.20/innovat... x Aras Innovator x Cargando..

File Edit Views Search Actions Reports Tools Help

Name  
Open Meeting

**Permission**

Access

Actions ▾ Pick Related ▾ Simple Search

Name	Get	Update	Delete	Can Discover	Show Permissi	Can change ac
Manager	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Innovator Admin	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Creator	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Owner	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Profesores	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Ingenieros	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 20.Meeting's permissions for Cycle 2

Name	Get	Update	Delete	Can Discover	Show Permissi	Can change ac
Profesores	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Manager	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Owner	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Creator	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Innovator Admin	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Ingenieros	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 21. Part's permissions for cycle 2

Issued from PDM standardization strategies, this planning stage also included the definition of a naming convention (nomenclature) for “document management” and “CAD management”.

- For document management it included (besides the Activity Name) the phase of the project in which the document is created. Also a consecutive number was included before, in order to distinguish documents (see Figure 22).

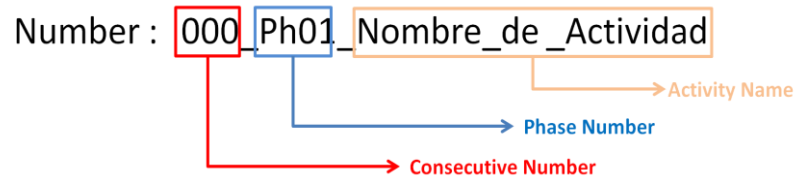
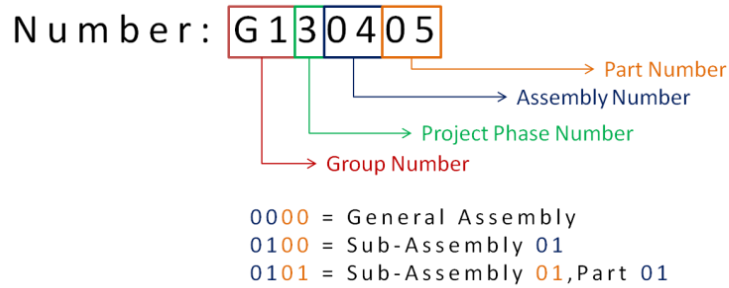


Figure 22. Naming convention (nomenclature) for documents management in cycle 2

- Likewise, CAD management naming convention (nomenclature) uses a prefix to differentiate it according to the group that owns the file. Then the project phase, followed by a code which indicates if it is an assembly, sub-assembly or a part. It ends with the Part Number. See Figure 23.



*Figure 23. Naming convention (nomenclature) for CAD management in Cycle 2*

Additionally the amount of documents uploaded in the system, “Document” module use, document duplication, nomenclature use, deliveries and activity report were defined to be analyzed through the further indicators:

- Amount of documents uploaded in the system
- Amount of people that uploaded documents in the system
- Amount of documents duplicated in the system
- Amount of documents with wrong nomenclature
- Amount of deliveries uploaded on time
- Amount of deliveries not uploaded
- Amount of activities reported on time
- Amount of activities reported as unfinished

Finally, for this C2-Acting AR phase, the implementation process was conducted in a reduced period of time (compared with previous cycles). Parallel to these activities, the training process for the members involved in the development of the project was also conducted through the use of presentations, tutorials and a demo database of Aras Innovator. Once all these activities were concluded the project started to run assisted by the PLM tool.

### **4.2.3 C2 - Observing**

In order to carry out the monitoring process, the variables which are shown in Figure 24 were defined and measured through the development of the project. The results obtained are also shown in Figure 24.

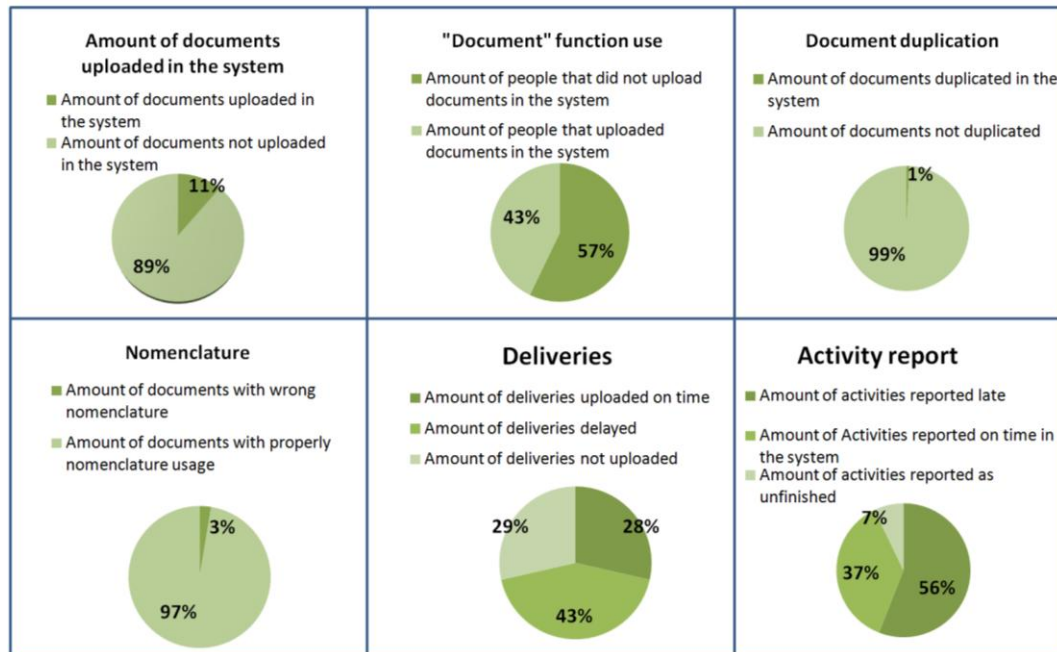


Figure 24. Indicators measured in Cycle 2 and results obtained

#### 4.2.4 C2 - Reflecting

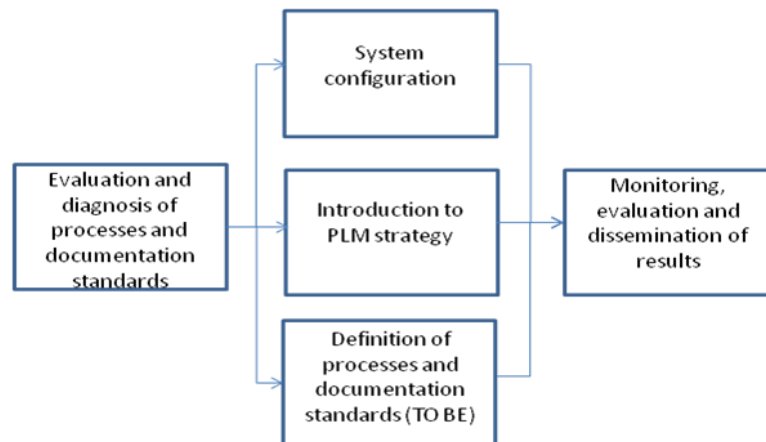
This cycle showed many problems due to light implementations which intended to reduce implementation time, specifically without a proper training process. This was evidenced by the low adaptation, use and adoption of the PLM strategy by the users. The problems identified were:

- Delays to upload documents in the system, along with the evidence that some documents related to a specific activity (scheduled in the system) were uploaded the same delivery day, shows that Aras Innovator was used merely as a documents repository rather than a work method support. This implies that the project was not carried out under the PLM strategy. This situation could be the effect of an inappropriate training process.
- Although most of the activities (66%) were reported on time in the system, 13% of them were reported as unfinished and 21% were not even reported. This implies that, even for project management and control, the tool was not properly used. A reason for this may be that many students are not used to report the progress of their activities. The training process did not emphasize the importance of this practice. Additionally, there was no direct monitoring done by the project leaders themselves, which generated loss of interest in the rest of the workgroup. 68.75% of the activities reported as unfinished, or not reported, correspond to the last scheduled activities.
- It is necessary to perform project planning jointly between all project actors in order to allow better performance and control through the "project" module.

- The monitoring process done by the company members involved in the project was poor. This situation could be due to an inappropriate training process in the tool use, a lack of interest or incentives to learn it and the restricted access to the system into the company.
- The group in charge of 3D modeling was reluctant to use Aras Innovator for CAD management. This situation could be due to the fact that this process must be done manually. It became a long and strenuous task, considering the amount of components which compose the final assembly model.

Considering the process performed during this implementation, the order of steps conducted in this process is shown in Figure 25. Based in the conclusions obtained, it is necessary to reduce the quantity of activities performed in parallel in order focus the implementation effort better and avoid problems during training. However, it is still important to avoid performing most of the activities sequentially. It is also important to follow the training process closely in order to avoid having users leave the strategy and stop using the system due to frustration resulting from lack of knowledge.

A standard new product development process was refined, in order to use it as a template for further projects, making the project planning process easier.



*Figure 25. Implementation stages for Cycle 2.*

### 4.3 Cycle 3 (C3)

According to the Figure 25, the development of this the stage “Definition of processes and documentation standards” was proposed to be conducted in this cycle independently before the stages “System configuration” and “Introduction to PLM strategy”, which were defined to be performed in parallel. This change aimed to assure more time and dedication by the implementation team for the training process and monitoring that must be performed in order to assure the adoption of the strategy. See Figure 31.

For the development of this project the activity “Evaluation and diagnosis of processes and documentation standards” was not performed, because it did not involve the performance of any current process of the company. Additionally it was the first time in which this kind of project was conducted so there was not any precedent to be analyzed.

This project was also carried out through the course “Special projects” during the second semester of 2010 and it was performed with a local clothing manufacturer. As in C2, the project was conducted by seven students from Mechanical, Production and Product Design Engineering programs. The main objective was to design and to develop two new machines which could be operated in the company in order to improve production time.

#### **4.3.1 C3 - Planning**

This project was divided in two sub-projects. One, oriented to the company’s packaging line and another one to the sewing line. The following activities were defined:

- Analyze the current situation of the sewing and packaging lines, considering times, activities and devices.
- Validate the information related with time and movements of each workplace through measuring activities.
- Validate the information related with machines, devices and tools in each workplace through measuring activities.
- Virtual model development of the company’s layout.
- Analyze existing solutions in order to create design concepts.
- Define design requirements
- Generate topologic design proposals and select one based on the design requirements.
- Analyze economic feasibility
- Generate the documentation and virtual models required for their implementation in the company.

Based on the activities defined, each sub-project was divided in three phases, namely:

- Current situation analysis
- Design proposal generation
- Design proposal evaluation

A research assistant was selected to carry out the PLM implementation and monitor the Project and one of the undergraduate student was chosen as project manager.

#### **4.3.2 C3 - Acting**

Once all phases were defined, the activities to be executed in the project were also set through the development of the Design Process and the definition of the project’s schedule, the



organizational chart of the project and the assignment of roles and activities were defined. Considering that the project was divided in two groups (packaging and sewing), two independent project schedules were defined (See Figure 26 and Figure 27). In this case the students were in charge of defining the project schedule in order to encourage team work for the project-planning and to foster a greater adoption of the strategy by all team members.

A new naming convention (nomenclature) for document management was also defined in order to facilitate its classification and avoid errors during document generation. CAD management kept the same naming convention (nomenclature) of Cycle 2 (view Figure 28). These activities concluded the TO-Be definition.

Once this phase was concluded, user accounts were created in Aras innovator for each team member of the team. In this project four roles were defined:

- Project management: Member/s in charge of monitoring the project's performance
- Workteam: Composed by all students who were involved in the Project. This group was defined in the system through the identity "Manager". This identity was selected in order to allow the team members to have access and visualize the project schedule.
- Reviewers or professors: Professors from EAFIT University who directed the project. This group was defined in the system through the identity "Owner". This identity is defined by default in the system for "Project managers".
- Engineers: The engineers of the company who were involved in the project.

Considering that the project was divided in two sub-projects, another two groups were created:

- Sewing: for one sub-project
- Packaging: For the other subproject

The permissions and functions defined for this project were the same that were used in Cycle 2. These last activities along with the project template definition in Aras Innovator composed the system configuration phase of the project which was conducted in parallel to the training process.

For the training process a series of presentations and meetings were performed in order to explain the strategy objectives and to train the users on the system use. A training platform was also developed in order to store and share all the tutorials, video tutorials and news related with Aras Innovator and the strategy development performance. The main goal of this platform was to allow users of the system to solve doubts and questions on their own at home. This web page is accessible through the address: <http://blogs.eafit.edu.co/plm/> (see Figure 29).

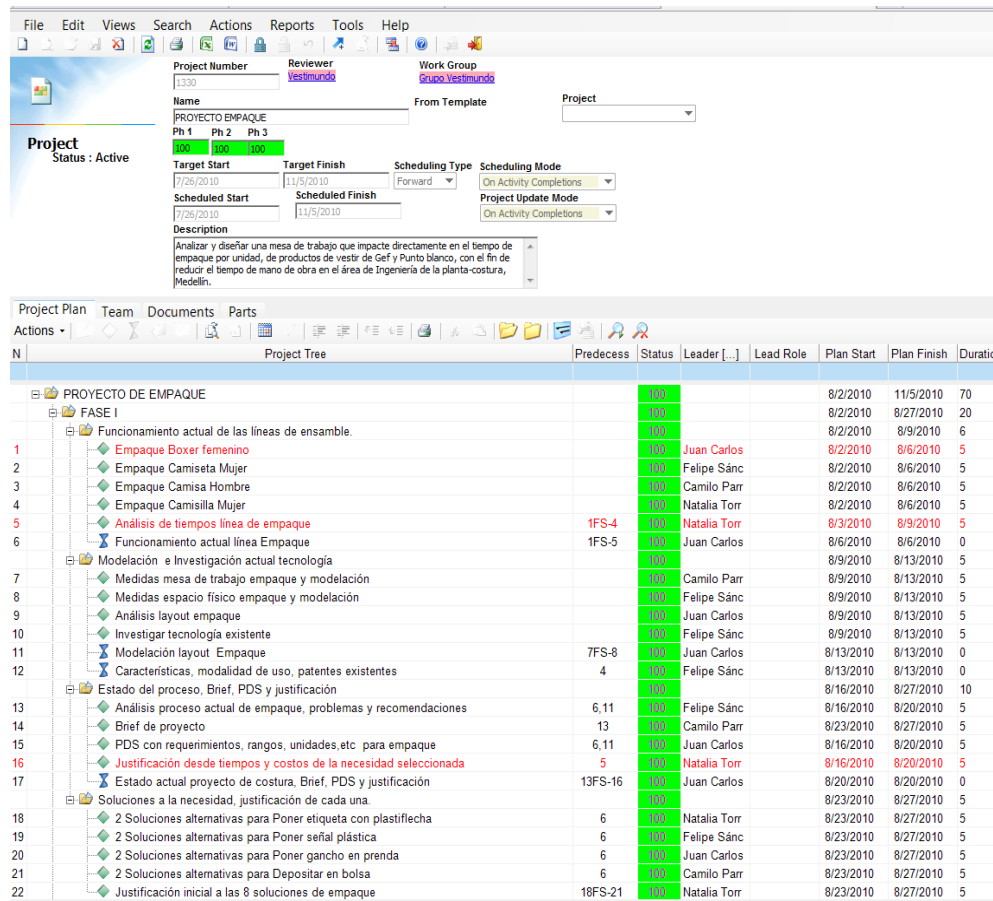


Figure 26. Project Schedule for packaging sub-project in Cycle 3

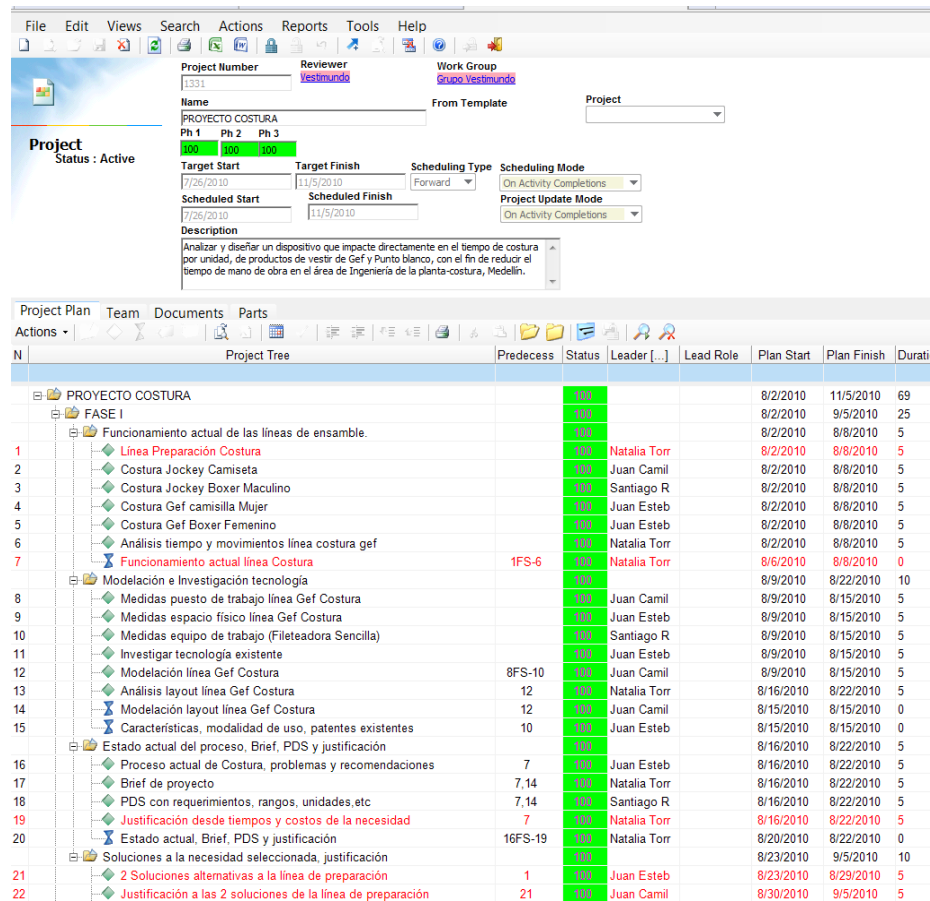


Figure 27. Project Schedule for sewing sub-project in Cycle 3

Number : **Ph01** **00**

→ Phase Number

→ Consecutive Number

Figure 28. Naming convention (nomenclature) used for document management in Cycle 3

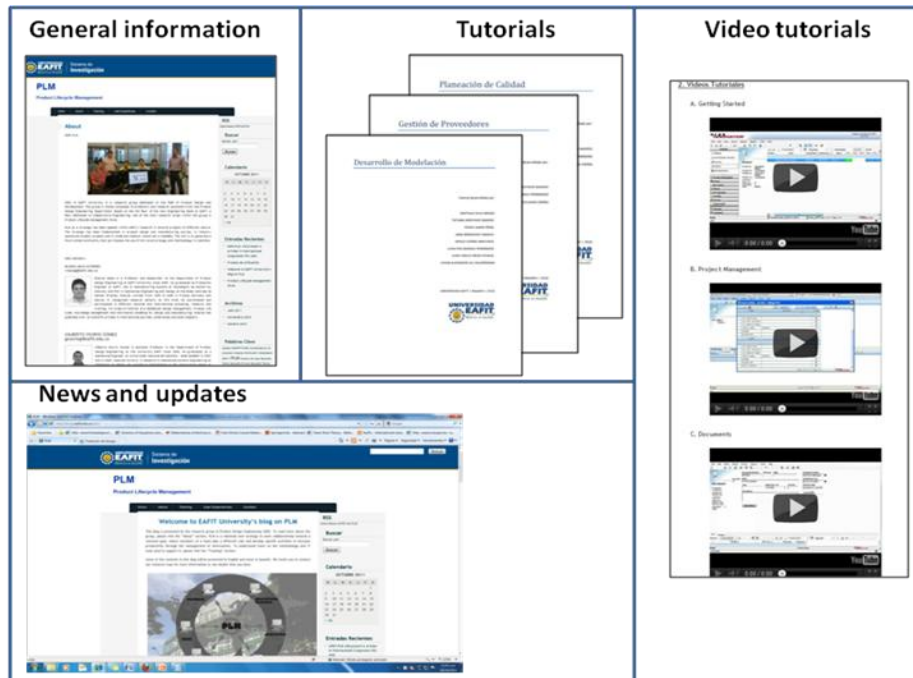


Figure 29. PLM blog for training purposes

### 4.3.3 C3 - Observing

In this phase the same indicators used in Cycle 2 were measured during the project performance. Results are shown in Figure 30.

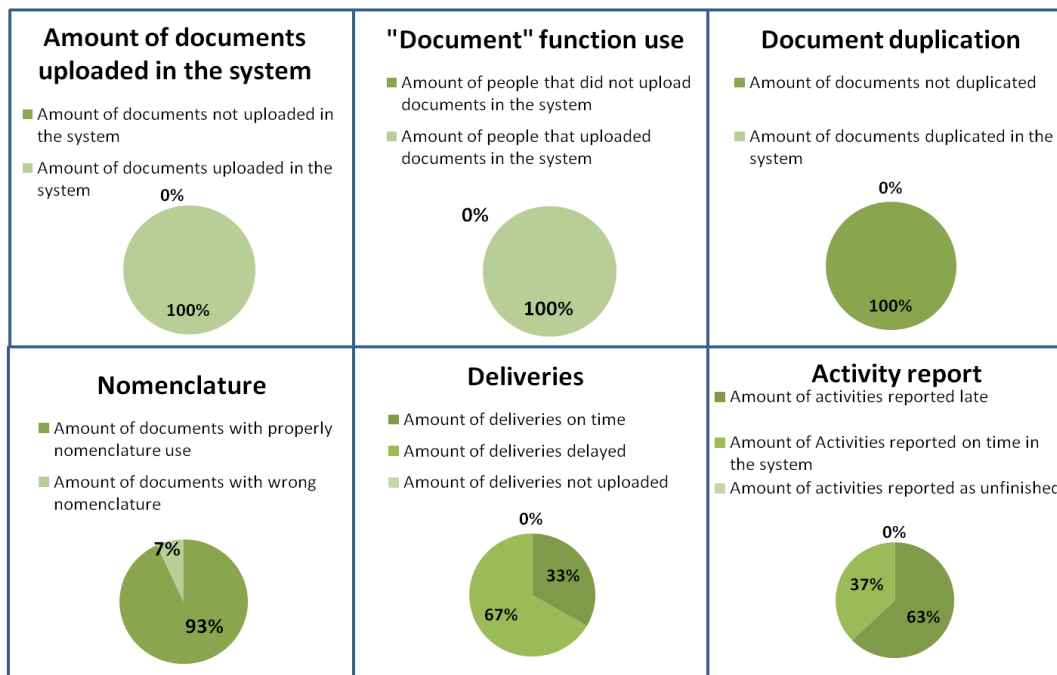


Figure 30. Indicators measured in Cycle 3 and results obtained

#### 4.3.4 C3 - Reflecting

The results obtained show that the adoption and use of the PLM tool improved significantly compared with the previous cycle. This situation can be evidenced due to the fact that 100% of the documents defined for the project execution were uploaded on the system and the project members participated. However, 66.6% of these documents were uploaded with delays showing that PLM was still used as a document repository and not as a work strategy.

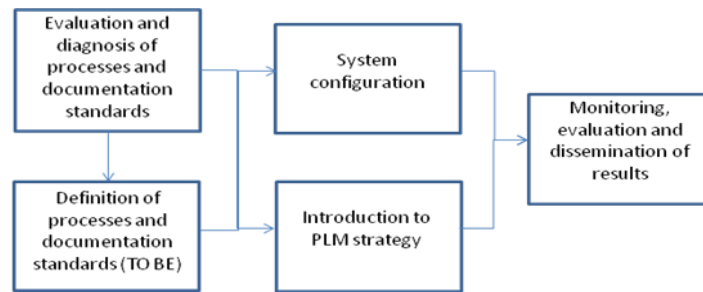
There was no document duplicity in the system and all the activities were reported on it; nevertheless, 37.17% of these activities were reported with delay.

Although the amount of errors in document naming convention (nomenclature) reduced with the new code implementation 16.41% compared to Cycle 2, this new code is not adequate for PLM implementations because it lacks important considerations for search processes. This situation is evidenced in the long list of documents, which forces any user which is looking for a particular file to open documents one by one in order to find it. Additionally, the number of identification items included in the code does not allow distinction between a document that corresponds to a given phase of a particular project to another document for the same phase of any other project. For example, the first document from the phase 1 of project A would be named as "Ph01\_01", as well as the first document from the phase 1 of project B.

Considering the aforementioned problems, the following corrective actions were proposed:

- In order to reduce delays in reporting activities and uploading documents it is required that reviewers and managers make these processes mandatory and define stimulus and sanctions. It is also important to conduct an even closer monitoring process during the first stage of the implementation, aiming to solve users' questions and quickly correct mistakes.
- It is important to improve the document and CAD naming convention (nomenclature) in order to ease the identification of parts and documents in the system. This naming convention (nomenclature) must be logically defined including all required components to differentiate them between all the documents and parts.
- New functions such as version control and document states control must be included in order to enhance the users' adoption of the PLM strategy, avoiding to have it exclusively as an information repository.

Although "Evaluation and diagnosis of processes and documentation standards" was not conducted in this Project, it was considered in the implementation process definition, based on the experience gained through the last cycles. This phase is proposed to be performed in parallel to "Definition of processes and documentation standards" in order to avoid a sequential process. The process conducted is summarized in Figure 31.



*Figure 31. Implementation stages for Cycle 3*

## 4.4 Cycle 4 (C4)

For this cycle a new academic project was set through the undergraduate course “Machine Design” from the Mechanical Engineering program at EAFIT University. The main objective of the course is to design and build All-Terrain Vehicles (ATV) in groups.

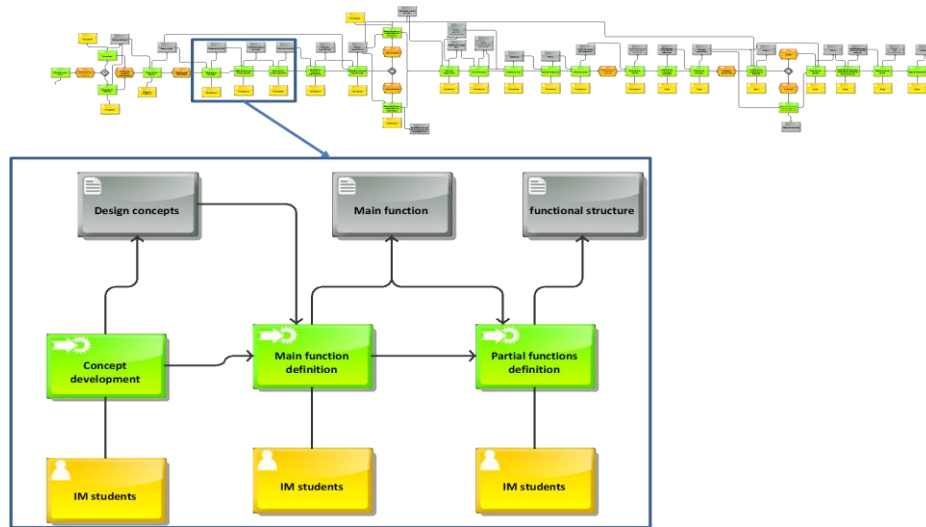
### 4.4.1 C4 - Planning

The current design process, along with the information related to the course, was analyzed. The information analysis includes the study of instructive documents per phase, templates, and the course program.

Once the Design process was analyzed, it was modeled in Aris Express (See Figure 32), including activities, milestones and information required in each activity. The information was structured based on the process model and it was not modified because it was well structured due to extensive previous implementations. This design process is composed by 5 stages:

- Stage 1.1: In this stage the design process is analyzed by students and the design problem is also studied. A requirement list is the main delivery of this stage, which must be performed by the entire group.
- Stage 1.2: The analysis process is fulfilled and conceptual design starts. For this stage each group is divided in subgroups composed by two students.
- Stage 2: Embodiment design is conducted and the entire group is together again as a whole.
- Stage 3: The construction process is carried out.
- Stage 4: Based on the experience gained through the development of the prototype, the design is refined and the project documentation is fulfilled and organized.

Each of these stages requires at least one control point, and due to this, five control points were defined.



*Figure 32. Product Design process scheme for C4*

For this particular case three groups were defined and each group was composed by the number of students shown in Table 9. The responsibilities of each team member were defined by themselves based on the information available in the course program and instructive material.

*Table 9. Number of participants per group*

Group	Number of members
1	8
2	6
3	6

This implementation included by first time document version control and document life cycle<sup>18</sup>. These lifecycles allow defining different permissions for a document or item depending on the state in which it is. The lifecycles defined for document, part and project are shown in Figure 33. These lifecycles were taken from the PLM tools implementation process proposed during the development of the research project “PLM tools implementation for engineering projects development” (Mejía-Gutierrez and Ruiz-Arenas, 2010) .

<sup>18</sup> A document lifecycle defines each of the states through which a document can pass before being approved.

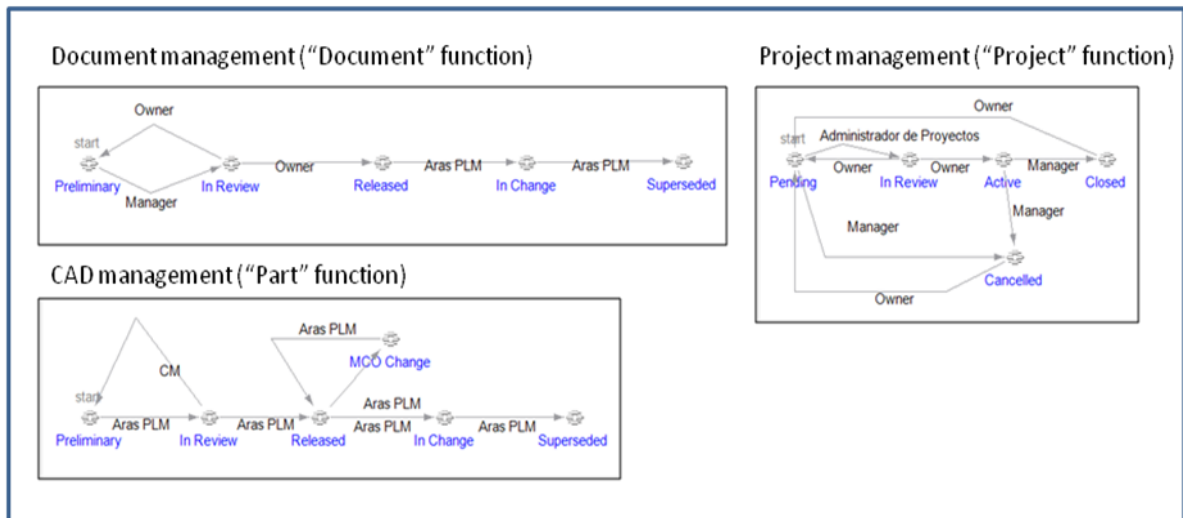


Figure 33. Lifecycle states for “Document”, “part” and “project” functions in C4

Considering the conclusions related to the naming convention (nomenclature) used in the previous cycles, a new naming convention (nomenclature) was defined based on the document standards provided by ISO 9001. See Figure 34

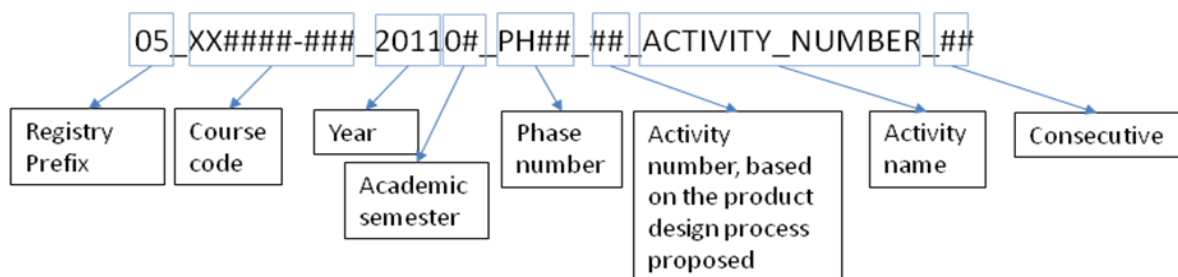


Figure 34. Document naming convention (nomenclature) definition for C4

#### 4.4.2 C4 - Acting

Previously developed training support material was also used to explain the use of the PLM platform. The training process was conducted through the development of three main presentations:

1. The strategy and the main goals of this implementation
2. Introduction to the system through the explanation of the modules “document” and “project”
3. CAD management through the module “parts”.

Once the “Definition of processes and documentation standards” was concluded, the “system configuration” stage started. It is important to note that the “Introduction to the PLM Strategy” stage (which was explained in last paragraph) started along with “Definition of processes and



documentation standards” and continued in parallel to “System configuration” through monitoring and custom advisory.

The organizational chart used for the user definition in the “System Configuration” stage is shown in Figure 37. This structure was used in order to define the document, part and project permissions to be used during the implementation. The permissions for each module were defined based in the Lifecycle stages presented in the planning stage and in the permissions defined in (Mejía-Gutierrez and Ruiz-Arenas, 2010).

During this step all instructive documents and project guides were uploaded in the system in order to be available for students (See Figure 35 and Figure 36). Project templates for Stage 1.2, 2 and 4 were also defined in order to perform project management. Stage 1.1 was not included because there was not enough time to perform the training process before this stage started. Stage 3 was not analyzed because it was mainly composed by prototype construction.

Codigo	Documento	Materia	Descripcion	Fase	Numero de la f
03_IM0240_PH01_1_05_Desarrollo_de_reporte_02	Requerimiento	Diseño de Máq	Instructivo de s	Análisis	1
03_IM0240_PH01_1_00_Guia_fase_01	Guia de introdu	Diseño de Máq	Guia de introdu	00	0
03_IM0240_PH04_01_Guia_fase_01	Guia Fase 4	Diseño de Máq	Memoria de Di	4	1
03_IM0240_PH01_1_02_Busqueda_de_literatura_	Estrategias rec	Diseño de Máq	Instructivo de p	Análisis	1
03_IM0240_PH01_1_05_Desarrollo_de_reporte_01	Cuadro Max N	Diseño de Máq	Instructivo de s	Análisis	1
03_IM0240_PH01_01_Recopilacion_de_memorias	Requisitos	Diseño de Máq	Instructivo de s	Memorias de di	4
03_IM0240_PH01_2_08_Analisis_de_componente	Pandeo 1	Diseño de Máq	Instructivo de s	Aspectos inicial	1
03_IM0240_PH02_02_Seleccion_de_conceptos_0	Selección del c	Diseño de Máq	Instructivo de s	Diseño de conf	2
03_IM0240_PH01_1_00_Guia_fase_04	Asignación de l	Diseño de Máq	Instructivo de s	0	0
03_IM0240_PH01_1_02_Busqueda_de_literatura_	Búsqueda de in	Diseño de Máq	Instructivo de p	Análisis	1
03_IM0240_PH03_01_Fabricacion_de_un_modelo	Codificación pl	Diseño de Máq	Instructivo de s	Materialización	3
03_IM0240_PH01_1_00_Guia_fase_03	Trabajo en gru	Diseño de Máq	Instructivo de p	0	0
03_IM0240_PH01_2_08_Analisis_de_componente	Funciones Rep	Diseño de Máq	Instructivo de s	Aspectos inicial	1
03_IM0240_PH01_2_08_Analisis_de_componente	Factores de Se	Diseño de Máq	Instructivo de s	Aspectos inicial	1
03_IM0240_PH04_01_Recopilacion_de_memorias	Online Technic	Diseño de Máq	Instructivo de p	Memorias de di	4
03_IM0240_PH01_2_01_Guia_fase_01	Guia Fase 1.2	Diseño de Máq	Se ocupa de l	Aspectos inicial	1
03_IM0240_PH01_2_08_Analisis_de_componente	Grados de liber	Diseño de Máq	Instructivo de s	Aspectos inicial	1
03_IM0240_PH03_01_Guia_fase_01	Guia Fase 3	Diseño de Máq	Durante la terc	Materialización	3
03_IM0240_PH01_1_01_Guia_fase_01	Guia Fase 1.1	Diseño de Máq	El trabajo de Di	Análisis	1
03_IM0240_PH02_02_Seleccion_de_conceptos_0	selección del c	Diseño de Máq	Instructivo de p	Diseño de conf	2
03_IM0240_PH01_1_02_Busqueda_de_literatura_	Criterios de bú	Diseño de Máq	Instructivo de p	Análisis	1
03_IM0240_PH01_1_01_Guia_fase_02	Definición del p	Diseño de Máq	Instructivo de p	Análisis	1
03_IM0240_PH02_07_Optimizacion_de_diseño_0	Soldaduras sec	Diseño de Máq	Instructivo de s	Diseño de conf	2
03_IM0240_PH02_01_Guia_fase_01	Guia Fase 2	Diseño de Máq	Una parte del p	Diseño de Conf	2

Figure 35. Instructive documents on the PLM system.

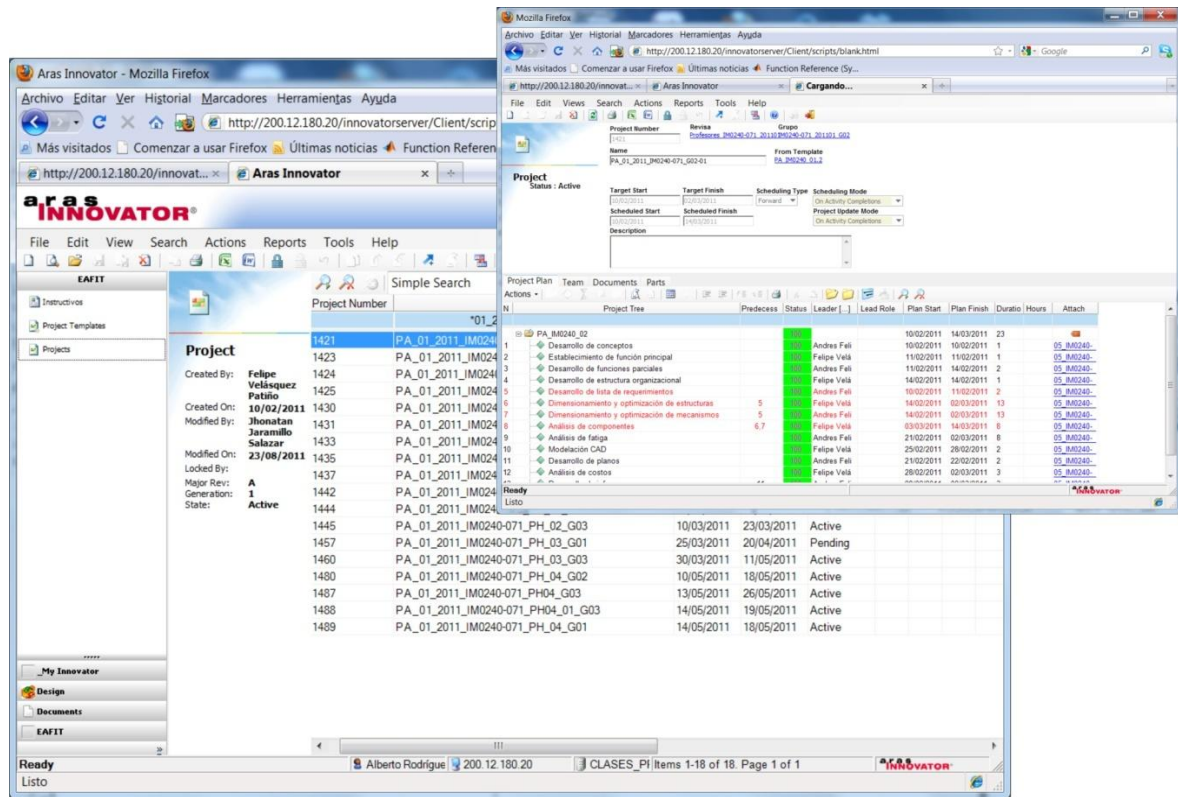


Figure 36. Stage definition for Project on Aras Innovator for C4

All system configuration elements (permissions, lifecycle, workflows, etc) defined in (Mejía-Gutierrez and Ruiz-Arenas, 2010) are adopted on the PLM implementation methodology presented in the current manuscript. These configuration elements were also a result of the experiences gained through the development of the previously described cycles.

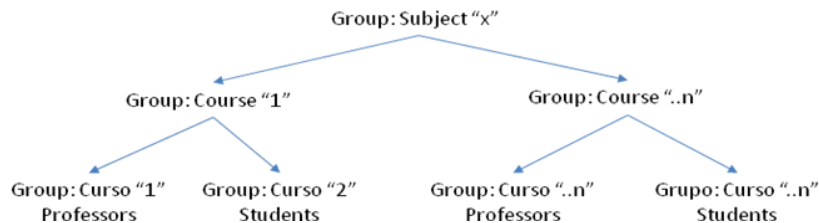


Figure 37. Organizational chart used in Cycle 4.

#### 4.4.3 C4 - Observing

New indicators were defined for analyzing the adoption of the PLM system and strategy, considering the application of new modules of the PLM tool in the project. The indicators can be seen in Table 10 .

Table 10. Indicators measured for Cycle 4

indicator's short name	Indicator	Value
PDU	Percentage of documents uploaded	82,66%
PDP	Percentage of documents promoted	52,77%
ADE	Amount of documents edited	240,5
PDWN	Percentage of documents with wrong naming convention (nomenclature)	100%
PDCN	Percentage of documents with correct naming convention (nomenclature)	0%
PPUD	Percentage of people who uploaded documents	60%
PDD	Percentage of deliveries delayed	0%
PDNU	Percentage of deliveries not uploaded	16%
PART	Percentage of activities reported on time	61,70%
PARD	Percentage of activities reported delayed	24,75%
PARM	Percentage of activity reports missing	13,53%

Let  $K$  be the set of Key Performance Indicators (KPI) used for PLM implementations, where  $i_n \in K$ , such that,  $K = \{i_1, i_1, \dots, i_n\}$ .

In this way,  $K = \{PDU, PDP, ADE, PDWN, PDCN, PPUD, PDD, PDNU, PART, PARD, PARM\}$

The implementation evolution measured per stage through the mentioned indicators, can be seen in Table 11 and Figure 38. This monitoring process was conducted in order to analyze the user learning pattern.

Table 11. Evolution of indicators for Cycle 4

Indicator	Stage 1.2	Stage 2	Stage 4
On time activity report	31,43%	75,0%	78,69%
Delayed activity reports	53,57%	12,5%	8,20%
Missed reports	22,14%	12,5%	13,11%
Promoted documents	25,00%	66,66%	66,66%
Loaded documents	48,48%	100,00%	100,00%
Percentage of document edition per person	3,81%	20,66%	17,33%
Document naming convention (nomenclature) errors	100%	100%	100%

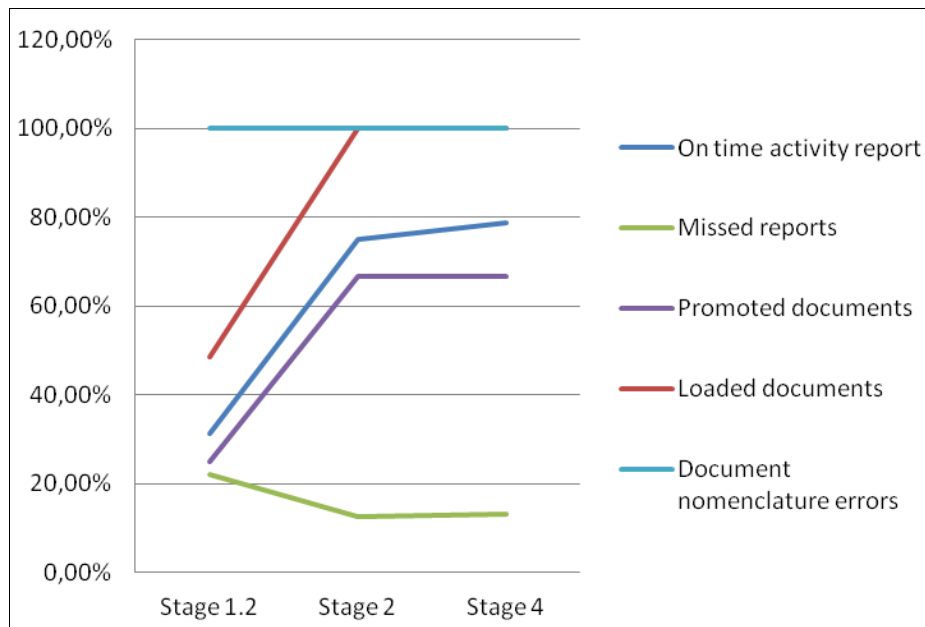
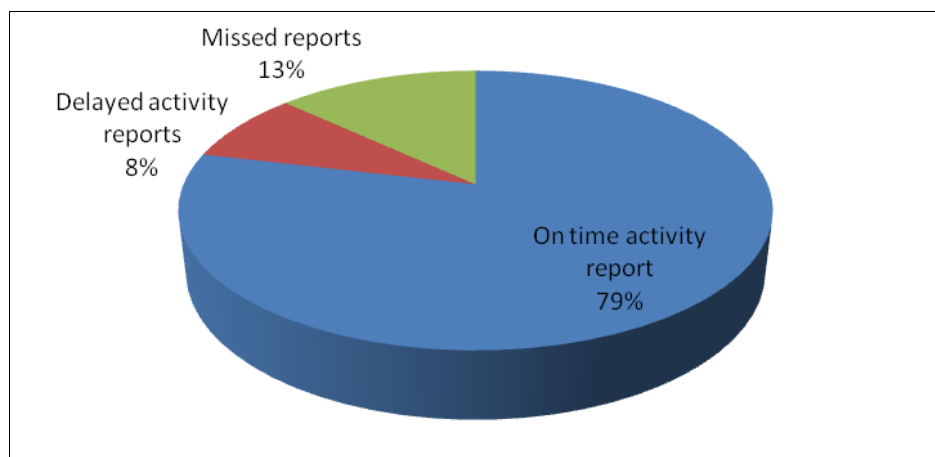


Figure 38. Evolution of PLM implementation for Cycle 4.

#### 4.4.4 C4 - Reflecting

The main reflections of C4 implementation are:

- Once the Figure 38 was analyzed, it is evident the improvement gained through the execution of each stage. This figure shows a strong enhancement in the report of activities, promotion and uploading of documents in the PLM system. This situation can be explained due to the close following process conducted by the PLM implementation team which included monitoring tasks during and after each stage of the design process.
- All documents uploaded in the system presented errors in their naming convention (nomenclature) and this situation was persistent throughout all stages of the process. It shows that the code used as naming convention (nomenclature) is not easily learned by the students, considering the number of information elements included in this code. Due to this, it is recommended to analyze this issue or look for new ways to automate the document code introduction. The user will only input some necessary elements.
- Although there was an evident improvement in the indicators during the implementation process, there was not enough time for the students to completely get used to the new management protocols which are necessary in the PLM strategy. This situation can be evidenced in the performance indicators report from Table 11 and Figure 39. Due to this, it is important to conduct longer implementations allowing users to get familiarized with the new protocols. However this process must be performed with a parallel monitoring process which guarantees that all the users' questions and problems are solved.



*Figure 39. Activity report performance for Stage 4 on Cycle 4*

- The introduction of document versions (which are reflected in document promotion) allowed to carry out a stronger PLM strategy implementation in which PLM system was really used for information management and not just as an information repository. This integration was coupled by a new definition of the work methodology which stated that every document must be uploaded empty to the system and edited each time a team member works on it. This process assures that only the latest version of the document appears on the system and its tracking process can be conducted.
- Another important element of this cycle is the early inclusion of support information related to the design process (such as Product Design Guides, Instructive Documents and Templates). This was included for the first time in this kind of implementation, supported by ISO 9001 guidelines which entailed an information analysis and naming convention (nomenclature) use. This showed to be very useful for further industrial implementations. It is important to note that these documents were developed by course's professor.

The process conducted in this cycle and its sequence can be summarized in Figure 42.

## 4.5 Cycles conclusions

The indicators measured for each cycle were compared, as shown in Table 12, Figure 40 and Figure 41. The first cycle was not included in the comparison, because it is part of an undergraduate project (Sanin Perez, 2010) which was only taken as reference for the implementation methodology. In this master project an interpretation of the implementation stages performed in the undergraduate project and a reflection about it was only conducted.

*Table 12. Comparison of indicators by Cycle.*

	<b>C2</b>	<b>C3</b>	<b>C4</b>
PDU	23%	100%	82,66%
PDWN	23,33%	6,92%	100%
PPUD	42,85%	100%	60%
PDD	42,82%	6,15%	0%
PDNU	28,57%	0%	16%
PART	65,95%	62,82%	61,70%
PARM	12,76%	0%	13,53%

The analysis conducted shows a significant improvement between C2 and C3 in all the items analyzed except in the percentage of activities reported on time. However C4 appears as a step back in comparison to C3, according to a decrease in PDU, PPUD, PDCN, PART and the increase of PDNU and PARM.

However, it is important to consider the following factors:

- C4 implied a mass implementation for which it was more difficult to conduct customized monitoring and focus the strategy in a better way. While C3 was composed by two teams of 3 members, C4 was composed by 3 teams of 8 and 6 students. Furthermore, in Stage 1.2 of C4 each group was sub divided in another 3 groups which meant a total of 9 teams working in parallel.
- In C3 and C2 the system was only used as an information repository which means that PLM strategy was not adopted by team members. In C4 however, the strategy was implemented through a new work method which implied that the document must be uploaded on the system before starting to work on it, assuring that such a document was always edited in the version stored in the platform. This situation can be evidenced in the decrease of PDD. This new work method implied new protocols and stronger changes in their work methodology, which could explain the decrease in the percentage of documents uploaded in the system.
- The new document naming convention (nomenclature) implemented in C4 was longer and included more information elements than the codes used for C2 and C3. Although this new naming convention (nomenclature) was difficult to memorize for team members, it was very useful for search processes in the system, considering the quantity of documents that could be managed in this kind of platforms. Additionally, the new naming convention (nomenclature) includes the prefix defined by ISO 9001. Instead, the naming convention (nomenclature) used in C3 was not adequate for this kind of systems because the lack of differentiating elements in the code. Due to this, it is important to analyze the document naming convention (nomenclature) again in order to apply it easier but still meet the searching process requirements. It could also be useful to automate the process of coding in each new document on the system.
- Some other variables, such as the team composition, should be analyzed in this comparison, because all the cycles developed were composed by different team members and implied the development of different projects and different products.

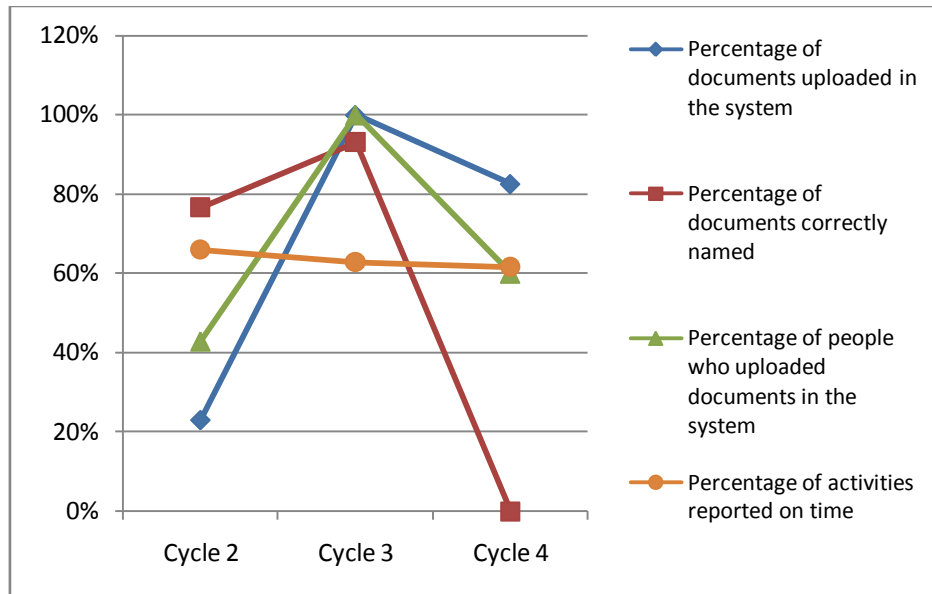


Figure 40. Comparison of PDU, PDCN, PPUD and PART by Cycle

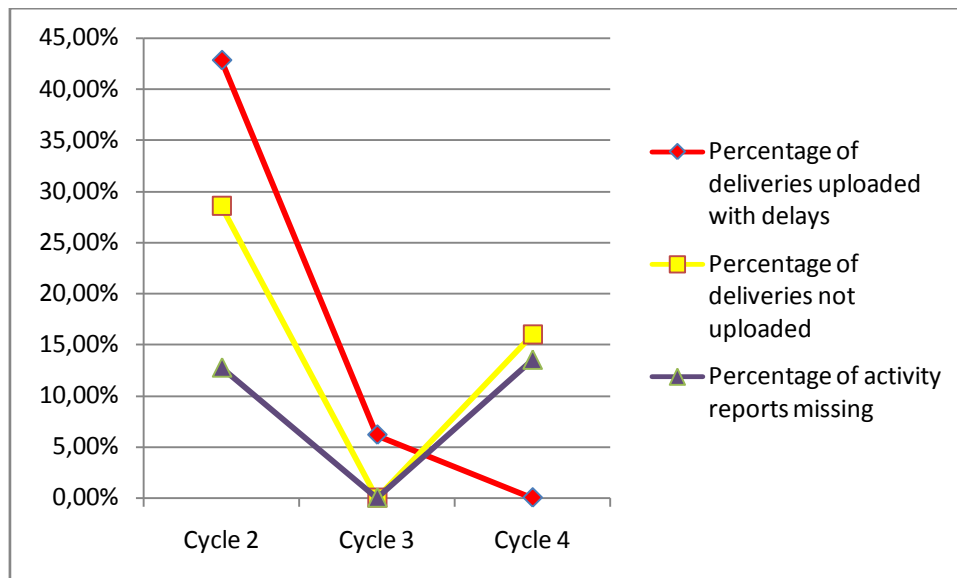


Figure 41. Comparison of PDD, PDNU and PARM by Cycle

Considering the factors mentioned above, the implementation process did not suffer a major drawback between C3 and C4. This situation can be due to in C2 and C3 the team of each project did not adopt the PLM work method. The lack of this adoption can be evidenced in the lack of traceability in documents which is very important in this kind of implementations and also missing out on benefits such as:



- Reduction of duplicated documents
- Control on document version
- Decrease in information search processes

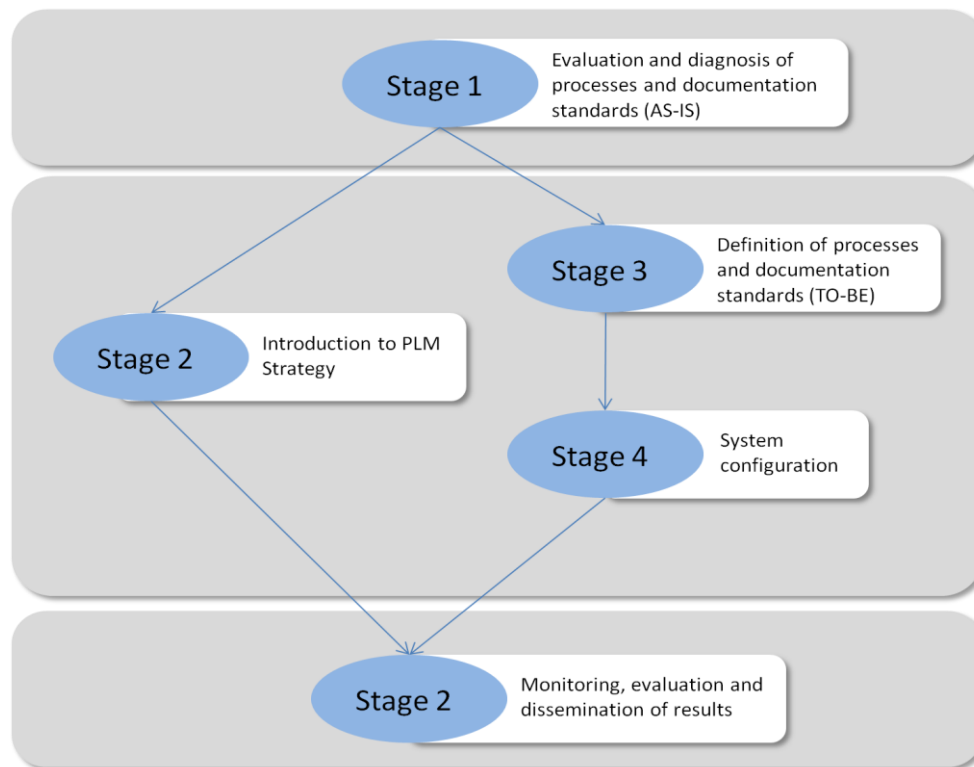
The positive learning behavior for C4 shown in Figure 38 evidences a significant improvement in all analyzed indicators. This means that a longer implementation, together with a well performed monitoring process, could provide the necessary learning process to improve the results on the remaining indicators.

## Chapter 5. Methodology description

Based on the knowledge gained through the development of the cycles described in Chapter 4, the implementation phases for the PLM implementation methodology can be organized in the following manner:

- Stage 1: Evaluation and diagnosis of processes and documentation standards.
- Stage 2: Introduction to PLM Strategy.
- Stage 3: Definition of processes and documentation standards
- Stage 4: System configuration
- Stage 5: Monitoring, evaluation and dissemination of results

This process is proposed to be conducted in the sequence shown in Figure 42:



*Figure 42. Stages of PLM implementation methodology*

1. The implementation starts studying the processes currently performed in the company. The focus will be in those that will be involved in the PLM strategy, in order to identify weaknesses, and to analyze the interaction between members. The inputs and outputs of each activity, as well as the methods and tools required for performing it must be considered during the analysis.

2. The introduction to the PLM strategy can start once Stage 1 is concluded. This step, which can start in parallel with stage 3, is performed in order to achieve a proper adoption of the strategy. Stage 2 can be conducted in two moments:
  - First moment: start with Stage 3 and carry it out in order to involve the future users in the strategy. This includes explaining what PLM is, the objectives of the strategy, how the company members will be involved, which processes will be affected, among others. In this moment a first approach to the PLM system can also be conducted through the use of DEMO systems. Once the user is aware of the changes required in the process, he can perform an active participation in the development of the re-engineering processes. This participation is very important in order to enhance the strategy adoption. Due to this it is convenient that each future user defines his own objectives (Doppler and Lauterburg, 1998).
  - Second moment: start with Stage 4. In this moment the training process in the system can be conducted in order to learn how to use it. This process can be performed once each module of the system is configured allowing a parallel process between both stages. Incremental training should be performed in order to help users to understand the system and it can be properly done through training process by module of the system to be implemented. Performing this process in parallel enables this incremental training and contributes to reduce the implementation time.
3. Stage 3 is performed in order to generate the new processes and documentation standards, considering the benefits and limitations of the PLM system to be implemented. This stage implies the development of a re-engineering process which must be conducted with the people involved in each process.
4. Once Stage 3 is concluded, Stage 4 can be performed. During this Stage, Stage 2 still may be in process, which means that both phases are executed in parallel. In this stage the system configuration is done, based on the configuration elements defined in (Mejía-Gutierrez and Ruiz-Arenas, 2010). The main objective of this step is to allow the execution of the processes and standards previously defined in the PLM system.
5. Once Stage 4 and Stage 2 are concluded, the system and processes defined can be executed and a monitoring process can begin. This process is carried out in Stage 5, allowing to analyze results and to identify and solve problems which can arise during the implementation. If these problems are not identified on time, users could drop the strategy because of a lack of motivation and frustration due to the problems faced during the system's use.

The implementation must be planned and conducted by a team composed by external members (i.e. people which are not part of the company staff) and internal members. The external members coordinate the implementation and should have a critical position in the process' evaluation. Its main function is to guide the company in the definition, establishment and

implementation of the strategy. They are involved in the performance of almost all activities, in the configuration of the PLM system and the training process. This team must have experience in the PLM strategy's implementation.

The internal team is composed by people who will be involved in the implementation. They contribute with their experience in the performance of internal processes through an active participation in the processes' analysis and definition and providing opinion about the issues defined during the implementation process. It is important to include as much people as possible in the process in order to engage them in the implementation and thus achieve a positive response from employees. Most of the new processes and protocols must be defined in collaboration with the internal team, advised by the external team.

The amount of people which compose both teams depends on the scope, impact and size of the implementation.

All the activities performed in each phase, together with its description and the objective of every stage, are described below.

## **5.1 Implementation model: Stage 1 (IM-S1)**

The main objectives of this stage are:

- Understand processes from product Life-cycle in order to identify key factors to consider for the PLM implementation. This can be done through gathering information, defining KPI, and analyzing BPM methodologies.
- Analyze currently used standards for information management within the work group in order to identify which are suitable for implementing in the PLM strategy. This can be conducted by reviewing formats, defining naming convention (nomenclature) and document version control.

In order to accomplish these objectives six activities were defined:

### **5.1.1 (IM-S1) Current processes analysis**

This activity is carried out in order to analyze and model the processes which are currently performed in the company, identifying advantages, limitations and deficiencies in them. Considering that one of the biggest problems of the local industry is the lack of standardized processes or their poor definition, this activity was divided in eleven sub-activities. For each of these sub-activities a method is proposed. Most of these methods are taken from the methodology presented in "The Reengineering handbook" (Manganelli, 1995) because it allows:

- Conducting the re-engineering processes without external advisors.
- It can be conducted in short periods of time.

- It does not require expensive tools.

The items previously shown meet the cost and time requirements of local companies identified during the local industry survey (See section 2.3). This methodology was analyzed in order to identify and select the methods which could be used for the PLM implementation process. Based on it, the sub activities and methods proposed are:

#### **5.1.1.1 (IM-S1) Analyzing the current company situation**

This activity is carried out in order to perform a diagnosis of the current company situation, for which employees and managers must be interviewed. It allows identifying weaknesses, strengths, opportunities and threats that must be considered during the PLM implementation. In order to achieve this, the method proposed to get this information is the SWOT analysis.

- *SWOT Analysis*: SWOT is the acronym of Strength, Weakness, Opportunities and Threats; strengths and weakness are related to internal variables which can be controlled by the company and opportunities and threats are related to the surrounding environment (thus they cannot be controlled). Its performance entails group sessions in which participants contribute to identify such items. This method allows conducting diagnosis processes based on consensus among participants. A deeper explanation of this method can be seen in (Kotler et al.). The chart proposed for its development can be seen in the Table 45 of Appendix C.

#### **5.1.1.2 (IM-S1) Defining the PLM implementation strategy**

Based in the SWOT analysis, the strategies to be implemented must be defined. It entails considering the Strengths that can be potentiated, the weakness that the company wants to strength and the opportunities and threats found in the environment. This definition is useful for setting the goals and directions to be taken during the implementation. These goals can be considered as the strategies and these must be formally declared. The method proposed for defining the way to achieve these strategies is the “Strategy definition table”.

- *Strategy definition table*: Based on the strategies defined it allows specifying the objectives related to each strategy and the activities which must be performed in order to achieve such objectives. Accordingly, it can be considered as an action plan for the implementation. This table includes the columns: Strategy, objectives per strategy, activities and goals. A template of this table can be seen in Table 46 of Appendix C.

#### **5.1.1.3 (IM-S1) Analyzing implementation priorities**

This task allows classifying the activities defined in the PLM strategy based on the benefit, effort and uncontrollable variables related to the performance of each activity. This is proposed considering that one of the most critical issues for local companies is the manager’s requirement

of obtaining short term results. The Effort-benefit-Uncontrollable Variables graphic is proposed as the method to conduct it.

- *Effort-Benefit-Uncontrollable Variables graphic*: It enables to classify and plot the objectives defined in the strategy definition table based on the benefits which these represent, the effort which must be invested on their performance and the uncontrollable variables which could affect the achievement of the objectives. This chart is developed based on the objectives previously defined in the implementation strategy. Each objective must be graded based on the following criteria:
  - A. In the Effort axis:
    - Time that must be invested to be achieved
    - Amount of resources required
    - Knowledge available
    - Amount of processes involved
  - B. In the Benefit axis:
    - Correlation between the objective and the strategy
    - Impact level of the objective over the strategy
    - Amount of areas or people which are positively impacted by the accomplishment of the objective
  - C. In Uncontrollable variables axis
    - Is based on particular issues related to each objective and the place in which it will be implemented

In order to grade each objective based on the criteria shown above, three main tables are proposed. The first one is used for estimating the value of the objective in the effort axis, the second one is for estimating its value in the benefit axis and the third one is for estimating its value in the uncontrollable variable axis. The process is fully explained below:

- Estimating effort ( $E$ ): Let  $C_{E_j}$  for  $j = 1, \dots, 4$  be the criteria shown in
  - A. These criteria are used as basis for estimating the effort value in the objective  $i$ , for  $i = 1, \dots, n$ . The table to be used is shown in Table 47 of Appendix C. For each  $C_{E_j}$  a weight  $W_{E_j}$  with  $\sum_{j=1}^4 W_{E_j} = 1$  should be assigned; Once  $W_{E_j}$  has been defined, a reference value  $R_{ij}$  for Objective  $i$  in  $C_{E_j}$  must also be set. This value will be used further ahead to calculate a target percentage value  $V_{EP_{ij}}$ .  $R_{ij}$  For each criterion must be set based on real data considering total values related to the implementation. For example if the time defined for the total implementation is 60 days, this is the reference number which must be specified in this field for the time criteria. Once  $R_{ij}$  is defined, the value  $V_{E_{ij}}$  of Objective  $i$  for each criterion  $C_{E_j}$  must also

be set. This entails the implementation team must discuss each objective based on the criteria proposed and defining  $V_{E_{ij}}$ . For example, if for implementing the objective 1 the time estimated for accomplishing it is 5 days, this is the value which must be set in this field. Once  $V_{E_{ij}}$  have been defined,  $V_{EP_{ij}}$  can be calculated through:

$$V_{EP_{ij}} = \frac{R_{ij}}{V_{E_{ij}}} * 100 \quad (1)$$

Then, based on  $V_{E_{ij}}$ , the score  $S_{ij}$  for objective  $i$  can also be set, for which the “Rating scale based on percentage table” which is shown in Table 48 of Appendix C is used; this table specifies  $S_{ij}$  in a scale from 1 to 5 based on  $C_{E_j}$ . For example, if the percentage value calculated for objective 1 is 5%,  $S_{ij}$  is 1, because 5% is between 0 and 20%. Once the  $S$  is calculated the weighted value  $W_{VE_{ij}}$  can be calculated through:

$$W_{VE_{ij}} = W_{E_j} * S_{ij} \quad (2)$$

Then, the position  $E_i$  of objective  $i$  is given by:

$$E_i = \sum_{j=1}^4 W_{VE_{ij}} \quad (3)$$

- Estimating benefit ( $B$ ): Let  $C_{B_j}$  for  $j = 1, \dots, 3$  be the criteria shown in B. This criteria is used as reference to find the value of objective  $i$ , for  $i = 1, \dots, n$  in the benefit axis. This process should be performed in the table shown in Table 49 of Appendix C. For each  $C_{B_j}$  a weight  $W_{B_j}$  with  $\sum_{j=1}^3 W_{B_j} = 1$  should be assigned. The implementation team discusses objective  $i$  based on  $C_{B_j}$  and sets the value  $V_{B_{ij}}$  of Objective  $i$  for each criterion  $C_{B_j}$ . This value should be set between 0 and 5. Then the weighted value  $W_{VB_{ij}}$  can be calculated through:

$$W_{VB_{ij}} = W_{B_j} * V_{B_{ij}} \quad (4)$$

Finally, the position  $B_i$  of objective  $i$  is given by:

$$B_i = \sum_{j=1}^3 W_{VB_{ij}} \quad (5)$$

- Estimating the Uncontrollable Variable ( $UV$ ): Let  $C_{UV_j}$  for  $j = 1, \dots, n$  be the uncontrollable variables related to objective  $i$  for  $i = 1, \dots, n$ . Each of these variables (identified by the implementation team) should be placed in Table 50. For each  $C_{UV_j}$  a weight  $W_{UV_j}$  with  $\sum_{j=1}^n W_{UV_j} = 1$  should be assigned. Once  $W_{UV_j}$ , has been defined, the

team defines the probability  $V_{UV_{ij}}$  of each variable  $C_{UV_j}$  affecting the objective  $i$ , in a scale from 0 to 5, being 5 the highest probability. Then the weighted value  $W_{VUV_{ij}}$  can be calculated through:

$$W_{VUV_{ij}} = W_{UV_j} * V_{UV_{ij}} \quad (6)$$

Finally, the position  $UV_i$  of objective  $i$  is given by:

$$UV_i = \sum_{j=1}^n W_{VUV_{ij}} \quad (7)$$

Once the rating process is concluded, each activity must be located in the space which is shown in Figure 43. Based on this analysis the objectives to be performed at first during the implementation process are those which are placed in the 1<sup>st</sup> quadrant because they generate a high benefit with a low effort and with few uncontrollable variables. Therefore, they allow to obtain short term goals. The following objectives could be those which are placed in the 3<sup>rd</sup>, 5<sup>th</sup> and 7<sup>th</sup> quadrant because although these imply less benefits or more uncontrollable variables, they can be performed with a low effort. These objectives can be considered as the midterm accomplishments. Finally, the objectives which are placed on the 2<sup>nd</sup>, 6<sup>th</sup>, 4<sup>th</sup> and 8<sup>th</sup> quadrants can be considered for long term accomplishments because those objectives imply greater efforts to achieve them.

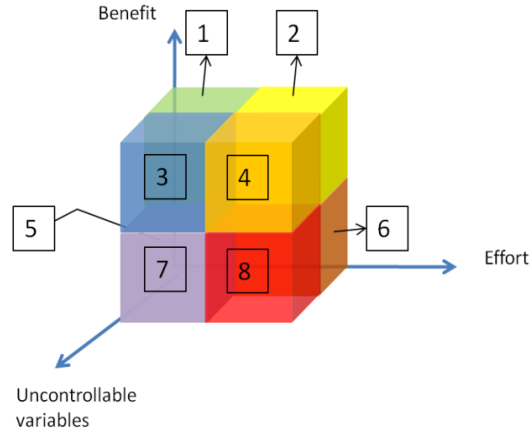


Figure 43. Scheme of the Benefit-Effort-Uncontrollable Variables graphic

#### 5.1.1.4 (IM-S1) Identifying entities

This activity entails the identification of entities, transactions and object states which can be present in the company. A state is an adjective which can be given to any item, i.e, “operating” for describing a machine state; transaction is a process which is conducted during a period of time such as a “request order” or “approval process”; and people or any other thing which can contain attributes can be considered as an entity (Manganelli, 1995) . The entities selected to be analyzed



are those which are related to the activities and strategies previously defined in 5.1.1.2. The method proposed to identify them is the “Entity table”.

- *Entity table*: This method allows identifying the processes conducted in the company as a sequence of state changes and the information related to those states. This method is taken from “The Reengineering handbook” (Manganelli, 1995), where a deeper explanation can be seen. Its template can be seen in Table 51 of Appendix C.

#### **5.1.1.5 (IM-S1) Identifying activities**

Based on the state changes analyzed on the “entity table”, the activities which compose each process are identified. The method proposed for it is the “Activity identification table”.

- *Activity identification table*: This activity is also taken from Manganelli and Klein (Manganelli, 1995), and it takes the entity table previously defined and determines the activities required to perform each change in a state. A deeper explanation can be seen in (Manganelli, 1995) . The template for this method can be seen in Table 52 of Appendix C.

#### **5.1.1.6 (IM-S1) Identifying roles**

This activity allows identifying the roles related to the processes analyzed in the Entity and Activity identification table. Through its performance it is expected to understand the responsibilities and contribution of each role in the company and in the processes analyzed. The method proposed for performing this activity is the “Roles characteristics table”.

- *Roles characteristics table*: It is used for analyzing each role associated to the processes identified or to *who* will participate in the implementation. This table is composed by 4 fields: “Role”, which specifies the name of the position in the company. “Responsibility”, where the main tasks of the role are described. “Knowledge”, which specifies the knowledge and skills required for the accomplishments of the responsibilities. Finally “tools”, where some of the resources required for the performance of tasks are described. This method is also explained deeper in (Manganelli, 1995). The template is shown in Table 53 of Appendix C.

#### **5.1.1.7 (IM-S1) Identifying the resources related to the processes**

This activity allows identifying the roles and resources related to each activity determined in the “Activity identification table”. The method proposed for performing this activity is the “Resources table”.

- *Resources table*: This method relates roles and resources to the activity previously defined in the “Activity identification table”. It allows visualizing the

steps and resources involved in each process. This method is explained better in (Manganelli, 1995), where it is taken from. The template is shown in Table 54 of Appendix C.

#### **5.1.1.8 (IM-S1) Analyzing processes' interactions**

This activity is proposed in order to identify the type of contribution or participation of the roles previously identified in the performance of the activities determined in the "Activity identification table". The method proposed for conducting this activity is the "R-N-I Table".

- *R-N-I Table*: This method is based on the resources table previously defined which relate roles and activities. The R-N-I table also specifies the type of participation of each role in the development of the activities classifying it with the labels "responsible" (R), "receives notification" (N) and "works as an input" (I). For PLM implementation a "monitoring" (C) label is proposed. This method also explained in (Manganelli, 1995). Its template is shown in Table 55 of Appendix C.

#### **5.1.1.9 (IM-S1) Modeling processes**

Based on the analysis conducted through the development of the previously mentioned methods, the process can be modeled including: activities, roles, tools required and information flow. For this modeling process it is proposed to use ARIS Event-driven Process Chain (EPC) notation, through the system Aris Express which is available for free download<sup>19</sup>.

#### **5.1.1.10 (IM-S1) Analyzing processes cost**

Once all activities and resources related for each process are identified, a brief cost analysis is proposed to be conducted in order to identify the activities and processes which must be modified or improved. This cost analysis is not deeply conducted, because the main objective of this activity is to estimate the resources used per process. The method proposed to conduct this activity is the "Resources correlation table"

- *Resources correlation table*: This activity allows calculating the expenses and costs for each activity which composes a process. This calculation is conducted based on the amount of people involved on the activity, percentage of time spent in the performance of the activity, frequency of the processes, purchases related to the process, among others. It allows calculating the estimated annual costs. This process is explained deeply in (Manganelli, 1995). Its template is shown in Table 57 of Appendix C.

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<sup>19</sup> <http://www.ariscommunity.com/aris-express/download>

#### **5.1.1.11 (IM-S1) Identifying the process modifications required**

The modifications required for each process must be identified based on the modeled processes, and the resources and costs which were previously analyzed in the “Resources correlation table”. These modifications are conducted in order to make the processes more efficient or to adapt them to the PLM strategy or system requirements. The method proposed for accomplishing this activity is the “Process Analysis Table”.

- *Process Analysis Table*: In this table the most expensive activities, as well as the activities which require to be reviewed, are identified for each process. It also includes the unitary cost of performing them. In order to analyze the situation of the activity and propose solutions, a comments field is also added to the table. Its template is shown in Table 57 of Appendix C.

#### **5.1.2 (IM-S1) Defining KPI**

The main objective of this activity is to define and measure the KPI, considering the information related to the processes analyzed. No method is proposed for developing this activity, considering that the KPI definition depends on the nature of the type of processes to be included in the implementation. It is advised to analyze literature on best practices in order to find the indexes and indicators which could work properly for the processes to be analyzed.

#### **5.1.3 (IM-S1) Reviewing formats currently used**

This process allows analyzing the currently established formats, considering the related processes. It is also important to analyze how processes are documented, which fields should be filled out, the roles in charge and the processes which do not have established formats. The method proposed for conducting this activity is the “Format’s Analysis Table”.

- *Formats Analysis Table*: This table is composed by the fields which are described below. Its template is shown in Table 58 of Appendix C.
  - Information required: allows indicating all the information which must be included in the form, based on the process analysis and in the interviews conducted with the people involved in the related process.
  - Information contained in the form: It allows specifying if the previously identified information is contained in the current form. It is recommended to use the words “yes” or “not” to indicate it.
  - Mandatory elements: It allows determining from the information identified in the “information required” field, which of this information is mandatory due to regulations or standardized issues. “Yes” or “not” can also be used to indicate it.

- Fields that can be combined: It allows identifying which fields of the form could be combined. This combination could avoid filling out redundant information in the form. Again, the words “yes” or “not” can be used to indicate it.
- Fields that can be eliminated: It allows identifying the information which is not relevant for being included in the form, based on the process related. “Yes” or “not” are also proposed to indicate it.

#### **5.1.4 (IM-S1) Reviewing the naming convention currently used**

This activity allows analyzing the codes and sequences used in the document naming convention (nomenclature) and identifying whether a standard is defined for this. To conduct this activity it is necessary to analyze if the elements included in the naming convention (nomenclature) allow differentiating the type of document, considering the amount of data which can be managed by a PLM system. It is proposed to review the standards and guidelines proposed in ISO 9001.

#### **5.1.5 (IM-S1) Reviewing sequences and document version control currently used**

This activity is conducted for Analyzing the way in which the control of document versions, change management and document lifecycles are carried out. In this step it is important to analyze the document approval processes and the states in which a document can be labeled during any particular process.

It is also important to consider the amount of versions which is required to be stored, considering the storage capacity of the systems and the company’s needs. It is recommended to consider the document version control which is established by default in the PLM tool to be implemented.

#### **5.1.6 (IM-S1) Identifying software currently used**

This activity is conducted in order to Identify the software tools currently used for the development of each document or file and assess its convenience versus the creation of customized modules in the PLM system. No particular method to perform this activity is defined (See section 2.2).

### **5.2 Implementation model: Stage 2 (IM-S2)**

The main objective of this stage is:

- Present the PLM strategy within the work group in order to prepare the future users of the platform. This can be done through the creation of support material, presentations and tutorials.

In order to reach this objective, five activities were defined:

### **5.2.1 (IM-S2) Installing and configuring the server for training purposes**

In this activity the host system server is set up for training purposes. This could entail the configuring and loading of a demo version in the system database to be implemented, in order to start the training process making use of simulated scenarios and information. This demo database could be used to explain and train users in the use of default PLM modules.

### **5.2.2 (IM-S2) Introducing PLM concepts**

In this activity the main concepts of PLM are presented to the users. In this session all the questions must be solved and the staff which will participate in the process must be motivated to contribute to the implementation through an active participation in the processes, document standards and definition of protocols. All related benefits to the implementation must be presented and the internal implementation team must also be trained.

The main objective of this activity is to present the strategy that will be implemented, the results of the previously conducted analysis and engage and motivate the staff in the PLM strategy's definition and implementation.

### **5.2.3 (IM-S2) Enabling computers from which the system will be used (Client side)**

In order to perform the training processes the user's computers must have access to the PLM system. The main objective of this activity is to allow users to access the system from their computers before the training process begins.

### **5.2.4 (IM-S2) Creating tutorials and support materials**

It is required to develop all the support material that will be given out to users in order to conduct the training sessions. Tutorials, Handbooks, and videos could be used for performing the learning processes.

Self learning materials are proposed considering that it is not easy to schedule a common meeting due to the user's daily obligations, allowing them to be used by each person on their own time. Thus, it is recommended the development of blogs or platforms which could contain this information available for all the employees.

### **5.2.5 (IM-S2) Starting training sessions**

The training sessions can start once all the support material is available and the PLM system is configured and enabled on each computer. It is recommended to conduct these sessions in groups of around five persons or less, in order to answer all questions which could arise in the process and to assure that all the trainees learn how to use the system.

### 5.3 Implementation model: Stage 3 (IM-S3)

In this stage the TO-BE process is defined. The main objectives of this stage are:

- Modify and adapt the current processes in order to make them more efficient and implementable in the PLM strategy and system.
- Adapt the document management standards currently used within the work group in order to implement them in the PLM platform.
- Define or adapt the currently used workflows in order to implement them in the PLM platform.

In order to reach these objectives, 4 activities were defined:

#### 5.3.1 (IM- S3) Business Process Modeling and Definition or adaptation of currently used workflows

This activity is conducted in order to redefine the processes that require be modified, basing on the process analysis performed in IM-S1. All related flows must also be defined or adapted considering the PLM tool constraints.

Special emphasis is applied in the performance of this activity considering the results obtained in the local survey which showed how poor processes were defined in the local industry (See section 2.3). Accordingly, it is subdivided in 4 sub activities which specify the methods to be conducted for its accomplishment. Most of these methods are taken from (Manganelli, 1995).

##### 5.3.1.1 (IM-S3) Defining implementation goals and opportunities

This activity allows defining the goals and opportunities which must be reached through the process performance. It provides guideline and focus for the new processes definition. The method proposed for conducting it is “objectives, goals and opportunities table”.

- *Objectives goals and opportunities table*: Based on the objectives set in IM-S1, goals and opportunities are defined. This process must be conducted jointly by managers, the implementation team and users. It is important to motivate those who will participate in the implementation to be part of this definition, because they will be more engaged with its success. The template of this method is shown in Table 59 of Appendix C.

##### 5.3.1.2 (IM-S3) Defining priority in processes

In this activity, goals and opportunities are matched with the processes identified in stage 1 in order to estimate the contribution of each of them to the goals achievement. The processes defined as priority must be modified and implemented first and they must also be coherent with

the rating given to objectives in the Effort-benefit table. The method proposed for conducting this activity is:

- *Priority process table*: The impact generated by each process to the opportunities and goals is estimated based on an agreement between the members of the implementation team and managers, as well as resources used and the scope. This process is performed through the development of two tables. The first one analyzes the opportunities versus processes and calculates the benefits provided. The second one focuses on goals and determines the process' priority. For a full explanation of this method view (Manganelli, 1995). The templates for the method are shown in Table 61 of Appendix C.

#### **5.3.1.3 (IM-S3) Modeling processes**

Based on the AS-IS modeling processes, resources correlation table and process analysis table, the processes defined in the priority process table are modeled considering the modifications proposed. This activity is also proposed to be conducted making use of ARIS. The objective is to have a TO-BE reference model of the priority process.

#### **5.3.1.4 (IM-S3) Analyzing changes implied for each role**

This activity allows analyzing the changes in which the staff of the company will be involved due to the modifications defined for the processes in “Modeling processes” activity (See section 5.3.1.3). This activity is conducted in order to identify the stages which require more dedication and attention in training sessions and to analyze the feasibility of making transitions of responsibilities for each role. The method proposed for performing it is the “career plans design table”.

- *Career plans design table*: This is to estimate the difficulty level that transition of responsibilities implies for each member involved in the implementation. To conduct it, it is required to consider the information obtained through the “Roles characteristics table” previously developed (See section 5.1.1.6). A transition weighting scale and modifications rating scale are used to determine the weighted score of the responsibilities transfer. This method is thoroughly explained in (Manganelli, 1995). The template for the method is shown in Table 62 of Appendix C.

### **5.3.2 (IM-S3) Defining new templates and documentation standards**

This activity allows defining the document standards and forms which will govern the document generation and management. This implies the definition of templates, information structure per document and form contents. This activity must be conducted considering the analysis previously performed in the “form’s analysis table” (See section 5.1.3) which indicates the fields to be included in each document. No method is proposed for the development of this

activity, due to it only implies the creation or adaptation of the forms based on the previously analysis. The process modeling must be considered as an input in order to consider the people, resources and information flow related to the analyzed document.

In this activity it is also important to define what kind of tools will be used to fill out and manage each form or document. This entails considering the limitations of the tool based on the requirements of the related process. For example, if it is required to fill out a purchase order, which is created and managed directly in a PLM system template, it will have different constraints and protocols to those created with an excel template.

### **5.3.3 (IM-S3) Defining or adapting naming convention (nomenclature) standards**

This activity is performed in order to define a code which allows the identification of documents when they are stored in large databases. It entails the inclusion of differentiating elements in the naming convention (nomenclature) structure. In order to achieve this, it is important to identify and classify the type of documents which are used in the company, the company's areas involved in the document management, the processes related to the document definition and management, the storage requirements and all the elements which could be required to differentiate it from any other. This naming convention (nomenclature) must be defined in agreement with users, eliciting requirements from them and defining together the nomenclature's structure.

In order to conduct this, the results obtained from section 5.1.4 must be taken as input and the functions provided by the PLM tool selected for automating this process must also be considered in the definition process.

### **5.3.4 (IM-S3) Defining or adapting document version control standards**

This activity allows traceability over the documents and information which will be managed in the PLM system. It entails defining the number of versions and time in which they are stored, the approval cycles to which these documents will be subjected, the type of information to be considered in the history records (such as who edited, who saw the content, who edited, etc) and the codification that indicates the document's version.

It is always important to consider protocols implemented by default for control version in the PLM system. If these default control version protocols will not be used, the standards defined by the implementation team must meet the requirements of the platform, considering that the PLM system will perform this control.

Due to the importance of the "document states" and the related approval cycles, this definition is thoroughly explained below:



**Definition 4.1. Document approval cycles definition:** *Once defined the entities in the “Entities table “ (See section 5.1.1.4), a distinction can be made among them. The entities that are affected by time can be named “transactions” and the remaining can be known as “permanent” (It could also imply people or any other thing to which attributes could be associated). A document for example can be considered as a permanent entity and every entity is composed by states that can be used to define the “Lifecycle of any document”. The activities related to the transition between states can also be considered as the approval processes. Based on this, these lifecycles and processes can be modeled and each state can be considered in the document version control to further define the permissions, storage and history recording conditions.*

## 5.4 Implementation model: Stage 4 (IM-S4)

The main objectives for this stage are:

- Select and adapt the methods and tools to be assisted by the PLM platform in order to assure its best performance. This can be done through a comparison between processes and methodologies which are frequently used in the work group with the functions available in the PLM system.
- Configure the PLM system according to the defined strategy. This can be done through the creation of user accounts, roles and the definition of identities, workflows (processes to be automated and approval flows) and permissions.

Seven activities were defined in order to achieve these objectives:

### 5.4.1 (IM-S4) Selecting PLM tools and modules to be implemented

In order to define the tools and modules (such as “Project”, “documents”, “Parts”, among other modules available in this kind of systems) to be implemented in the PLM system it is required to:

- Understand well how the system works, the functions and applications available, and its constraints and benefits.
- Once company processes are analyzed, define which of them could be automated or managed in the PLM system, considering the premise established in the last item. Modules such as workflows and project management could be used for it: a workflow can be used for processes which are activated by the occurrence of any particular event (there is a situation or action which activates it, for example a purchase order is activated when a spare part is required); whereas project module is used when the activities can be scheduled (for example a preventive machine revision process).
- Define how the control version and documentation standards is going to be performed in order to establish if it is required to define a template for it in the system or if the default control can be executed. New template development entails defining how

many versions are going to be stored in the system and which code will be used to differentiate each version.

- Identify the information widely used as an input in the processes' performance in order to define the libraries required and how to upload it in the system.
- Identify what else could be assisted by the platform, even if no default module exists. If it does not exist, a new module could be developed based on the knowledge of the system.

Based on these items the functions to be implemented in the PLM system can be determined.

#### **5.4.2 (IM-S4) Creating user's accounts and define roles and identities**

This activity allows creating an user account for each member that is going to use the PLM platform, in order to allow them to access the system. This activity must be done considering the organizational chart which is going to be used to define the identities on the system based on the definition of roles. This organizational chart is uploaded in the system through the definition of identities.

#### **5.4.3 (IM-S4) Defining and configuring suppliers and distributors on the system**

According to the Extended Enterprise Strategy adopted by the company, the integration with client and suppliers start here. The objective is to upload the database of suppliers and distributors which will participate in the project in the PLM system. This implies the configuration of user accounts and the definition of related identities, but also the definition of approval processes and suppliers' rating (if it is required by the company). If the supplier was defined as an entity the approval processes can be defined from the "entity table".

#### **5.4.4 (IM-S4) Configuring workflows to be automated in the system**

Processes that can be automated in the system through workflows (See section 5.4.1) can be uploaded in the system. This implies defining the way in which they are going to be activated, either when:

- A form is created
- A state is activated on a lifecycle or
- An activity is activated into the project function.

Lifecycles are also created and uploaded on the system. The states defined in the "entity table" for each entity can be used to define the lifecycle map. Each state represents a node in the map and its promotion from a state to another can be defined based on the activities associated to the transition processes between them.

#### **5.4.5 (IM-S4) Creating libraries on the system**

This activity is conducted in order to create the libraries required for the processes and projects involved in the implementation. These libraries include all information which is used often as input for the process activities. This uploading process could imply the development of customized templates, due to the different meta-data which can be required for each kind of information.

#### **5.4.6 (IM-S4) Developing customized modules in the system**

As it was explained in section 5.4.1, not all processes have a default module in the PLM system. However, depending on the functionalities required it can be developed in order to assist the performance of any particular process or application. This requires a good knowledge of the software.

#### **5.4.7 (IM-S4) Defining and configuring permissions on the system**

Once all modules and tools to be used in the PLM system are defined and the organizational chart has been created through the definition of identities, the permissions for each module can be determined and created on the platform. For the definition of permissions the method to be conducted is the “permission definition table”.

- *Permission definition table*: It is used to determine the permissions that will be applied to any particular module in the PLM system. This table includes on its first column the list of roles involved in the implementation. In the top of the table is the PLM module name for which the permissions will be defined. The second row also specifies the lifecycle state in which the permissions will operate and the third row has the affirmations which are shown in Table 13. For each affirmation a related permission exists. Considering if a role matches an affirmation and such affirmation applies for that role, an “x” can be located there and it would indicate that the related permission applies for such a role. The template is shown in Table 63 of Appendix C.

*Table 13. Descriptive information for “permission definition table”*

<b>Affirmation</b>	<b>Permission</b>
People or identity allowed to create a new instance of the function	Can Add
People or identity allowed to perform any action over the function or edit it	Update
People or identity allowed to control and monitor the related process or activity	Get
People or identity that requires information related as an input for performing any other activity	Get
People or identity that can delete this information or instance	Delete
People or identity allowed to approve, unapproved or promote the instance or item	Promote

Once concluded IM-S4, the PLM implementation can be launched. Thus, the company is ready to start working based on the strategy defined.

## **5.5 Implementation model: Stage 5 (IM-S5)**

The objective to be accomplished through this stage is:

- Analyze the assimilation and use of the PLM system in the work group, through KPI measuring and comparison.

This objective is proposed with the development of five activities:

### **5.5.1 (IM-S5) Monitoring processes and running projects**

This activity implies the execution of the ongoing processes and monitoring them through task reports, document version control, traceability analysis reports and solving user’s queries. This process allows performing fast corrective actions if problems arise during implementation.

If there is not a fast response when problems arise during the implementation, people involved in the process may become unmotivated and finally quit. It is recommended to assure the presence of at least one member of the external implementation team in the company in order to face this kind of situations. Customized explanations could be required for some of the company’s members involved in the implementation.

### 5.5.2 (IM-S5) Measuring KPI

The KPI previously defined in the IM-S1 (See section 5.1.2) must be measured again in order to evaluate the performance of the implementation and its results. It allows making comparisons and establishing the effectiveness of the implementation. KPI are related to the processes performance.

Additionally it is required to define and measure indicators that allow determining the company's member level of use of the PLM tool. This item can be measured through the use of the indicators proposed in Table 14. These indicators do not include some other modules of the system, such as "Part", or any customized one.

*Table 14. Proposed indicators for measuring the "level of use" of the PLM tool*

<b>Document function use</b>	Percentage of documents uploaded in the system
	Amount of document editing
	Percentage of documents promoted
<b>Project function use</b>	Percentage of activities reported on time
	Percentage of activity report missing
	Percentage of deliveries not uploaded
	Percentage of deliveries delayed
<b>Workflow process function</b>	Percentage of workflows started
	Percentage of workflows fully completed
<b>Measuring the level of use of the tool by the users</b>	Percentage of people who uploaded documents
	Percentage of people who reported activity completion report
	Percentage of people who have edited any document or item type
	Percentage of people who have seen any particular item type
	Percentage of people who have promoted items being in charge of doing so

### 5.5.3 (IM-S5) Comparing KPI measurement

Once the KPI are measured after the PLM implementation these must be compared with the KPI measured before, in order to determine its success level and plan the necessary corrective tasks (if they are required).

### 5.5.4 (IM-S5) Planning corrective tasks

Based on the KPI comparison and the monitoring processes explained in section 5.5.1, corrective tasks must be defined in case of any problem. This is conducted in order to solve the problems and inconveniences that arise and assure the success of the implementation. Members of the external implementation team and users that require corrective tasks should participate in planning these tasks. Users can also provide feedback and make recommendations towards problems solution.

#### **5.5.5 (IM-S5) Implementing corrective tasks**

This activity is conducted in order to carry out all corrective tasks previously defined. It implies performing monitoring processes again in order to determine the effectiveness of the implemented tasks or the need to define new corrective tasks. Some modules such as “Dashboards” which are available in PLM systems could be very useful to perform the monitoring process in an automated way, making use of graphical tools. Its implementation can facilitate and reduce the time invested in performing it.

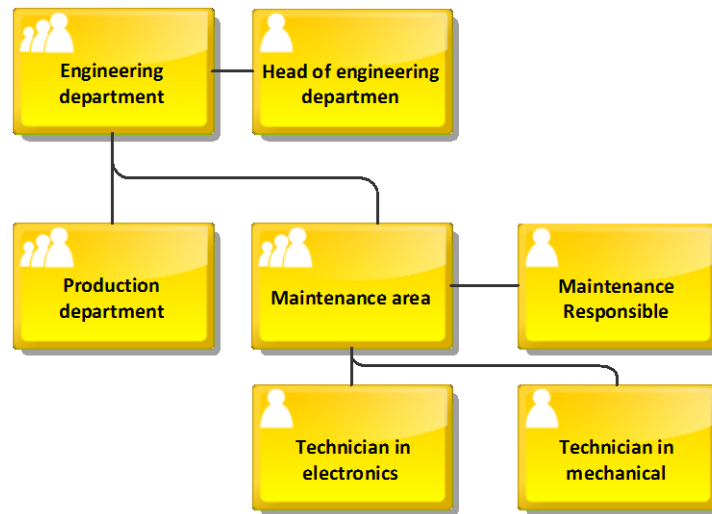
Once defined the implementation process (full Chapter 5 section), it is required to test it in a local industry in order to determine how effective is. Through this evaluation process each tool and method should be analyzed in order to receive feedback and improve it.

Thus, a new Cycle was conducted. This new cycle was performed in a local company and due to its characteristics this cycle is reported as “Case Study” in Chapter 5.

## Chapter 6. Case Study

In order to test the PLM implementation methodology, the maintenance department of a local textile company was selected.

The company's maintenance area is managed by the Engineering department. Thus, engineering analysts are also related with the maintenance area, even though they are not directly linked to it. The maintenance area is composed by a head of maintenance, an electronic technician, a mechanical technician and two assistants which carry out supportive tasks, as shown in Figure 44.



*Figure 44. Organizational chart of the company*

The maintenance area was selected because it was in a restructuration process in which a new plan for preventive processes had been recently established in order to reduce corrective tasks. Another important factor considered was the size of the area. A small amount of people and information was required in order to conduct a small scale pilot project.

The implementation team was composed by the members shown in Table 15. This team was composed by 7 members from EAFIT University; in charge of coordinating the implementation project and company employees. These Company members were involved in the implementation of supportive tasks for the process analysis and definition; however their time dedication was not defined.

Table 15. Implementation team

Name	Dedication	Institution/Company	Function
PhD supervisor		EAFIT University	Project director
MSc Student	Full time	EAFIT University	Project Coordinator
PDE Student	Quarter time	EAFIT University	Process analysis and definition and monitoring.
PDE Student	Quarter time	EAFIT University	Process analysis and definition and monitoring.
Software Eng student	Quarter time	EAFIT University	System Support
Software Eng student	Quarter time	EAFIT University	System Support
Software Eng student	Quarter time	EAFIT University	System Support
Head of Engineering Department	-	Company	Project Co-director
Internship	-	Company	Monitoring
Maintenance responsible	-	Company	Process analysis and definition.
Technician	-	Company	Process analysis and definition.
Technician	-	Company	Process analysis and definition.

The implementation process is described below based on the stages described in Chapter 4.

## 6.1 Stage1. Evaluation and diagnosis of processes and documentation standards

In order to carry out the analysis of the process performed in the company before the implementation, the process described in Chapter 4 was executed.

### 6.1.1 Analysis of current processes and diagnosis of approval processes

The analysis of current processes was carried out through the development of the activities that are described ahead.

#### 6.1.1.1 SWOT Analysis

The first activity involved all members of the maintenance area through the execution of personal open interviews in which personnel was questioned about the strengths, opportunities, threats, and weaknesses that each of them perceived in the area. These activities included the analysis of documents and the main processes which were executed in this area.

The information obtained through each interview was analyzed by the implementation team and compared with the information obtained from all members of the area in order to define the main items to be considered in the SWOT analysis. The main conclusions are:



- There is a lack of documented knowledge, which means that this knowledge is concentrated in one person.
- It is difficult to predict times or maintenance situations because of the lack of data gathered.
- There is a lack of prevision by the maintenance members related to supply times when spare parts are required.
- There are no indicators defined or measured in the maintenance area which enable to conduct further projective analysis.
- Most of the processes conducted in the maintenance area are corrective.
- The technical drawings which are managed in the maintenance area are not in digital version and some machine drawings are missing.
- There are major delays in approval processes.

The strategies and goals to be achieved after the implementation are based on the conclusions obtained through the SWOT analysis. For demonstrative purposes one of each component of SWOT identified in the company is shown in Table 16.

*Table 16. SWOT Analysis table example*

SWOT ANALYSIS TABLE			
Strengths	Weakness	Opportunities	Threats
They are starting to implement schedules for preventive maintenance and component replacement in order to avoid corrective tasks	Due to the amount of corrective tasks, the preventive maintenance is not always met	Cooperation among companies of the group	Most of the maintenance technicians do not know how to use a computer
.	.	.	.
.	.	.	.
.	.	.	.

#### **6.1.1.2 Strategy definition**

Based on the results obtained through the SWOT analysis, four strategies were developed for the PLM implementation. These strategies were:

- I. Reducing time, costs and machine downtime due to breakdowns.
- II. Document the existent knowledge within the maintenance area.
- III. Increase the monitoring and tracking of processes in the maintenance area.
- IV. Reduce times related to supply and approval processes.

In order to achieve this, a series of objectives and activities per strategy were also defined. These objectives are set by the implementation team along with the people involved in the

implementation. For defining objectives the team must analyze “How PLM could help to achieve each strategy”. These objectives and activities are shown in Table 17.

*Table 17. Definition of objectives and activities for the PLM implementation*

Strategy number	Objectives	Activities
I	1. Implement the preventive maintenance plan in the PLM system so it can be managed by the software.	Identify the processes performed in the maintenance area
		Upload the preventive and components replacement schedules, the machine's history document and related formats on the PLM system
	2. Classify and organize all tools, parts and components available at the maintenance workshop, document and upload the list on the PLM system.	Carry out the inventory of tools and components which are currently stored in the maintenance workshop
		Classify tools and components available at the maintenance workshop based on their characteristics and functions
		Register the location of the tools and components on the PLM system
	3. Automate approval workflows in order to reduce related time.	Identify the process to be automated and the staff involved in it
		Upload the process in the PLM system as a workflow.
	4. Identify the components that are required in stock, document the current situation (how many of them are available) and schedule notifications on the PLM system for unavailable components, in order to reduce the machine's downtime.	Make an inventory of parts that must be always available in the maintenance workshop.
		Count the number of components that are currently in stock
		Upload the stock on the PLM system
		Schedule notifications in the PLM system
	5. Schedule notifications on the PLM system that act as reminders for maintenance staff to carry out component changes and revision activities in the previously defined time.	Test the system configuration
		Monitor the system's use in order to assure the notification's execution.
II	6. Create instructive documents for the change of components activity and upload them in the PLM system in order to allow all maintenance staff members to access them.	Interview the maintenance staff
		Document the information given by the maintenance staff
		Upload the instructive documents on the system

	7. Organize and structure the information available at the maintenance area on the PLM system, and indicate the current location of the physical documents.	Make an inventory of the information available in the maintenance area that must be uploaded on the PLM system
		Organize and classify the information on the PLM system
	8. Scan all information that is not available on a digital format.	Scan documents
		Upload the scanned information on the PLM system
	9. Create an activity to review with checklist machines and locative areas.	Interview maintenance staff
		Document the information given by maintenance staff
		Upload checklists on the system
III	10. Automate the main processes related to the maintenance area on the PLM system	Identify each process and the staff members involved.
		Upload the process on the system through the “workflow” function
		Test the workflows on the system
	11. Define and measure indicators related to processes and machines at the maintenance area	Identify information that can be measured in the maintenance area
		Define the indicators to be implemented and their measurement’s frequency
		Measure the previously defined indicators
	12. Reduce errors when filling maintenance reports	Identify the most common errors currently made
		Train staff involved in the PLM implementation
		Analyze and implement required changes in the previously established forms
		Monitor the process
IV	13. Identify dates in which components of each machine must be changed and unify the approval processes	Report the change of components due to corrective maintenance
		Upload information in the system
		Analyze information search for patterns
		Modify the maintenance plan

### 6.1.1.3 Effort – Benefit – Uncontrollable variables graphic

Considering the company's requirement of achieving short term results, a Benefit-Effort-Uncontrollable graphic was developed. This chart was based on the objectives defined on section 6.1.1.2.

Each of these objectives was graded by the implementation team, considering the analysis conducted through the SWOT matrix and the company's requirements. The results obtained are shown in Figure 45.

According to the obtained results, objectives located in the first quadrant (Q1) were the objectives 1 and 5. The objectives 6, 7, 8, 9 and 10 were located in the 3<sup>rd</sup> quadrant (Q3) and the objective 2 was placed in the 7<sup>th</sup> (Q7). The remaining objectives were located in the 4<sup>th</sup> quadrant (Q4).

Accordingly, objectives 1, 2, 5, 6, 7, 8, 9 and 10 must have priority in the implementation because they provide high benefits with a relatively low effort, enabling to get results quicker than the other objectives. Therefore, these objectives were selected to be the implemented first. The objectives which were not labeled as priority are not considered in this project report due to the time span that they require.

For demonstrative purposes, the effort estimation for objective 1 is shown in

Table 18, as well as the benefit estimation table (See Table 19) and the uncontrollable variables estimation table (See Table 20).

Table 18. Effort estimation table for objective 1

Criteria ( $C_{Ej}$ )	Weight ( $W_{Ej}$ )	Reference ( $R_{ij}$ )	Objective $i$ ( $V_{Eij}$ )	Objective $i$ ( $V_{EPij}$ )	Objective $i$ ( $S_{ij}$ )	Objective $i$ ( $W_{VEij}$ )
$C_{E1}$ : Time	0,4	61	5	8,20%	1	0,4
$C_{E2}$ : Amount of resources required	0,15	11	6	54,55%	3	0,45
$C_{E3}$ : Knowledge available	0,3	5	5	100,00%	1	0,3
$C_{E4}$ : Amount of processes involved	0,15	10	10	100,00%	5	0,75
					$E_i$	1,9

Table 19. Benefit estimation table

		Correlation between the objective and the strategy ( $C_{B_1}$ )	Impact level of the objective over the strategy ( $C_{B_2}$ )	Amount of areas or people that are positively impacted by the accomplishment of the objective ( $C_{B_3}$ )	
Strategy	Objectives	$W_{E_1} : 0,3$	$W_{E_2} : 0,4$	$W_{E_3} : 0,3$	Benefit ( $B_i$ )
Strategy 1	Objective 1	$V_{E_{11}} : 4,5$	$V_{E_{12}} : 4$	$V_{E_{13}} : 4,5$	4,3

Table 20. Uncontrollable variables estimation

OBJECTIVES	DESCRIPTION	UNCONTROLLABLE VARIABLES ( $C_{UV_j}$ )	POSSIBILITY OF AFFECTATION ( $V_{UV_{ij}}$ )	WEIGHTED ( $W_{VUV_{ij}}$ )	Total ( $UV_i$ )
Objective 1	Implement the preventive maintenance plan in the PLM system so it can be managed by it.	The information provided may contain errors or be incomplete	3,5	1,05	2,45
		The time required to achieve the goal depends on the availability of maintenance personnel	2	1,4	

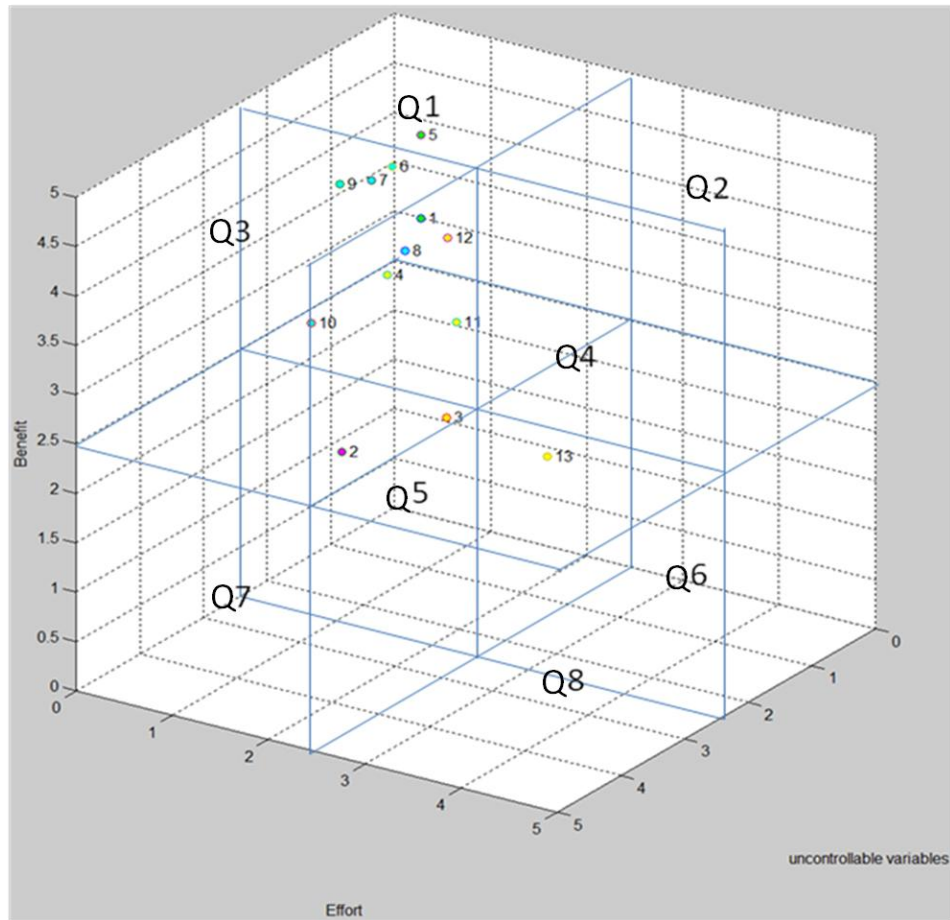


Figure 45. Effort – Benefit – Uncontrollable variables graphic

#### 6.1.1.4 Entity table

Considering the interviews conducted with the maintenance staff, nine entities were identified through the development of the chart:

1. Revision (preventive process)
2. Change of components
3. Corrective process
4. Component request
5. Machines
6. Locative areas
7. Spare parts
8. Spare parts and part reception
9. Outsourcing of processes

It is important to note that the items 1, 2, 3, 4, 8 and 9 are processes or transactions identified in the maintenance area and the items 5, 6 and 7 are permanent objects. It is considered

permanent because these are not subject to changes due to the time effect as it is in transactions. For each entity a series of states and interactions were identified. For demonstrative purposes the “Revision” entity definition is shown in Table 21.

*Table 21. Entity table for “Revision” entity*

Entity: Revision
Type of entity: Transaction
In Review -Maintenance chart
Filling out form -Ending of machine's review
Failure notification -Failure identification in revision activities
Reviewed -Control form filled out

#### **6.1.1.5 Activity identification chart**

In order to identify the activities that allow a change in the states or interactions identified in 6.1.1.4, the “Activity identification chart” was created. This chart was made by the implementation team and the maintenance manager. For demonstrative purposes the “Revision” entity’s Activity identification chart is shown in Table 22.

Table 22. Activity identification chart for “revision” entity

Process: Revision	
State'sTransition	Activities to be completed
In Review	<ul style="list-style-type: none"> <li>-Checking if the machine or area requires to be reviewed in the preventive maintenance schedule.</li> <li>- Checking dates, tools and assignees of each activity in the preventive maintenance schedule</li> <li>-Notifying failure.</li> </ul>
"Filling out form"	<ul style="list-style-type: none"> <li>-Performing the preventive maintenance task indicated for the machine or area</li> <li>-Identifying each failure’s causes and repairing it.</li> </ul>
"Notifying failures"	<ul style="list-style-type: none"> <li>-Notifying the maintenance manager the anomalies found.</li> <li>-Identifying time and spare parts required for repairing each failure.</li> </ul>
"Reviewed"	<ul style="list-style-type: none"> <li>-Reporting the preventive maintenance task conducted in the maintenance form related to the machine or area reviewed.</li> <li>-Starting next process</li> </ul>

#### 6.1.1.6 Roles’ characteristics chart

The roles’ characteristics and functions were analyzed by the implementation team based on the interviews conducted with the maintenance staff and the engineering analyst. The following roles were analyzed:

- maintenance manager
- Technician in electronics
- Technician in mechanical
- Maintenance Assistant
- Head of engineering department
- Internship
- Purchase supervisor
- Purchase assistant

For demonstrative purposes, the maintenance responsible description is shown in Table 23.



*Table 23.Roles' characteristics chart*

<b>Role</b>	<b>Responsibility</b>	<b>Knowledge required</b>	<b>Tools</b>
maintenance manager	Planning the activities to be performed in the area  -requesting approval for purchases, spare parts and outsourced services  -Monitoring the accomplishment of the activities assigned in the maintenance schedule	Time rate of repairing  -Maintenance schedule  -Preventive and corrective work method  - Service suppliers	Maintenance schedule  -Machine catalogs  -quotation and price lists  -Purchase form
...	...	...	...

#### **6.1.1.7 Resource chart**

The activities previously identified were analyzed in order to determine the roles and people involved. This process was conducted in order to consider the resources used in each activity for the process modeling. For demonstrative purposes Table 24 shows the “Resources chart” for “Check if the machine or area needs to be reviewed in the preventive maintenance schedule” activity from “Revision” entity (from Table 22).

Table 24.Resource chart example

	Maintenance area				Engineering department		Purchase department	External	
Activity	Maintenance Manager	Mechanics technician	Electronic technician	Assistant	Eng. head	Eng. analyst	Purchase assistant	Supplier 1	Resources
Check if the machine or area needs to be reviewed in the preventive maintenance schedule	X	X	X	X					Schedule
									Computer
									Forms
									Phones
									Basic tools
									Purchase order
									Spare part
									ERP System

#### 6.1.1.8 R-N-I Chart

Once the resources related to each activity were identified, the involvement level of each person in the performance of every activity was analyzed. Due to this, the function of each person was classified in “responsible”, “notification’s receiver”, “input provider” or “activity controller”. This activity is useful to understand the interaction between the members of the staff on each activity. For demonstrative purposes the R-N-I chart for the “Revision” entity is shown in Table 25.

Table 25.R-N-I chart for “Revision” entity

		Revisión				
		Checking if the machine or area needs to be reviewed in the preventive maintenance schedule	Checking the date, tools and assignee of each activity in the preventive maintenance schedule	Notifying failure.	:	Starting next process
Maintenance area	Maintenance manager	R	R		...	R
	Mechanics technician	R	R	N	...	R
	Electronic technician	R	R	N	...	R
	Assistant				...	
Engineering department	Head of department	C			...	
	Engineering analyst	C			...	
Purchase	Purchase assistant				...	
External	Supplier 1				...	

Once the revision entity was analyzed the main conclusion was:

- In the revision entity, five of eight activities are conducted as “responsible” by all members of the maintenance staff in the same way. However the mechanical and electronics technicians are in charge of notifying the maintenance manager about failures and anomalies found as well as spare parts required for a particular machine or area. This notification is not always registered or documented. Therefore it is not possible to measure indicators related to corrective processes. All technicians and the maintenance manager are in charge of checking the preventive maintenance schedule weekly in order to identify the activities to be performed. One of the engineering Analysts and the engineering manager are in charge of monitoring the accomplishment of filling out the preventive maintenance form.

This activity allows defining the order of activities in each process, before the process modeling activity.

### 6.1.1.9 Process modeling (AS-IS)

Based on the procedures identified through the development of the activities explained below, each process identified on the entity chart was modeled using ARIS Event-driven Process Chain (EPC) notation. For demonstrative purposes the Revision's (preventive maintenance) process is shown in Figure 46 and Table 26. However the processes identified in the "Entity table" step (see section 5.1.1.4), such as "change of component", "corrective maintenance process", "component reception", "spare part", "component request" and "Outsourcing request" were also modeled.

In this case the activities were identified in "Activity identification" (see section 5.1.1.4 ) and assignees are identified in Resource and R-N-I charts (see section 5.1.1.8). It is important to note that the analysis conducted through an R-N-I chart helps to validate the order of the activities, due to the analysis of each role's responsibilities.

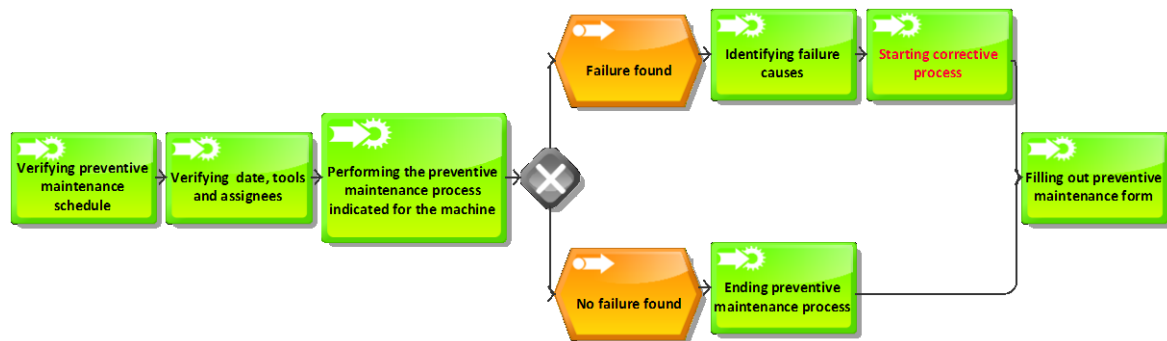


Figure 46. Revision (preventive maintenance) process

*Table 26.AS IS: Revision process*

Revision process		
Number	Activity	Predecessor
1	Verifying preventive maintenance schedule	
2	Verifying date, tools and assignees	1
3	Performing the preventive maintenance process indicated for the machine	2
4	Identifying failure causes	3
5	Ending preventive maintenance process	3
6	Starting corrective process	5
7	Filling out preventive maintenance form	3,6

#### **6.1.1.10 Analysis of labor cost**

Based on the entities identified on section 6.1.1.4 and the related activities identified on section 6.1.1.5, a labor-cost chart was created. This chart was made in order to analyze the cost of each activity related to an entity for a further identification of the processes that can be modified, combined or eliminated. For demonstrative purposes the cost analysis for “Revision” process is shown in Table 27. The form has been simplified for the case study and the values of the fields have been modified due to the confidentiality of the information.

*Table 27. Labor cost analysis for “Revision” process*

	<b>Activities</b>	<b>Frequency</b>	<b>UNIT TIME (MIN)</b>	<b>UNIT COST</b>	<b>ANUAL TIME (MIN)</b>	<b>ANUAL LABOR COST</b>
<b>Revision</b>	Verify preventive maintenance schedule.	20	3	\$ 30	60	\$ 600
	Verify date, tools and assignees	20	3	\$ 30	60	\$ 600
	Notify failure.	40	5	\$ 50	200	\$ 2.000
	Perform the preventive maintenance process indicated for the machine	50	240	\$ 2.400	12000	\$ 120.000
	Identify failure causes	100	240	\$ 2.400	24000	\$ 240.000
	Inform the anomalies found to maintenance responsible	100	10	\$ 100	1000	\$ 10.000
	Identify time and spare parts required for corrective process	100	60	\$ 600	6000	\$ 60.000
	Fill out preventive maintenance form	200	5	\$ 50	1000	\$ 10.000
	Labor cost per minute	10				

#### **6.1.1.11 Process analysis chart**

Based on the “analysis of labor cost” the most expensive processes and the processes which must be reviewed were identified in the “Process analysis chart”. For demonstrative purposes the “Revision” entity’s “Process Analysis chart” is shown in Table 28.

Table 28. Process analysis chart fragment for “revision” entity

Process	High cost processess	Unit cost	Comments
Revision	Perform the preventive maintenance process indicated for the machine	2400	The most critical activities in revision processes are less expensive than the activities of a corrective process; however the performing time for revision activities can be optimized through instructive document definition. In time, the failure record history can be used to reduce the failure cause identification task and perform a predictive maintenance plan
	Identify failure causes	2400	
	Identify time and spare parts required for repairing failure	600	
	<b>Process to be reviewed</b>	<b>Unit cost</b>	<b>Comments</b>
	Verify preventive maintenance schedule	30	Both activities can be merged. Probably the automated notifications can help to reduce the revision performing time.
	Verify date, tools and assignees	30	

#### 6.1.1.12 KPI definition

The measured data for the diagnosis corresponds to the information obtained through the corrective, preventive and change of components forms, filled out between the 11<sup>th</sup> and 17<sup>th</sup> week. The indicators proposed to evaluate the implementation measure costs and effectiveness issues, through the following equations:

- For costs:

$$PC_{pm} = \frac{C_{pm}}{T_{mc}} * 100 \quad (8)$$

$$PC_{cm} = \frac{C_{cm}}{T_{mc}} * 100 \quad (9)$$

- For effectiveness:

$$E_r = \frac{f}{t} \quad (10)$$

$$A_{tf} = \frac{t}{f} \quad (11)$$

$$A_{tm} = \frac{\sum t_i}{f} \quad (12)$$

Where:

$PC_{pm}$ : Percentage of costs of preventive maintenance  
 $PC_{cm}$ : Percentage of costs of corrective maintenance  
 $F_r$ : Failure rate  
 $A_{tf}$ : Average time among failures  
 $A_{tm}$ : Average time in repairing  
 $C_{pm}$ : Preventive maintenance costs  
 $C_{cm}$ : Corrective maintenance costs  
 $T_{mc}$ : Total maintenance costs  
 $f$ : Amount of failures  
 $t$ : Amount of worked hours  
 $\sum t_i$ : Sum of entire repairing time per machine, been  $i$  each machine considered for it.

The results of the measured indicators can be seen in section 6.5.2. Because the failure report form and activity completion form were recently implemented, there is only information of the 11<sup>th</sup> to the 15<sup>th</sup> week to measure the indicators used to evaluate the performance of maintenance processes before the PLM strategy. A simplified schedule of the project is shown in Appendix D.

Before of report template implementation, no indicator were measured at the maintenance area and therefore there is not enough historical data to make further effective comparisons.

Some other indicators were defined and measured and the results of applying the equations (8) to (12) are shown in Table 29.

*Table 29. KPI for diagnosis processes*

Amount of corrective failures reported	23
Percentage of failures which could be avoided with preventive maintenance	17,39%
Percentage of preventive forms not filled out	11%
Amount of errors on filled out forms	10
Total of machine's Down time hours	137

During the 11<sup>th</sup> to 15<sup>th</sup> week not all the corrective and preventive tasks were reported in the forms by the maintenance members, because they were just starting to get used to perform this activity.



### 6.1.2 Review of currently used forms

Once identified processes were analyzed and documented in the “As-Is” modeling activity, the information and documents related to these processes resulted in:

- Machine description document
- Preventive maintenance form per machine
- Corrective maintenance form per machine
- Instructive documents for preventive maintenance processes and change of components
- Check lists for preventive maintenance processes
- Plant distribution
- Machine 8’s Hydrostatic test form
- Machine 5’s air leaks form

Considering that the form analysis was required, the “Preventive maintenance”, “Corrective maintenance”, “Change of components”, “Boiler’s Hydrostatic” and “compressor’s air leaks forms” were studied. These are the only forms used in the maintenance department. As an example, the corrective and preventive maintenance form’s analysis are shown in Figure 47, Table 30 and Table 31.

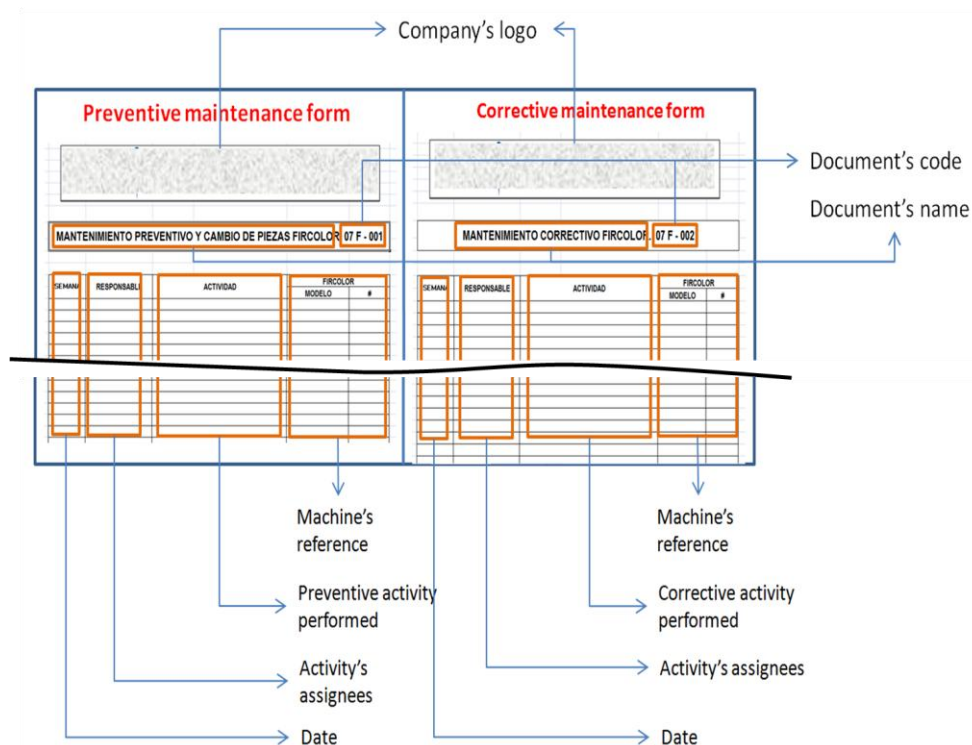


Figure 47. Preventive and corrective maintenance form fields identification

*Table 30. Corrective maintenance form analysis chart*

<b>Corrective maintenance form</b>				
<b>Information required</b>	<b>Information contained in the form</b>	<b>Mandatory elements</b>	<b>Fields that can be combined</b>	<b>Fields that can be eliminated</b>
Company's logo	yes	yes	no	no
Document's code	yes	yes	no	no
Document's name	yes	yes	no	no
Machine's reference	yes	no	no	no
Corrective activity performed	yes	no	no	no
Activity's assignee	yes	no	no	no
Date	yes	no	no	no
Observations	no	no	no	no
Failure cause	no	no	no	no
Component replaced	no	no	no	no

*Table 31. Preventive maintenance form analysis chart*

<b>Preventive maintenance form</b>				
<b>Information required</b>	<b>Information contained in the form</b>	<b>Mandatory elements</b>	<b>Fields that can be combined</b>	<b>Fields that can be eliminated</b>
Company's logo	yes	yes	no	no
Document's code	yes	yes	no	no
Document's name	yes	yes	no	no
Machine's reference	yes	no	no	no
Preventive activity performed	yes	no	no	no
Activity's assignee	yes	no	no	no
Date	yes	no	no	no
Observations	no	no	no	no

Based on the results obtained in Table 30 and Table 31 the following three fields that could be required in the Corrective maintenance form (for indicator measurement and failure history reports) were identified:

- Observations: In order to specify the circumstances or features found during the corrective process, the actions conducted to repair it or comments which must be considered in the process assessment.
- Cause of failure: In order to create a database of failures and actions conducted which could be useful for further repairing processes and failures.
- Component or part replaced: required to identify the parts and components which fail the most.

No field was identified to be combined or eliminated neither in the corrective maintenance form, nor in the preventive maintenance form. For the preventive maintenance form, the only change defined through the analysis was adding the observations field.

### 6.1.3 Review of currently used naming convention (nomenclature)

The company has standardized their process documentation based on the ISO 9001 documental pyramid which defines five main levels that are shown in Figure 48:

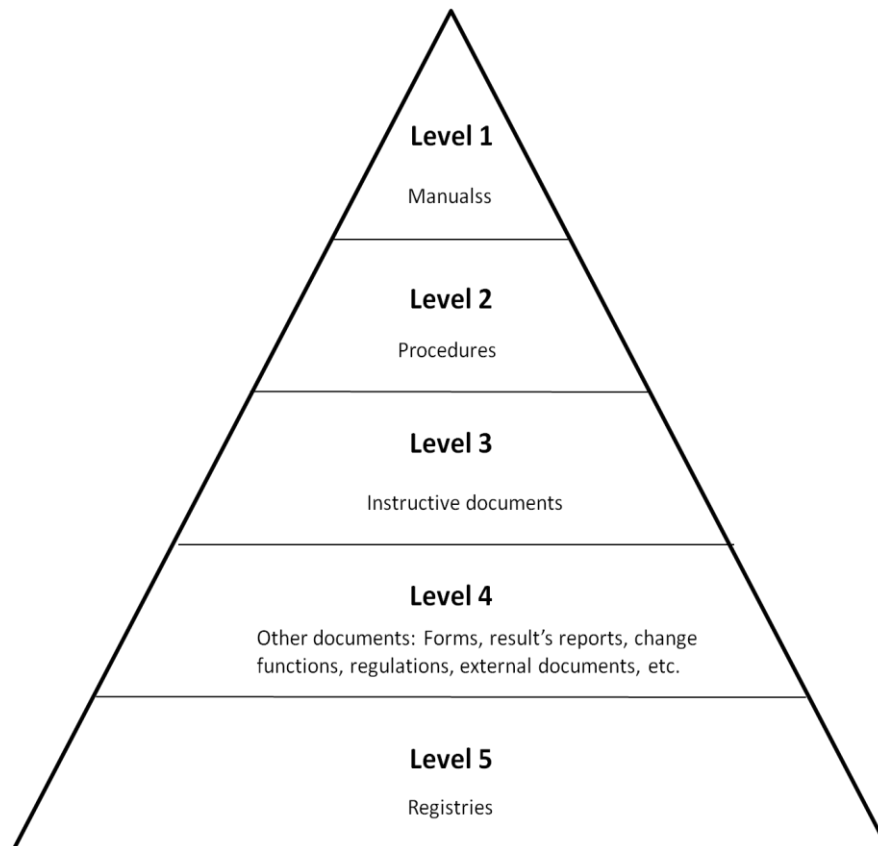
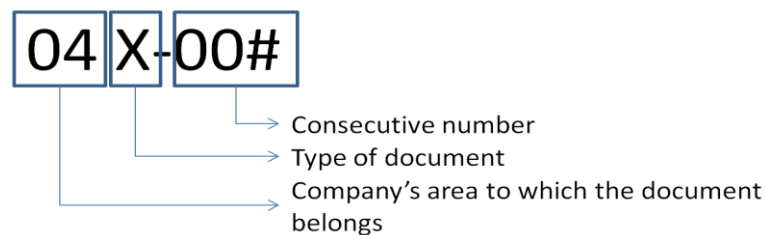


Figure 48. Company's document pyramid

These levels are described below:

- Manual: describes all quality regulations of the processes. It is the main document of the quality implementation.
- Procedures: Describes in detail all standardized processes related to the company, considering the activity sequences and decision processes.
- Instructive documents: Describes and indicates how to perform any particular activity which is part of a specific process.
- Other documents: Includes the documents described in the fourth level of Figure 48
- Registries: Are the documents created during the activity's performance. These documents are created in order to evidence the development of the activity.

Considering the document pyramid, the company defined the document naming convention (nomenclature) which is shown in Figure 49.



*Figure 49. AS-IS company's documents naming convention (nomenclature)*

The code for maintenance area is 07 and the Type of document codes are:

- M: Defined for manual
- P: Defined for procedure
- I: Defined for instructive
- F: Defined for form
- D: Defined for any other type of document

This codification is widely used in the company; however the maintenance area has not standardized their documentation enough. It is important to note that this naming convention (nomenclature) was established for all departments of the company. Nevertheless its structure does not provide enough differentiation between the documents established due to the few elements defined. For example it is not easy to recognize if a document from the maintenance area labeled as "D" is a manual, catalog, a machine description document, and so on. These situations can difficult searching processes.

#### **6.1.4 Review of sequences currently used for document version control**

Currently the company has not document version control established or document history recording. Consequently, it is not possible to monitor who make changes on documents or to retrieve previous versions of them. Therefore defining a proper document version control and document history record is required in Stage 3.

#### **6.1.5 Identification of currently used software**

Nowadays the software most commonly used at the maintenance area is Microsoft Office Word® and Microsoft Office Excel®. The first one is used for writing letters and quotation requests and the second is used in the forms definition for preventive, corrective and component change processes. No special software is used for conducting maintenance tasks.

### **6.2 Stage2. Introduction to PLM Strategy**

#### **6.2.1 Installation and configuration of the server**

The installation and configuration of the server was conducted by members of the company's IT department. A demo project was created for demonstrative purposes in order to explain how to see notifications and how to report the activity completion. However, considering that training process was mostly carried out with real information and performing processes, this configuration is explained better in section 6.4.

#### **6.2.2 Presentation and concepts introduction**

This stage was conducted by carrying out meetings with the maintenance staff. Considering the small amount of members in this area, together with the difficulty to schedule common meeting hours, these meetings were performed individually. These personalized meetings were used to explain users what was going to be implemented, what kind of contributions were required from them and to answer all the questions they could have.

Additionally, maintenance members had an active participation in the diagnosis phase and the definition of new processes through personal interviews. Considering that the system implementation was conducted in different stages, training in the PLM software operation was carried out in a gradual way. It started by a revision of the maintenance schedule and notifications in the tool, implementation of the Activity's progress reports and filling out forms in the platform based on the Excel template.

The training process was carried out by the implementation team with the maintenance members individually, so they could operate the computer, get their questions answered and so the training sessions would adjust with their work schedule. It was also established to keep an implementation team member available in the company in order to solve doubts and assist maintenance members during the system's use.

This first stage in the training processes allowed maintenance members to get used to the system use and identify the main procedures and protocols related to the PLM tool. Once the implementation team remarked that the staff was ready to implement new functions (from those already configured in the system), new information related to machines and areas was included. This information was:

- Suppliers data base and rating process
- Machine description documents
- New preventive, corrective and component change forms
- manuals and machine drawings

The introduction of this information was conducted jointly between maintenance members, the engineering analyst and the implementation team as part of the training process. Once this information was uploaded in the system, the final maintenance module (see section 6.4.7) developed for the implementation was introduced and explained to the staff through training sessions which were also carried out individually. This concluded the activities conducted on this stage.

Part of the monitoring process was performed in this stage because it entailed early implementations over real processes and information.

Based on the analysis explained in section 6.3.1.4, which stated that the main difficulties in the training process for the mechanical and electronic technician would be getting used to reporting the activity completion and verification of failures history, it was established to make special emphasis in the performance of these activities during the training processes. In the case of the maintenance manager, it was decided to emphasize the performance of purchase requests on the PLM system.

### **6.2.3 Tutorials and supportive material development**

A document tutorial and two posters (which explained the steps and issues that the maintenance members should be careful with) were created and located next to the PC where they accessed the system. This support material basically describes how to conduct the activity completion report and how to fill out the maintenance forms, considering the main difficulties found in section 6.3.1.4. See Figure 50.

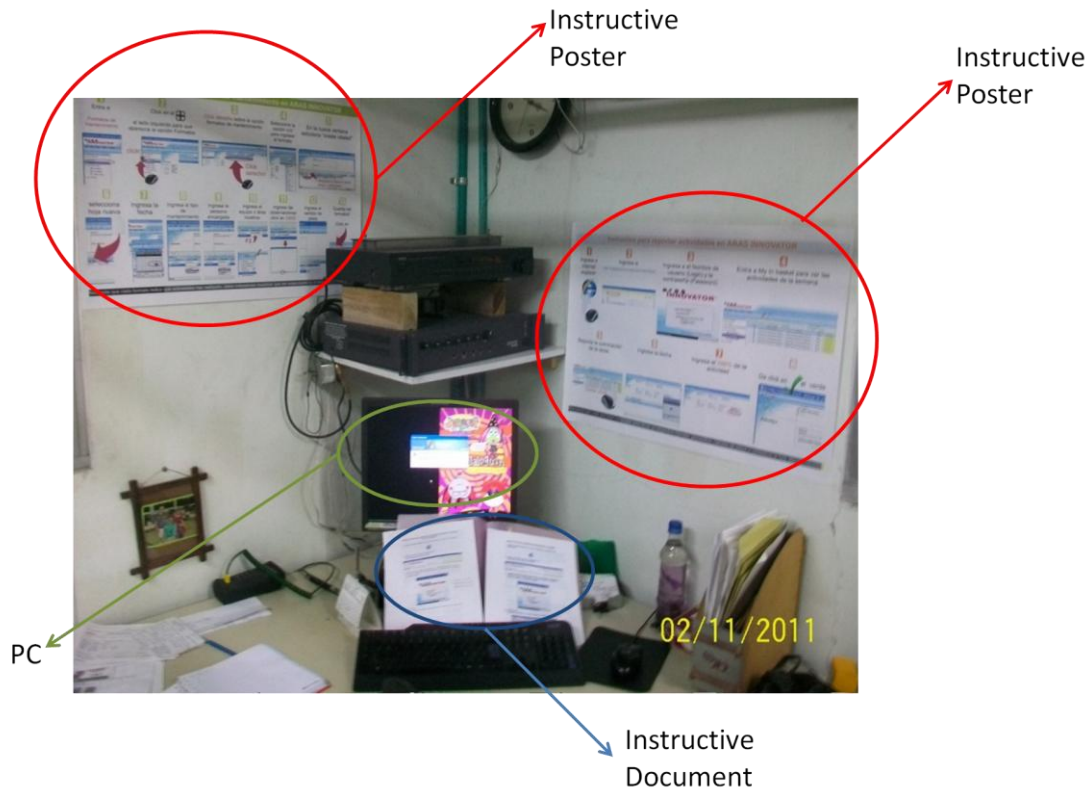


Figure 50. Support material for training processes

### 6.3 Stage 3. Definition of processes and documentation standards

Based on the previously conducted diagnosis, new processes and documentation standards were defined, as shown in the further sub-sections.

#### 6.3.1 Business Process Modeling and Definition or adaptation of currently used workflows

The development of this activity was performed through the “Objectives, goals and opportunities chart”, “Priority process chart”, “Process modeling (TO-BE)” and “Career plans design chart”. This development is shown in sections 6.3.1.1, to 6.3.1.4.

##### 6.3.1.1 Objectives, goals and opportunities chart

Based on the SWOT analysis and the process analysis, the implementation team defined the goals and opportunities of the implementation. The objectives were not defined because these had already been defined on the Strategy definition (see section 5.1.1.2). The goals and opportunities are shown in Table32.

*Table32. Goals and opportunities*

Goals	Opportunities
Activities completed for preventive maintenance and components change on 90%	Preventing further failures
Reduce times, costs and machine downtime	Assuring continuous production
Generalize knowledge among the maintenance area.	Improving how templates are filled out on maintenance processes
Increase monitoring and tracking of processes in the maintenance area.	Reducing costs and times related to failures
Reduce times related to purchases and approval processes	Assisting component request processes
Reduce process times	Reducing process times
Reduce times on components request and changes	Reducing the approval request time
	Reducing the amount of failures through the preventive maintenance process implementation

#### **6.3.1.2 Priority process chart**

As objective 10 was previously defined as a priority in the effort-benefit chart, the processes analyzed were also prioritized in order to identify the most relevant for the implementation. The benefit estimations table is shown in Table 33 and a priority table in Table 35. The explanation for the naming convention (nomenclature) used in each table is shown in Table 33 and Table 36. For this activity the goals previously defined on section 6.3.1.1 were taken as rating criteria. Table 33 is used only to synthesize information which could be useful to the activity's assignee to rate the processes for.

To indicate that an opportunity is related with any process or goal in the Process benefit estimation table, an "X" is located in the common field (see Table 33). The processes' rating in Table 35 is conducted in a scale of 0 to 10, where 0 means that the process do not affect the goal analyzed and 10 is the highest level of impact of the process over the goal.



Table 33. Process benefit estimation

		Affected processes							Related with goal						Expected benefits
Opportunities	Main process	RV	CP	CR	SC	RP	RRP	TR	1	2	3	4	5	6	
Preventing further failures	RV-CP	x	x		x	x		x	x			x	x		40%
assuring continuous production	RV	x	x	x		x		x		x			x	x	40%
Improving how templates are filled out on maintenance processes	RV-CR-CP	x	x	x					x	x		x			80%
Reducing costs and times related to failure	CR	x	x	x					x	x	x	x	x	x	25%
Reducing the approval request time	SC				x	x		x	x			x	x	x	65%
Reducing process times	MQ-AL	x	x	x	x	x	x	x			x		x	x	40%

Table 34. Nomenclature for Table 33

Processes naming convention (nomenclature)	
Revision	RV
Change of component	CP
Correction	CR
Component request	SC
Spare part	RP
Spare part reception	RRP
Outsourcing processes	TR

Table 35. Process priority table

	Goals						Resources		Factors			
Processes	Meeting of preventive maintenance activities	Reduce times, costs and downtime machines	Generalize knowledge among the maintenance area.	Increase the monitoring and tracking of processes in the area.	Reduce times related to purchases and approval processes	Reduce processes time	Unit time (Min)	Unit cost (COP)	Imp time	Imp cost	Risk of imp	Priority
Revision	4	2	3	2	1	2	580	34.661	S	D	D	1a
Component replacement	3	2	3	2	1	2	755	45.119	M	M	M	1b
Corrective processes	0	1	2	2	1	1	5330	318.52	H	H	H	
Spare part request	1	1	1	2	3	2	128	7.649	M	H	D	2
Spare part	1	1	1	2	2	2	25	1.494	S	M	D	3
Spare part reception	1	1	0	1	5	1	105	6.275	M	D	D	
Outsourcing processes	1	2	2	1	2	2	760	45.418	M	M	H	4

Table 36. Nomenclature and definition of items for Table 35

Time	Long (L)	
	Medium (M)	
	Short (S)	
Impact	Very down (Vd)	0-2%
	Down (D)	2-5%
	Acceptable (A)	10-20%
	Medium (M)	20-30%
	High (H)	30-40%
	Very High (VH)	40-50%
	Superior (S)	50-80%
		80-90%
		90-100%
	0	No impact

Once the activity was concluded, the processes that were considered as priorities (in this order) were:

1. Revision (preventive maintenance)
2. Component replacements
3. Spare part request
4. Spare parts (Life cycle)
5. Outsourcing Processes

### **6.3.1.3 Process modeling (TO-BE)**

Once the processes currently performed in the company were analyzed, and the modifications proposed in 6.1.1.11 were done, the TO-BE model was defined through process modeling. As in 6.1.1.9, ARIS Event-driven Process Chain (EPC) was used for this model. For demonstrative purposes, the changes conducted in revision process are shown. The explanation of changes defined in this process is detailed below:

- Revision (Preventive maintenance):
  - The schedule verification process and date, tools and assignee verifications were merged through the implementation of reminders and notifications in the system. This entails that each maintenance member in charge of performing a specific activity will receive an activity notification in his user account, thus avoiding this verification process.
  - The introduction of instructive documents for the preventive maintenance activities was proposed in order to standardize the process, regardless of who performs the activity. This was done through a “checking instructive document” activity definition.
  - The filling out process of the preventive maintenance form was proposed to be implemented on the PLM system.
  - The activity completion report was also included in the process in order to monitor the execution of the scheduled activities.

A schematic image of the current and new revision process is shown in Figure 51. Processes are not defined for machines and locative areas entities because they are permanent entities. Consequently, these are going to be used in the stage of system configuration.

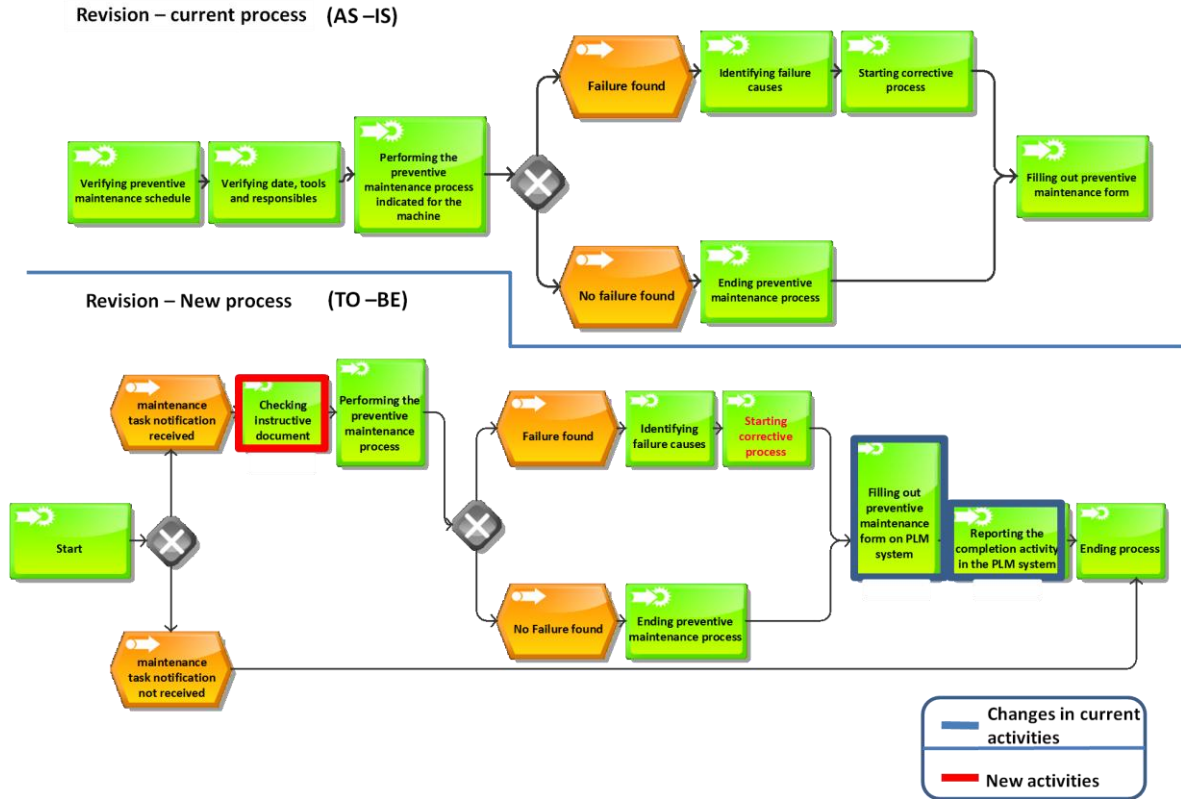


Figure 51. Changes defined for “revision” process

#### 6.3.1.4 Career plans design chart

Based on the new processes defined, the changes in the activities and processes in which each member of the maintenance department would be involved were analyzed. This analysis included the difficulty level that a modification in each person responsibilities entails for every maintenance member. It is important to note that for this pilot implementation the company’s management was not willing to allow staff changes, so only assignment transfers were considered.

For demonstrative purposes the changes in activities and processes for “Maintenance manager” and “Maintenance assistance” is shown in Table 37. As there can be seen in the “Total” field, the difficulty level for “Maintenance manager” is higher than the level of the “Maintenance assistant”. For this implementation there was only considered the changes in the activities to be performed by each role (the knowledge, orientation and skills were implicitly considered in the change of activities analysis). The symbols used in Table 37 are explained in Table 38.

Table 37. Example of Career plan design chart for “Maintenance manager” and “Maintenance assistance” roles

	Future activity	Future activity	Future activity	Future activity	Future activity	Future activity	
	Digital report of activities	Check failure history	Implement reminders for the spare part request which are scheduled	Implement reminders for the outsourcing services which are scheduled	Approval request via email	Fill out just one purchase request per month	
Role	10	9	8	7	8	8	<b>TOTAL</b>
Maintenance manager	+	+	++	++	+	++	73
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
Maintenance Assistant	+	+					19

Table 38. Symbols explanation for Table 37

Symbol	Symbol meaning	Numerical value
+++	Big change level	3
++	Moderate change level	2
-o+	Easy change level	1
	No change	0

Considering all the activities, the biggest changes were identified for:

- Electronic technician in the digital report of activities and failure history verification as feedback for repairing new failures.
- Mechanical technician in the digital report of activities and failure history verification as feedback for repairing new failures. The change level is lower

than the electronic technician due to his level of commitment in the report of activities.

- Head of engineering in the use of the digital purchasing request form for approval processes and in the reduction through unification of filling out purchase forms.

The training process must pay special attention to the performance of these activities and the adoption of new changes.

### **6.3.2 New forms definition**

Once the forms in section 6.1.2 were analyzed the following was proposed:

- Adding the fields “Causes of failure”, “observations” and “component replaced” for corrective maintenance form.
- Adding the field “Observations” to the preventive maintenance form
- The development and standardization of a form for the machine’s description document, adding the “company’s logo” and “document’s code” field and defining a standardized structure for the document. This document is shown in Figure 52 for demonstrative purposes.
- The definition of a standardized form for the creation of instructive and checklist documents.
- Keeping the current forms for plant distribution, Boiler’s hydrostatic test form and Compressor’s air leaks forms.

However, considering that maintenance members had started a familiarization process with these documents, these changes were not implemented at the beginning, with the intention of evaluating if they were really required. Nevertheless the implementation team proposed to develop a new form considering these changes, in order to modify it, depending on the results obtained through the monitoring stage.

The “approved by” field was eliminated in the forms which will be managed by the PLM system, considering that the lifecycle defined for this kind of documents enables the system to control the approval processes and document tracking.

**COMPRESSORS MAINTENANCE INSTRUCTIVE**

Date: \_\_\_\_\_ Page 1: Of: 1

**PARTS THAT REQUIRES BEING IN STOCK**

MACHINE	SUPPLIES	AMOUNT REQUIRED	LEAD TIME	PURCHASE FREQUENCY	STOCK REQUIRED

**PROCESS 1 INSTRUCTIVE**

1. Step 1  
2. Step 2  
3. Step "n"

**PROCESS 2 INSTRUCTIVE**

1. Step 1  
2. Step 2  
3. Step "n"

**PROCESS 3 INSTRUCTIVE**

1. Step 1  
2. Step 2  
3. Step "n"

**PROCESS "n" INSTRUCTIVE**

1. Step 1  
2. Step 2  
3. Step "n"

Figure 52. Instructive document form

### 6.3.3 Naming convention (nomenclature) adaptation

Considering the naming convention (nomenclature) defined in the company for the internal documents and processes, the same naming convention (nomenclature) was initially implemented in order to meet the company regulations. Consequently, the naming convention (nomenclature) used is the same described in section 6.1.3. This naming convention (nomenclature) was automated in the PLM system as it is shown in Figure 53.

Sequence - Formato mantenimiento (read only) - Windows Internet Explorer

File Edit Views Search Actions Reports Tools Help

Name  
Formato mantenimiento

Prefix Current Value Suffix  
007 F - 49

Pad With Pad To Step  
0 3 1

Ready INNOVATO

Figure 53. Naming convention (nomenclature) automation

### 6.3.4 Sequences and version management adaptation

Considering that the company had not used any kind of sequences and version management for the documents related to maintenance area, this version control had to be defined. Therefore the tools provided by the “PLM version control and history record template” (see section 0 and 2) for this kind of processes were analyzed.

The implementation team decided that the control version function performed by PLM could be used at the maintenance area. It is easy to understand, apply and enables to store several versions into the lifecycle (an example of its application can be see in Figure 54).

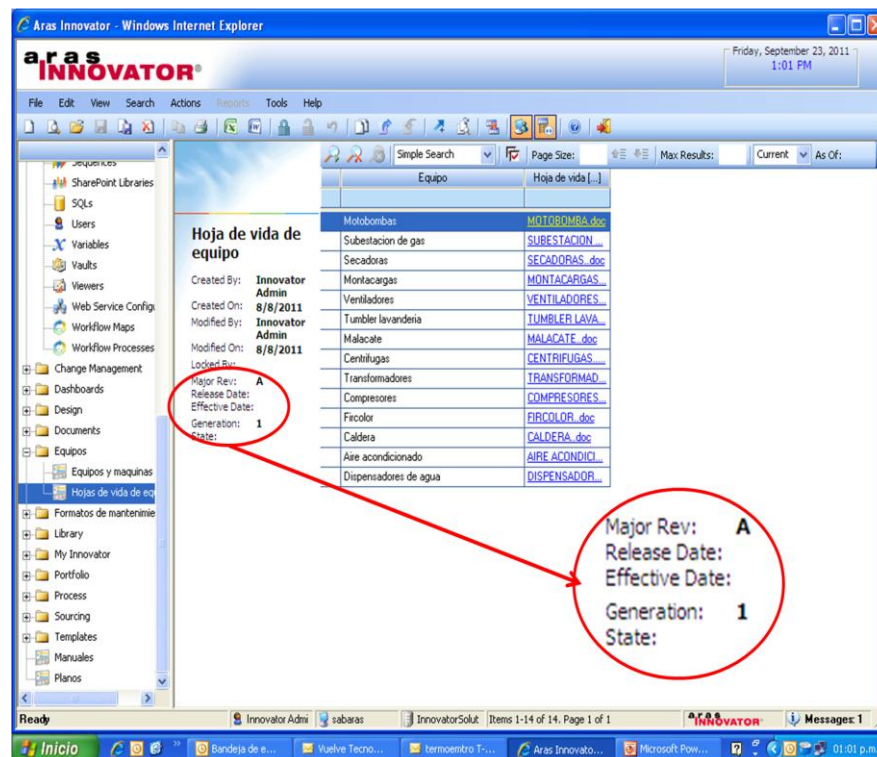


Figure 54. Example of “Version Control” in Aras®

However the history record template was not adequate for the implementation because it was also necessary to control the members that:

- View a document in order to evaluate if it has been used by the maintenance staff for their maintenance activities.
- Perform check-in or check-out activities, in order to know who has made changes on the document. This includes changes on the data (the file) and not only on the metadata (the PLM template form), because the “update” record which is established on the default template only controls the changes and editions performed on metadata.



- Make changes on the document Lifecycle.

A new template for history record was defined. This template records:

- Add: When a new document is created
- Update: when the PLM form (metadata) is edited
- File Check-in: When a document file (data) is downloaded to be edited
- File Check-out: When a document file (data) is uploaded to the system after been edited
- File View: When the document is opened to be seen, not to be edited
- Set Default Lifecycle: When the lifecycle of a document is changed for a new lifecycle
- Reset Lifecycle State: When the state of a document or item is forcedly changed

This new History record template enables a better tracking of every document or item in which it is implemented.

## **6.4 Stage 4. System configuration**

The system configuration was carried out by the implementation team and some members of the company's IT department that were in charge of installing the platform in the server and enabling the stations from which the system would be accessed. The system configuration process is explained in the following paragraphs.

### **6.4.1 Selection of methods and tools**

In this step the following modules were selected:

- Project: For scheduling the preventive and component change processes and enabling the reminder notification through the system. This module implementation was identified through the second activity of the strategy definition. View Table 17.
- Workflow: for automating the Component and Outsourcing Request Processes. This module implementation was defined through TO-BE processes definition and entity chart. For workflow implementations just the entities labeled as "Transaction" in the entity chart can be selected to be implemented through workflows. It was then analyzed if it was convenient to automate them, based on the activities of each process. Of all processes, only "Component" and "Outsourcing Requests" were selected because they could be conducted through the system without depending on other activities that could not.
- Lifecycle: for managing suppliers, machines and area states. This is selected based on the entities chart, by selecting the entities labeled as "permanent".

- Sequences: for the automation of naming convention (nomenclature)'s use. This module is selected when new sequences are defined.
- Customized templates for: machines, spare parts, areas, forms, suppliers, manuals and drawings through the definition of libraries. This was defined based on the information identified in the maintenance area in the “process definition” and “new forms definition” (see section 6.3.1.3 and 6.3.2).

The selection of these modules was based on the experience and knowledge of the implementation team in the use of Aras Innovator and the necessities of the maintenance area issued from the strategy and the processes' definition.

#### 6.4.2 User account creation, roles definition and identities

The first step in the system configuration was the creation of identities and user accounts (Figure 55). This process was carried out considering the organizational chart of the area previously identified in the beginning of this chapter (see page 95).

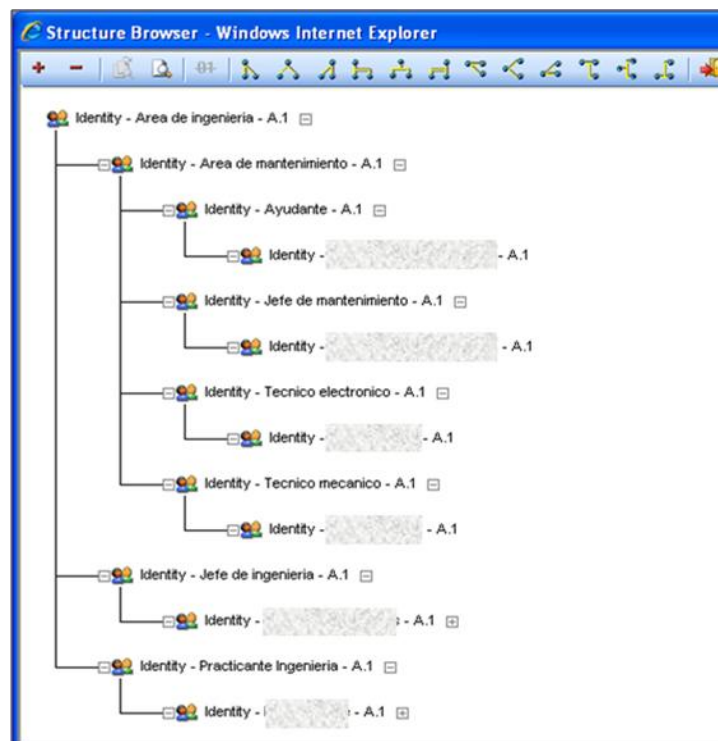
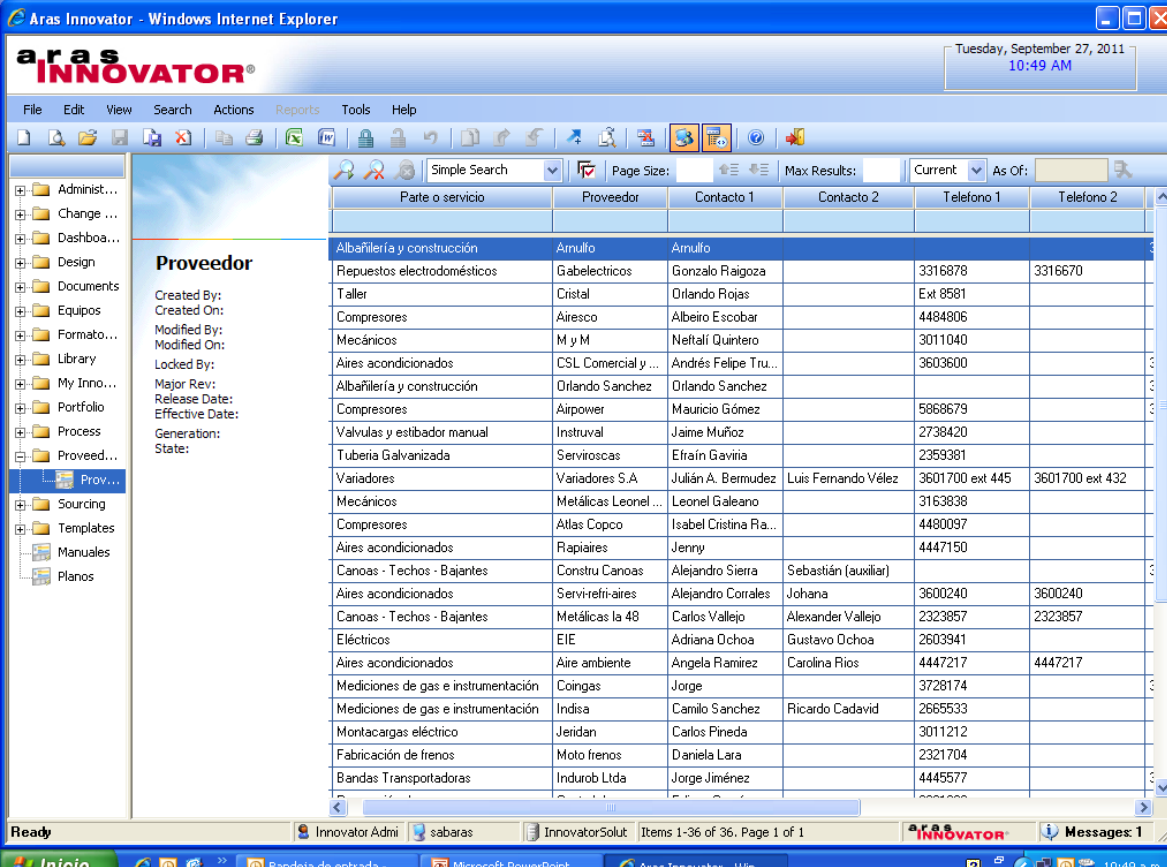


Figure 55. Users and identities definition in ARAS Innovator®

### 6.4.3 Definition and configuration of suppliers and distributors

The main suppliers for the maintenance area were identified through interviews performed with the maintenance manager. During these interviews a suppliers list was identified and it was defined not to use the default supplier's system module due to its complexity at use. Consequently it was decided to create a suppliers library (see Figure 56) and a lifecycle (see Figure 57) for labeling each supplier depending on its convenience for the development of specific activities related to each machine or locative area. Considering this, each supplier was classified depending on the processes that he conducts and the related machines and areas.



**Aras Innovator - Windows Internet Explorer**

Tuesday, September 27, 2011  
10:49 AM

File Edit View Search Actions Reports Tools Help

Simple Search Page Size: Max Results: Current As Of:

Parte o servicio	Proveedor	Contacto 1	Contacto 2	Telefono 1	Telefono 2
Albañilería y construcción	Amulco	Amulco			
Repuestos electrodomésticos	Gabelectricos	Gonzalo Raigoza		3316878	3316670
Taller	Cristal	Orlando Rojas		Ext 8581	
Compresores	Airesco	Albeiro Escobar		4484806	
Mecánicos	M y M	Neftali Quintero		3011040	
Aires acondicionados	CSL Comercial y ...	Andrés Felipe Tru...		3603600	
Albañilería y construcción	Orlando Sanchez	Orlando Sanchez			
Compresores	Airpower	Mauricio Gómez		5868679	
Valvulas y estibador manual	Instruval	Jaime Muñoz		2738420	
Tubería Galvanizada	Serviroscas	Efraín Gaviria		2359381	
Variadores	Variadores S.A	Julián A. Bermudez	Luis Fernando Vélez	3601700 ext 445	3601700 ext 432
Mecánicos	Metálicas Leonel ...	Leonel Galeano		3163838	
Compresores	Atlas Copco	Isabel Cristina Ra...		4480097	
Aires acondicionados	Rapiaries	Jenny		4447150	
Canoas - Techos - Bajantes	Constru Canoas	Alejandro Sierra	Sebastián (auxiliar)		
Aires acondicionados	Servi-refri-aires	Alejandro Corrales	Johana	3600240	3600240
Canoas - Techos - Bajantes	Metálicas la 48	Carlos Vallejo	Alexander Vallejo	2323857	2323857
Eléctricos	EIE	Adriana Ochoa	Gustavo Ochoa	2603941	
Aires acondicionados	Aire ambiente	Angela Ramirez	Carolina Rios	4447217	4447217
Mediciones de gas e instrumentación	Coingas	Jorge		3728174	
Mediciones de gas e instrumentación	Indisa	Camilo Sanchez	Ricardo Cadavid	2665533	
Montacargas eléctrico	Jeridan	Carlos Pineda		3011212	
Fabricación de frenos	Moto frenos	Daniela Lara		2321704	
Bandas Transportadoras	Indurob Ltda	Jorge Jiménez		4445577	

Ready Innovator Admini s abaras InnovatorSolut Items 1-36 of 36. Page 1 of 1

Inicio Bandeja de entrada ... Microsoft PowerPoint ... Aras Innovator - Win... 10:49 a.m.

Figure 56. Suppliers list in Aras innovator®

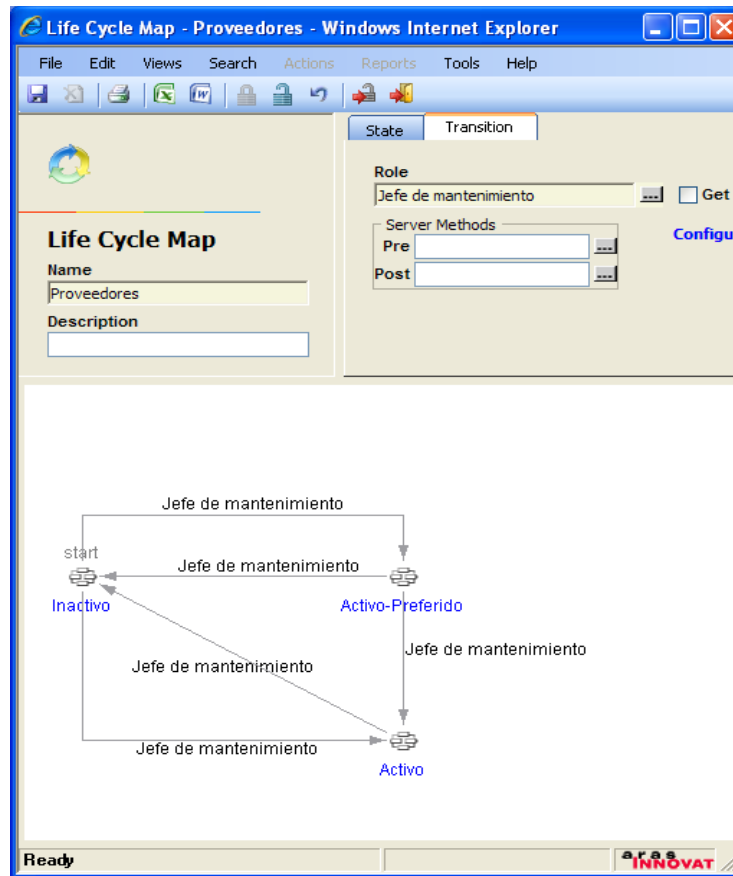


Figure 57. Life-cycle developed for “Suppliers” in Aras innovator®

#### 6.4.4 Workflow configuration

Two processes were selected to be automated through workflows. These processes were selected because their activities could be managed by the system through the use of templates and notifications. Its implementation made the activity completion easier and represented benefits for the area through time reduction, and process tracking improvement.

For demonstrative purposes the “component request process” is shown in Figure 58. The activities and assignee role which compound the workflow were taken from the processes defined in section 6.3.1.3.

Additionally, “Lifecycles” were created for maintenance form, machines and locative areas, suppliers rating, machine’s description document and spare parts. It is important to note that the Lifecycles for machines, locative areas and spare components were created based on the entity chart as shown in Figure 58. Entities were not defined for the other functions (which are mainly based on document management), considering that most of this information did not exist in the company before the implementation.

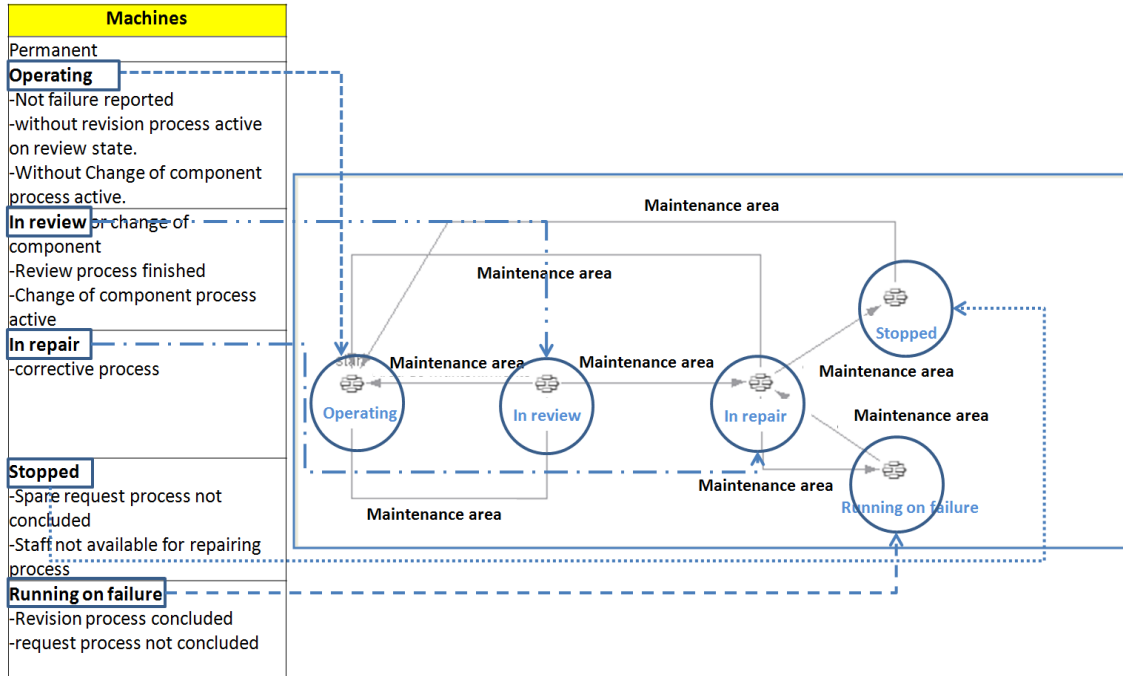


Figure 58. Lifecycle definition based on the entity chart

It is important to note that although these workflows were defined and uploaded in the system their implementation had not been performed yet because they require longer testing times as they require special system developments.

#### 6.4.5 Permissions definition

The permissions are critical point in PLM. They were created based on the functions to be used throughout the implementation. These functions were mentioned in section 6.4.1.

- For “project” and “Project template functions” the permissions were defined based on the project “PLM tools implementation for engineering projects development”. In this project these functions were used for managing the preventive and change of components processes and due to that the project administrator assigned was the engineering analyst.
- For “New workflow maps function” the administrator of the system is the only one in charge of adding a new workflow in the PLM platform. Consequently, the Default permissions were kept for the implementation. For “Lifecycle function” the permissions were also kept by default, considering that just the administrator is in charge of managing this function.
- Sequence functions do not require establishing new permissions; however only the administrator is in charge of creating and associating a new sequence to any item type in the PLM system.

- For the customized functions new permissions were defined, based on the people in charge to make use of each function and in the responsible roles of performing monitoring over the process. For demonstrative purposes, the permission definition for instructive documents function is shown in Table 39. The Lifecycle of the function was considered in this definition.

*Table 39. Permissions defined for “Instructive documents function”*

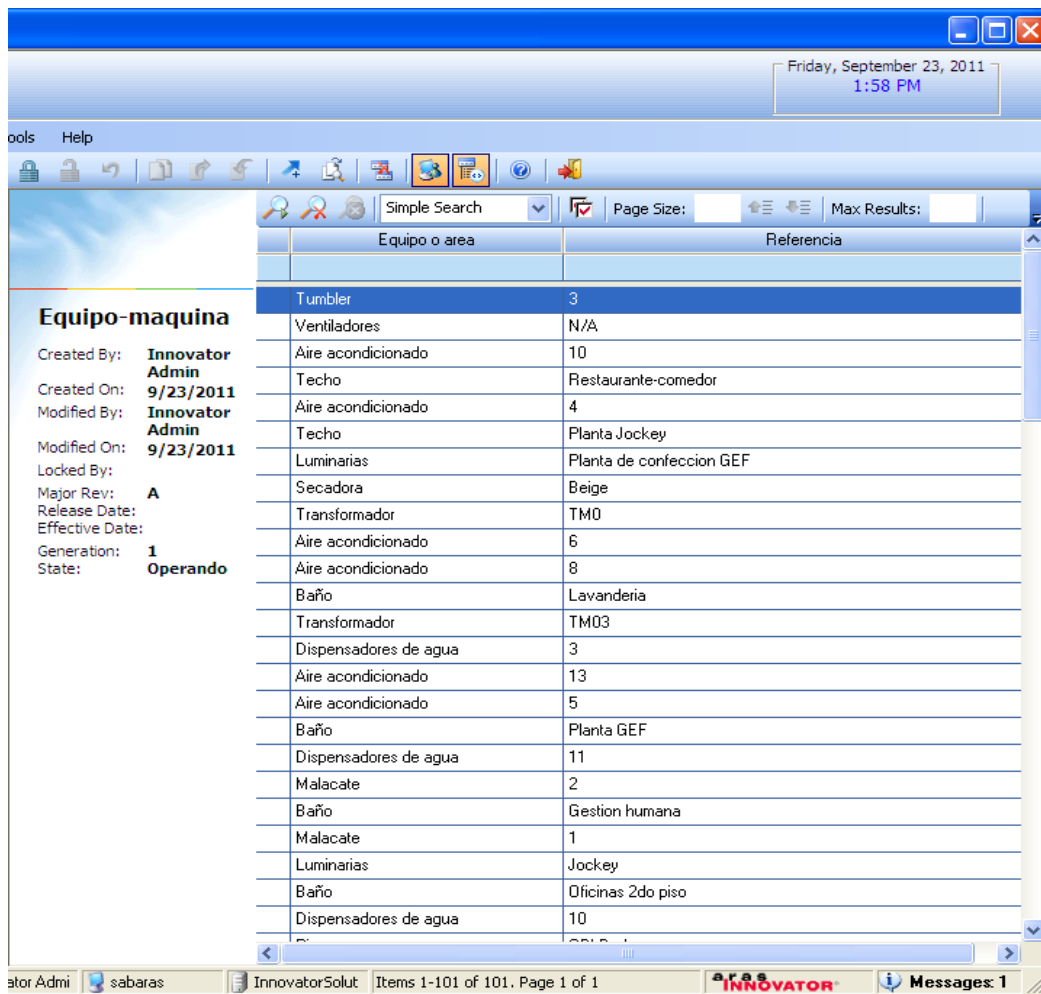
Instructive documents						
State of lifecycle	N/A	Preliminar				
Permission	Can Add	Update	Get	Get	Delete	Promote
Questions	People or identity in charge of creating a new instance of the function	People or identity in charge of performing any action over the function or editing it	People or identity in charge of controlling and monitoring the related process or activity	People or identity that requires related information as an input to perform any other activity	People or identity that can delete this information or instance	People or identity in charge of approving, disapproving or promoting the instance or item
Engineering department						
Maintenance area				x		
Maintenance's Auxiliar				x		
Maintenance manager				x		
Electronics technician				x		
Mechanica ltechnician				x		
Engineering head				x		
Engineering analyst	X	X	x	x	x	x
System administrator	X	X	x	x	x	

### 6.4.6 Library creation

Based on the information identified in the maintenance area, the activities defined in the strategy definition and the inputs and outputs related to the processes defined, several libraries were created on the PLM system. These libraries are:

- Machines and area lists
- Suppliers list
- Machine Drawings
- Machine and area description documents
- Machine manuals
- Areas and machine components
- Forms

For demonstrative purposes, the machines and areas lists are shown in Figure 59.



Friday, September 23, 2011  
1:58 PM

Tools Help

Simple Search Page Size: Max Results:

Equipo o area	Referencia
Tumbler	3
Ventiladores	N/A
Aire acondicionado	10
Techo	Restaurante-comedor
Aire acondicionado	4
Techo	Planta Jockey
Luminarias	Planta de confeccion GEF
Secadora	Beige
Transformador	TM0
Aire acondicionado	6
Aire acondicionado	8
Baño	Lavanderia
Transformador	TM03
Dispensadores de agua	3
Aire acondicionado	13
Aire acondicionado	5
Baño	Planta GEF
Dispensadores de agua	11
Malacate	2
Baño	Gestion humana
Malacate	1
Luminarias	Jockey
Baño	Oficinas 2do piso
Dispensadores de agua	10

**Equipo-maquina**  
 Created By: **Innovator Admin**  
 Created On: **9/23/2011**  
 Modified By: **Innovator Admin**  
 Modified On: **9/23/2011**  
 Locked By:  
 Major Rev: **A**  
 Release Date:  
 Effective Date:  
 Generation: **1**  
 State: **Operando**

ator Admi | sabarar | InnovatorSolut | Items 1-101 of 101. Page 1 of 1 | **INNOVATOR** | Messages: 1

Figure 59. Machines and areas list

### 6.4.7 Customized module developments

During the system configuration stage just the preventive, component change and library forms were developed, including fields such as code, name, comments, file, among others depending on the function. For demonstrative purposes, the suppliers form is shown in Figure 60. For the definition of form fields, personal interviews were conducted with the maintenance members that would make use of this function and the related documents were analyzed.

Parte O Servicio	Proveedor	Contacto 1	Telefono 1	Celular 1
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
		Contacto 2	Telefono 2	Celular 2
		<input type="text"/>	<input type="text"/>	<input type="text"/>

**Proveedor**

Observaciones

*Figure 60. Suppliers form developed in PLM system*

Considering all the information stored in the libraries and forms previously defined, an integrator module was created, in which, based on the classification of machines, users can access all the information related to the machine.

E.g., if a user wants to see blueprints, instructive documents, suppliers or a Machine's description document, among others, related to a forklift, he will just have to open the forklift item and find all this information classified by tabs. See Figure 61. The code developed in AML language for generating the "Failure rates graph" is shown in Figure 62.



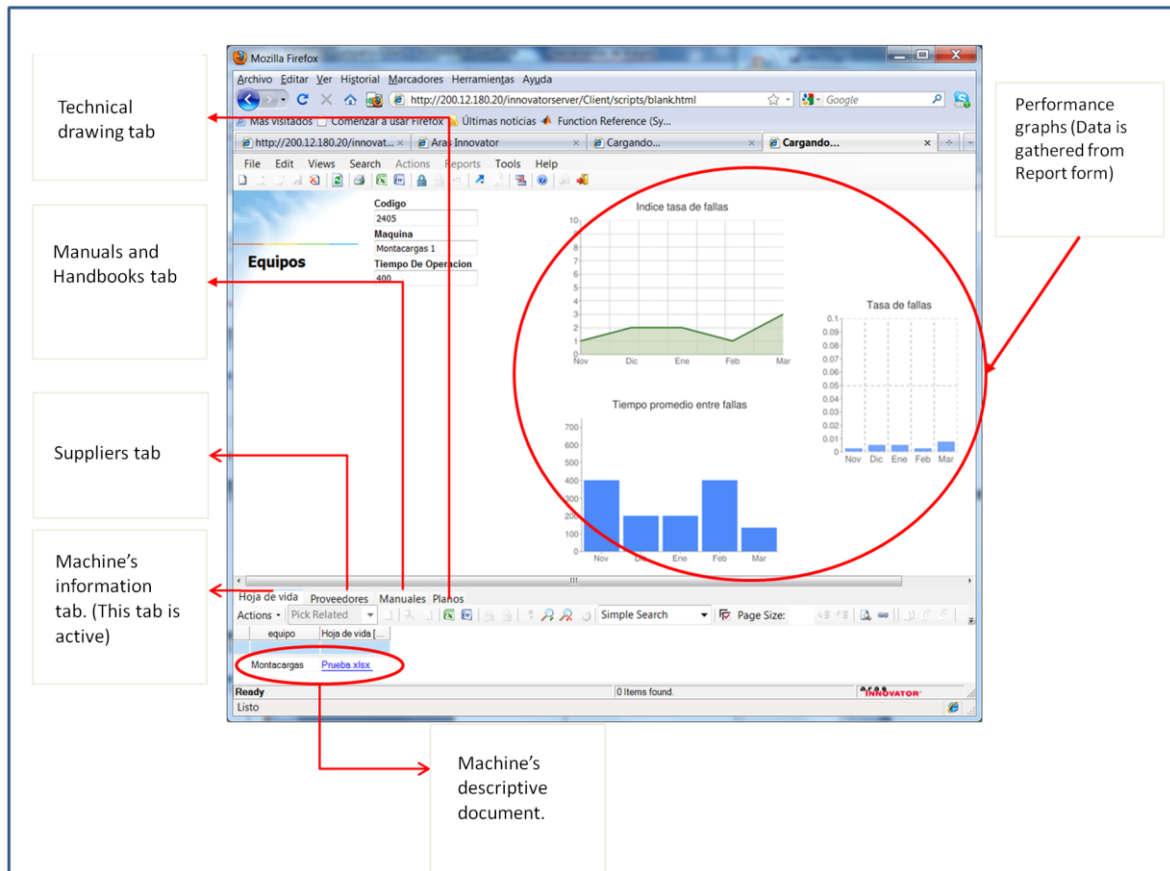


Figure 61. Customized module developed in Aras Innovator® (Test version)

```

Mozilla Firefox
http://200.12.180.20/innovatorserver/Client/scripts/blank.html
Aras Innovator
Cargando...

File Edit Views Search Actions Reports Tools Help

Name GraficaTasaFallas Comment
Client-side JavaScript

001 // Esta funcion permite ordenar de manera ascendente un arreglo de
002 var date_sort_asc = function(date1, date2) {
003   if (date1 > date2) return 1;
004   if (date1 < date2) return -1;
005   return 0;
006 };
007
008 // Esta funcion permite ordenar de manera descendente un arreglo d
009 var date_sort_desc = function(date1, date2) {
010   if (date1 > date2) return -1;
011   if (date1 < date2) return 1;
012   return 0;
013 };
014
015 // Obtiene el id de la "maquina" asociada al formulario en el que s
016 var user = document.item;
017 var msj = "No hay datos relacionados con esta maquina para graficar
018 try {

```

Figure 62. Code developed for "Failure rates graph" in a test version

Although this module was developed and implemented in the company, the performance graphs shown in Figure 61 could not be used there because of a system error in the company's server. The image shown in Figure 61 corresponds to a test version which was developed in a trial server. The cause of the system error can be seen in section 6.7

## **6.5 Stage 5. Monitoring, evaluation and dissemination of results**

On this report only the monitoring of the preventive maintenance plan and preventive maintenance form implementation are included. This situation is due to the company's decision to start the project on June 2011, despite being scheduled to start on February of that year. Additionally, all the process of strategy definition and process re-engineering corresponding to Stage 1 and 3 lasted until the first weeks of August and the system configuration (Stage 4) was completed in mid-August. This implies that the execution of the system could only be performed in late August (see Appendix D).

Consequently, and considering the primordial objectives defined on section 6.1.1.3, the preventive maintenance plan and the maintenance forms for notifying failures and completion activities were executed since the last week of August. Thus, its monitoring process was performed between late August and early November in order to document this part of the project in this report.

However, the documentation process which included the check lists and instructive documents definition, the scanning of physical information that did not have any digital version, the organization and documentation of the workshop's tools in the system and the identification of components required in stock was finished one week after finished the monitoring process described in the last paragraph (see Appendix D). Therefore, although it is already uploaded in the system, it was not possible to monitor it. An image of the project execution can be seen in Figure 63.

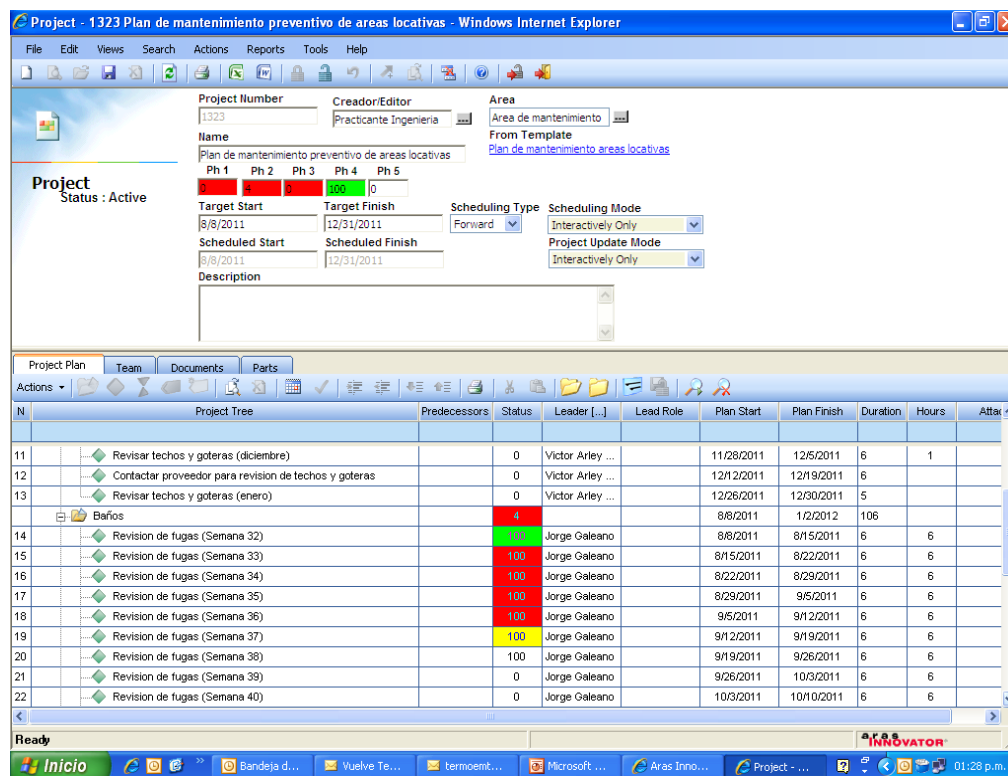


Figure 63. Preventive maintenance schedule in execution in Aras Innovator®

### 6.5.1 Monitoring processes and running projects

For monitoring processes the implementation team established one day of the week as the evaluation day. In this day the digital forms and the activity completion report of preventive maintenance plan corresponding to each week completed was analyzed in order to identify the employee's level of accomplishment. This information was used to define corrective actions in order to assure the success of the implementation.

Additionally there were weekly interviews conducted with the maintenance members in order to identify issues and problems related to the implementation process. For demonstrative purposes, some of the issues identified are shown in Table 40.

*Table 40. Corrective actions conducted during the monitoring process*

<b>Week</b>	<b>Corrective action</b>	<b>Causes</b>
36	Some assignees were reassigned for some of the preventive maintenance activities such as: "Checking water level on the lift"	Several activities were not properly assigned
38	Notifications for requesting provider's service were added to the preventive maintenance schedule	The maintenance manager asked adding notifications for requesting provider's service in order to avoid forgetting performing the activity on time.
39	A new preventive form was defined in order to unify the existing maintenance forms which used to be one per machine or area.	Recurrent mistakes in the filling out of the preventive maintenance form, such as filling out the completion report for any machine in the form corresponding to other machine were found.
40	The new preventive form was defined directly in a system template in order to enable to use the information for internal processes such as plotting and generating reports.	The excel form did not allow taking this information for automating functions in the system such as plotting.
40	New machines were added to the preventive maintenance schedule.	The maintenance member requested adding missing machines to the preventive maintenance schedule such as: "Fircolor", "KDK" and "winch"
42	The "Restroom" areas were differentiated by an identification number in order to assist filling out failure reports	Restrooms were not differentiated in the area list, so it was not possible to specify in which one the failure occurred.

## 6.5.2 Measuring and comparing KPI

Considering all the information obtained in the weekly revision, and the modules and functions that could be tested through the implementation, the indicators measured are the same used in section 6.1.1.12 in Table 29. The results obtained are shown in Figure 64.

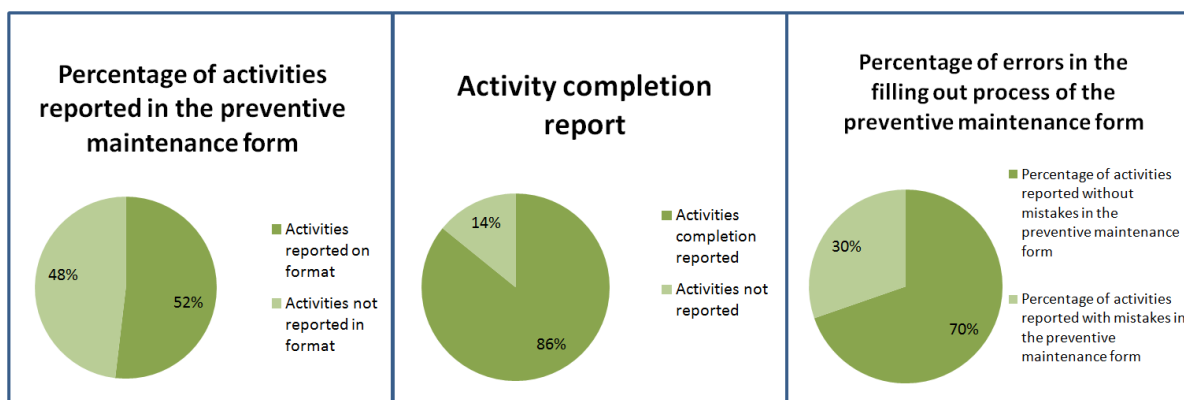


Figure 64. performance information

In order to analyze the contribution of each of the maintenance area members in the data measured, the last mentioned KPI were also measured by maintenance member. The results can be seen in Figure 65 to Figure 67.

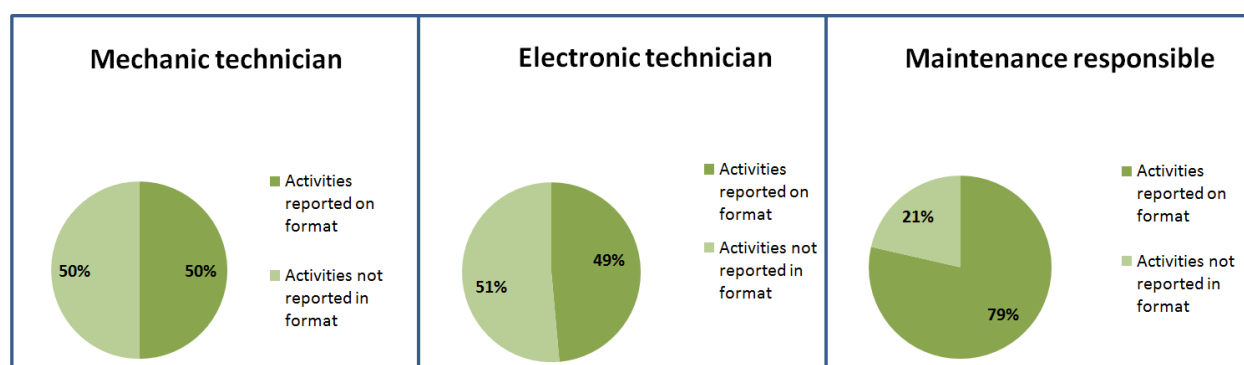


Figure 65. Percentage of activities reported in the preventive maintenance form measured by maintenance member

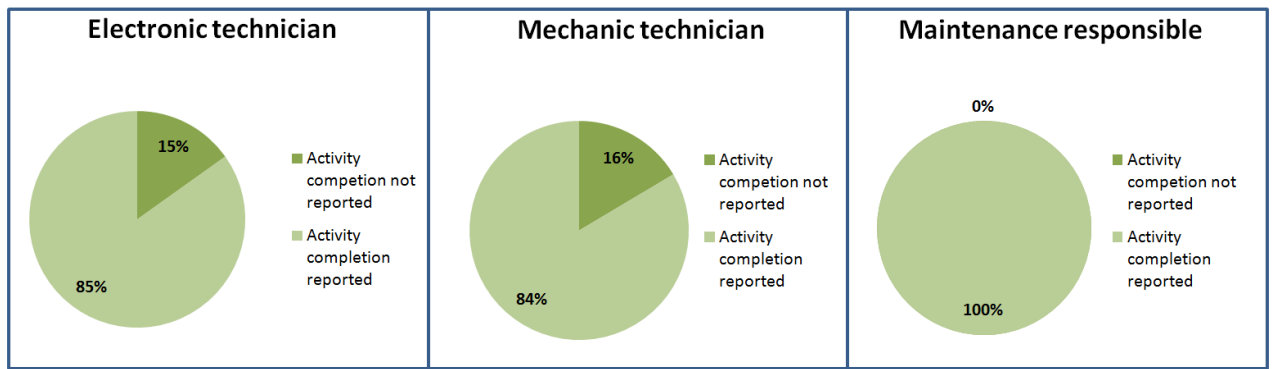


Figure 66. Activity completion report measured by maintenance member

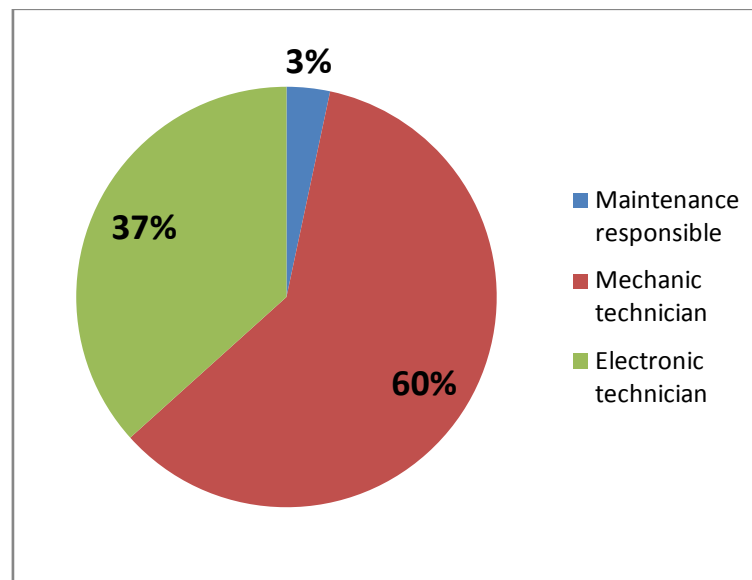


Figure 67. Percentage of errors in preventive maintenance filling out per maintenance member

Considering that the percentages shown above include the first weeks of the implementation and that this data is subject to the learning process, the evolution of: the activity report process of the preventive maintenance format, the activity completion report process and the percentage of errors in preventive maintenance form completion per week were also analyzed and it is shown in Figure 68 to Figure 70.

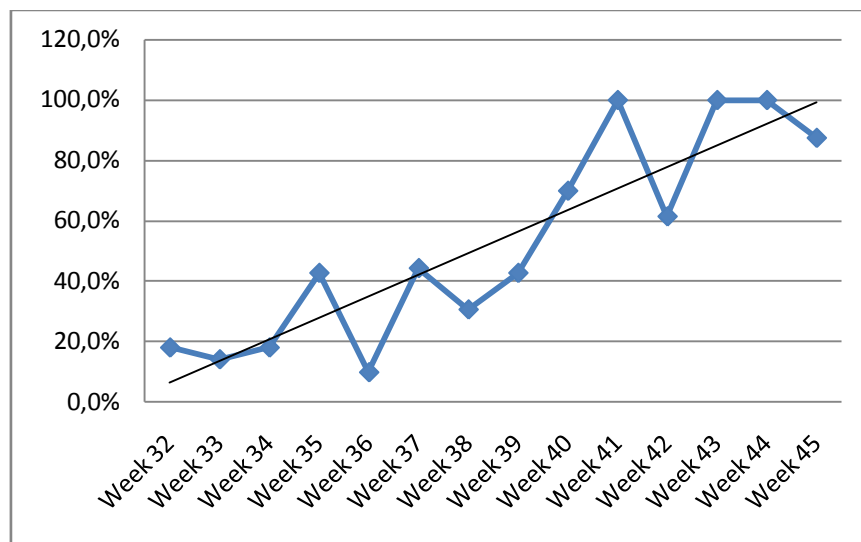


Figure 68. Evolution of the activity report process of the preventive maintenance format

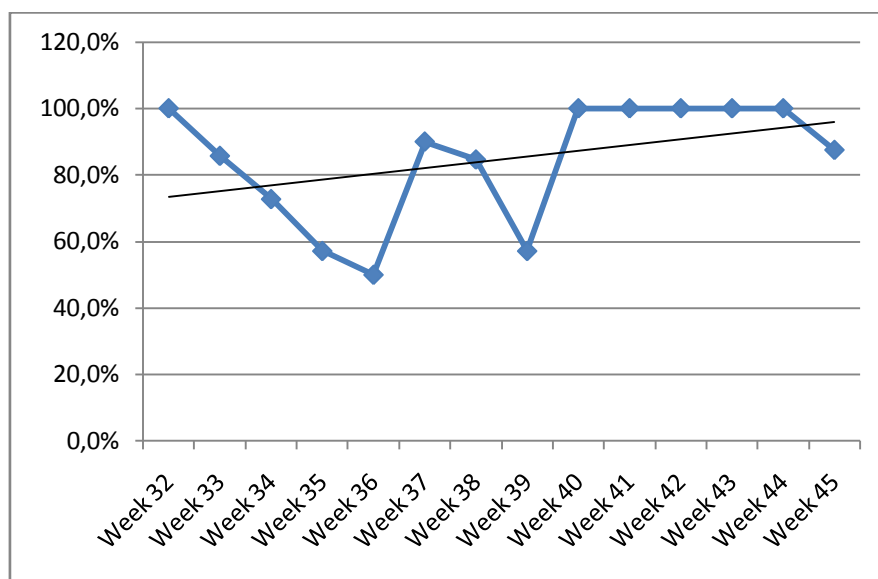


Figure 69. Evolution of the activity completion report process (PART indicator)

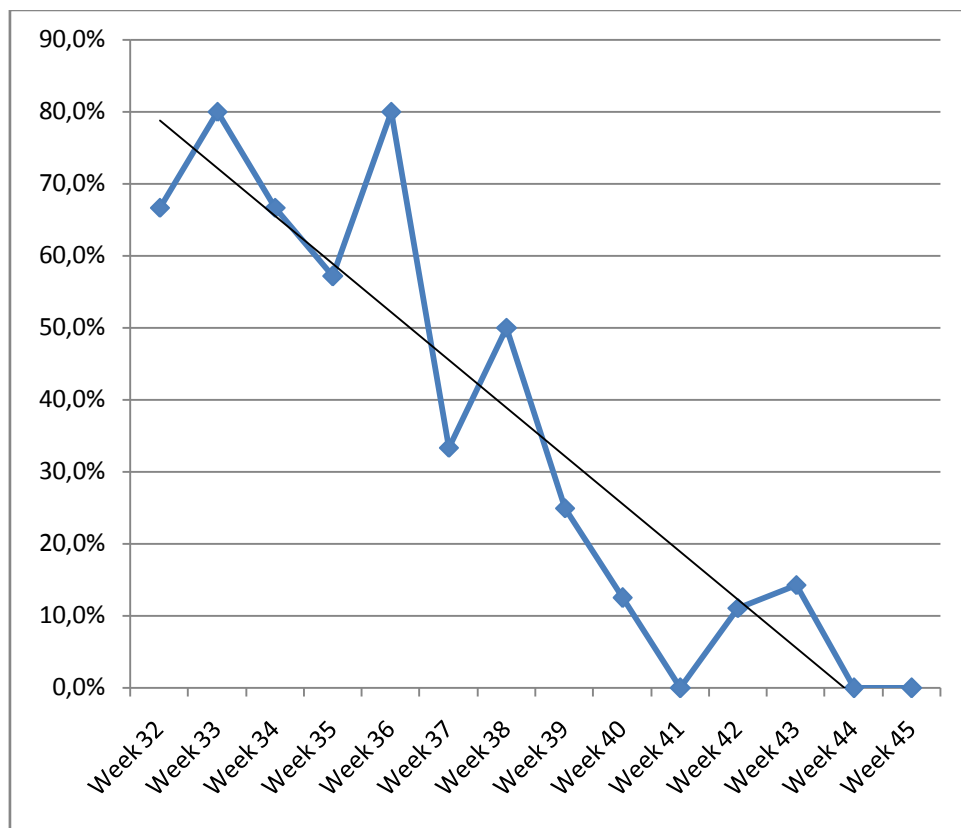


Figure 70. Evolution of the percentage of errors in preventive maintenance filling out process per week

The individual process of each maintenance member is shown in Figure 71 to Figure 73.

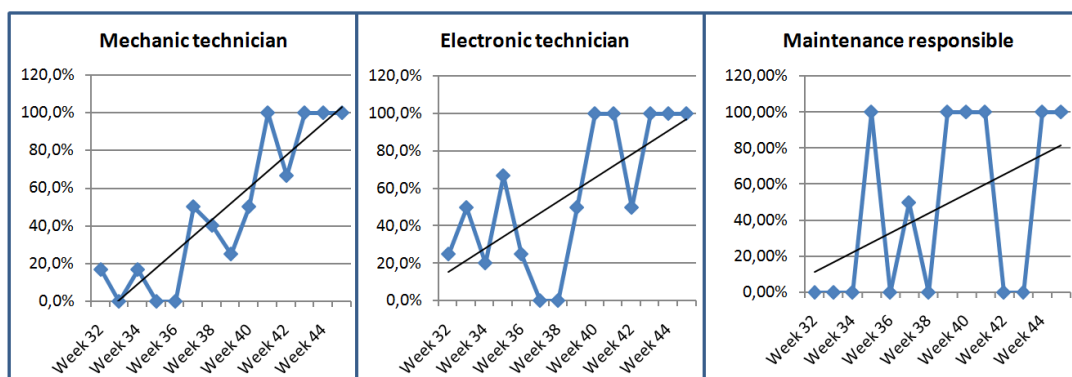


Figure 71. Evolution in the percentage of activities reported in the preventive maintenance form per maintenance member



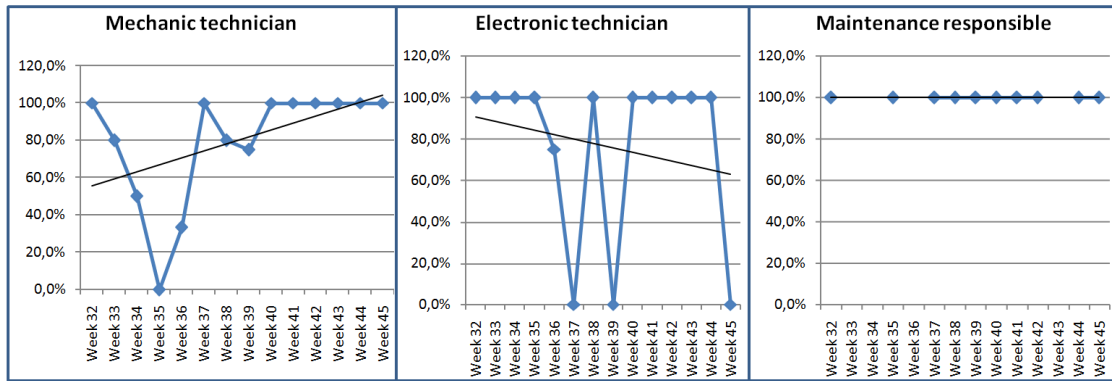


Figure 72. Evolution of activity completion report (PART indicator) per maintenance members

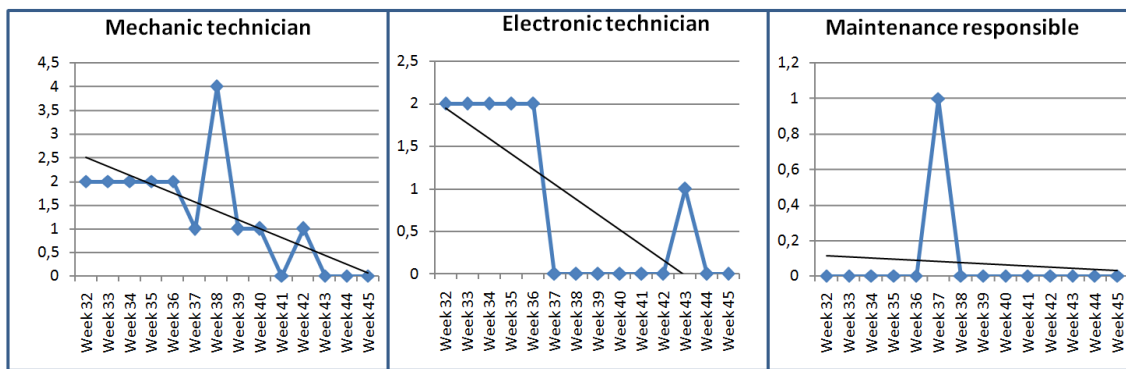


Figure 73. Evolution of the amount of errors in the preventive maintenance's form filling out process per week

Finally, the indicators defined as (8), (9), (10), (11) and (12) in section 6.1.1.12 were also measured for a sample of nine machines. An average of the “failure rate” indicator before and after implementation was calculated. The data considered before implementation was measured between the 11<sup>th</sup> and 15<sup>th</sup> week and the data considered after implementation was measured between the 32<sup>th</sup> and 45<sup>th</sup> week. It is shown in Figure 74. As well as it was done for “failure rate” the “Average time among failures”, “Average time in repairing”, “Percentage of cost of preventive maintenance” and “Percentage of cost of corrective maintenance”. These results are shown in Figure 75, to Figure 78.

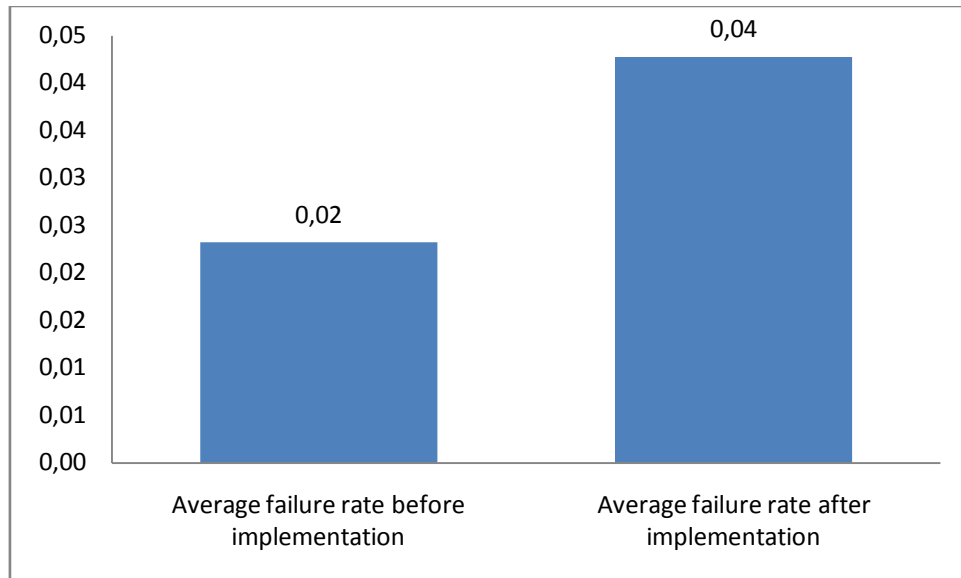


Figure 74. Comparison of average failure rate before and after implementation

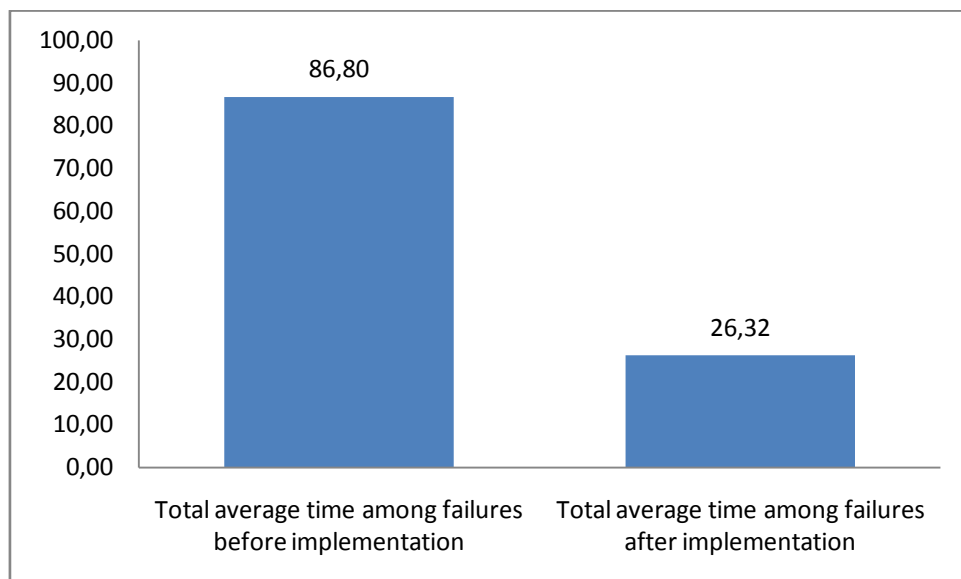
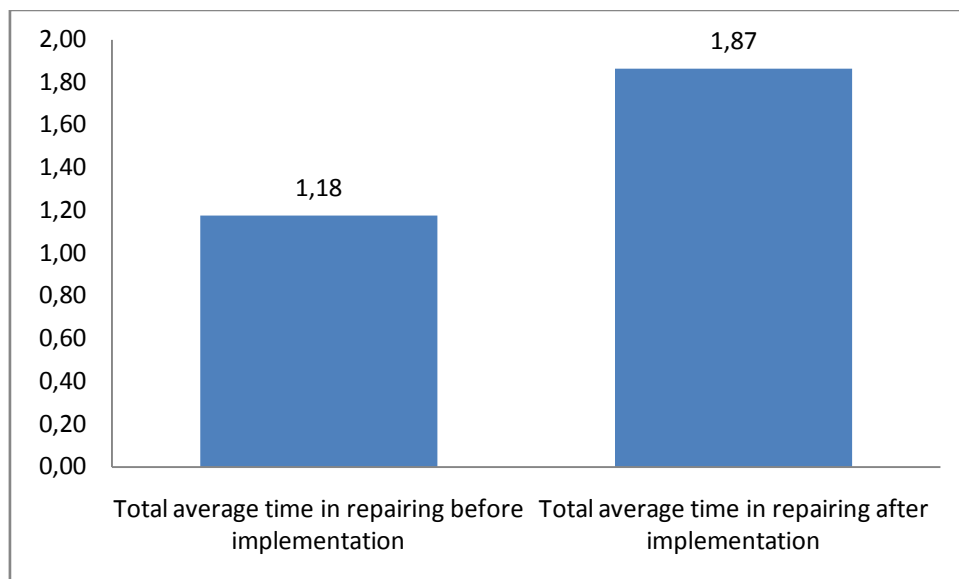
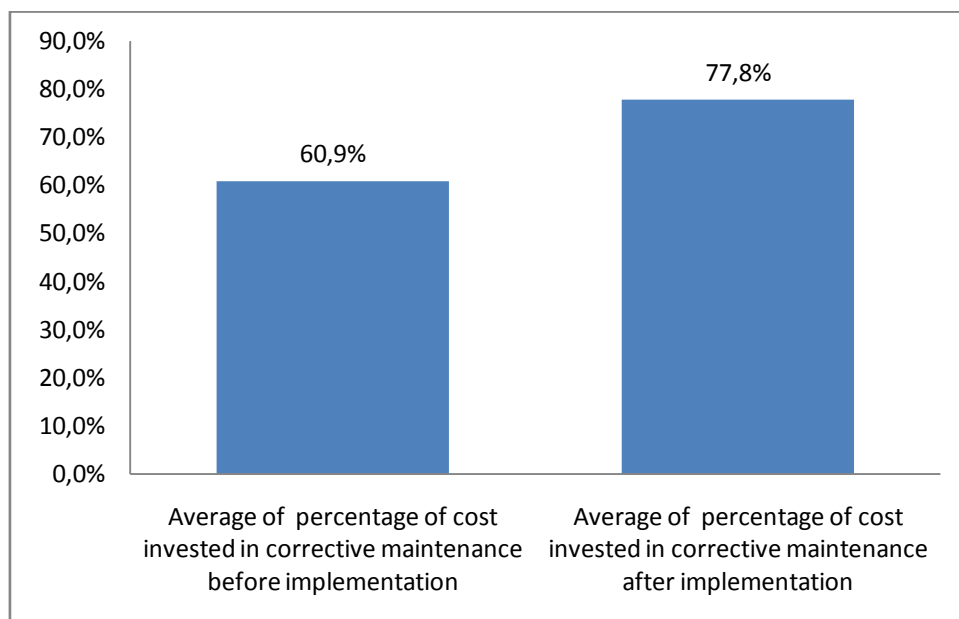


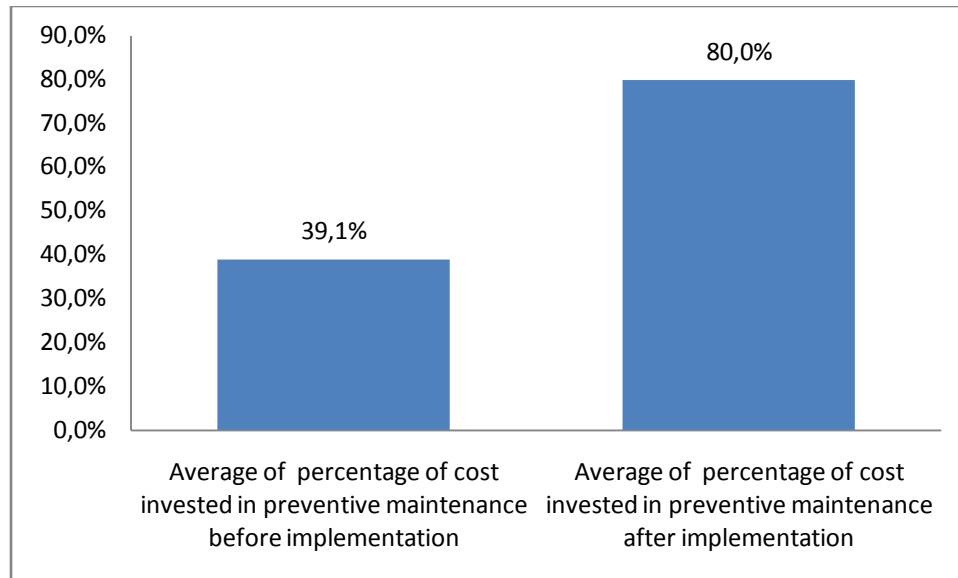
Figure 75. Comparison of the total average time among failures before and after implementation



*Figure 76. Comparison of the total average time in repairing before and after implementation*



*Figure 77. Comparison of the total average of the percentage of cost invested in corrective maintenance before and after implementation.*



*Figure 78. Comparison between the total average of percentage of cost invested in preventive maintenance before and after implementation.*

Additionally to the previously measured indicators, during the implementation 49 suppliers were uploaded to the system by the maintenance manager and 81% of them were already promoted. 17% of the manual documents were also already added to the system and 17% of the instructive documents were uploaded by the engineering analyst. 100% of the instructive documents added to the system were already promoted. This part of the implementation is still being executed and has not been evaluated yet, considering the prioritization process conducted in section 6.1.1.3.

### **6.5.3 Planning corrective tasks and implementing them**

Once the results were analyzed, it was established to continue following the activity completion report and maintenance form filling out process. This monitoring allows assuring that all data related to the machines performance will be stored on the system and will contribute to get proper process traceability.

Additionally, it was decided to closely follow the reporting process of the mechanical technician in order to reduce the amount of errors made by him (as shown in Figure 73). This closer monitoring must include a new explanation of the activities to be performed by him.

Finally, it is also required to simplify the monitoring process which must be performed by the engineering analyst through the use of automated graphics. These graphics would be created to plot the performance of each maintenance member and to show which machines were subject to a greater number of corrective actions.

## 6.6 Conclusions of the implementation process

- Although the total percentage of activities reported in the preventive maintenance form is only 52% (as shown in Figure 64), this process significantly improved during the last weeks, reaching 100% in the 43<sup>rd</sup> and 44<sup>th</sup> weeks. This evolution can be seen in Figure 68, and it demonstrates the importance of a proper monitoring process during new implementation procedures and the effect of the natural learning process of people. This situation is also evidenced by the following facts:
  - Although the total percentage of errors found in the filling out process of the “preventive maintenance form” was 30% (see Figure 64), this value fell to 0% in the 44<sup>th</sup> and 45<sup>th</sup> week, as shown in Figure 70.
  - The total percentage of activity completion reports was of 86% (see Figure 64); however this value also reached 100% between the 40<sup>th</sup> and the 44<sup>th</sup> week, as shown in Figure 69.

This evolution shows an advance in the implementation process and in the strategy appropriation by the maintenance members in the activities defined as priorities. One of the most relevant issues that must be highlighted is that the electronic technician and the mechanical technician did not have any knowledge and experience in the use of computers before the implementation.

Analyzing the performance of each maintenance member shows that all of them have a positive evolution as shown in Figure 71 to Figure 73.

- Analyzing the results obtained through the measurement of the indicators (8), (9), (10), (11) and (12) seems that there is a decline in the results of the maintenance processes and a decrease of quality levels after the implementation. This situation is explained by the fact that the indicators defined depend on the number of failures and corrective actions reported on the maintenance forms. After the implementation, the maintenance members had already appropriated the strategy and used the system to report all conducted activities and failures found. Whereas before the implementation, few failures and activities were reported by them in the forms. Basically, it is not that fewer failures occurred before the PLM strategy implementation, but that less of them were reported. This situation makes it impossible to carry out effective comparisons between the results before and after the implementation based on the data available.

As a final conclusion, a positive trend can be seen in the implementation of the strategy in the company and in the appropriation of it by the maintenance members. However it is not possible to compare the quality evolution of the maintenance processes due to the lack of adequate data before the PLM implementation. This lack of initial data can be explained because the maintenance plan was recently formulated and applied in the company few weeks before the PLM

strategy implementation and only data from the 11<sup>th</sup> to 15<sup>th</sup> weeks were available. It is important to consider that these data were incomplete as shown in the following facts:

- During the 11<sup>th</sup> to 15<sup>th</sup> week the total average of preventive maintenance reports (fully filled out) was 60%, compared with 90% during the 40<sup>th</sup> to 45<sup>th</sup> weeks.
- During the 11<sup>th</sup> to 15<sup>th</sup> week only 23 corrective actions were reported and 11% of the corrective maintenance forms were never completed. It is important to note that the cost analysis provided by the Engineering head revealed a greater number of expenses due to corrective actions than the amount reported in the forms. However these expenses are not specified.

Hence, it is important to mention that enough data should be available and measured before the implementation, in order to be able to compare the effect of the PLM strategy implementation on the quality of the processes involved. This step is one of the main reasons that PLM implementations may take long time as current process analysis should be properly and data gathering is not easy (Specially in not well structured companies or departments).

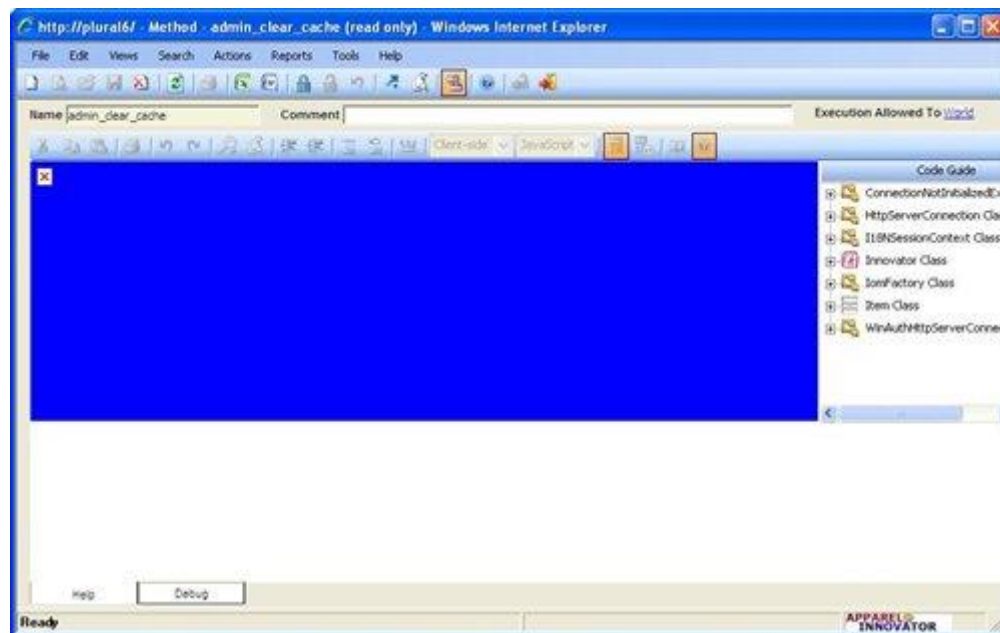
## **6.7 Difficulties related to the system implementation**

The following are some of the difficulties that arose in the case of study related to the implementation of Aras Innovator®:

- Considering that there were not people trained to program in AML language in the local context, it was required investing long time learning it during the case study. This lack of knowledge in this language made difficult achieving better results in the customized module developments in the company.
- Upgrading the Aras Innovator® version is a difficult process, because it implies a database restoring which requires long time and experience by the system administrator. There is available a special software for performing it, however it is required to pay for an Aras Innovator® membership. Due to that the version available in the company (Aras Innovator 9.2) could not be upgraded, even when a new system version was available. This problem affected the compatibility between the installed Aras Innovator® version and the new web browser version (which worked properly with Aras Innovator® 9.3), preventing also the web browser upgrade. Additionally the customized modules development was also affected because these were programmed in a trial server which worked with Aras Innovator® 9.3. This situation made impossible to replace the company's database for a copy of the trial server database which included the new modules developed.
- The use of "Google chart" in the performance graphs development was required, due to the few graphs styles available in Aras Innovator® and the lack of documentation related.

- Current Aras Innovator versions® could present a “blue screen”, instead of the method’s editor provided by the system (see Figure 79). This situation is due to a control ActiveX, known as “.cab”, which is not executed properly by “Internet Explorer®”. The control execution is required for creating “methods” in the system.

Although there is a patch available which solves this problem, it does not work in all servers. In the “case study” the patch worked properly in the trial server (which allowed programming customized modules test versions), but it did not in the company’s one. Due to this problem the performance graphs described in section 6.4.7 could not be implemented in the company, even when they were tested in the trial server.



*Figure 79. Blue screen in the “Methods editor”*

## Chapter 7. Conclusions

Considering that local industry, particularly the Small and Medium Size Enterprises (SME) do not have their internal processes structured, it is important to make special emphasis in the formalizing and structuring of these processes during the definition and implementation of PLM strategies. No PLM software can be effective if the company processes do not work properly and the protocols and procedures are well assimilated by the company employees.

The proposed PLM implementation methodology includes a proper diagnosis and re-engineering process which contributes to structure the company processes. However it is required to measure the results and quality of the processes in a long term. In local industry one of the main problems for PLM implementations is the lack of information and historical measured data, which compels to conduct a proper diagnosis process and further comparisons after the strategy is implemented. Due to that, and based in the experience gained through the industrial case study, it is recommended to conduct a longer indicator measurement before the implementation in order to be able to highlight effective results after the implementation and enabling feedback.

Considering that local managers are usually skeptical to make high investing which does not bring short term results, it is important to be able to show concrete results after first stages. It allows assuring that they will not stop the process before it is concluded. Consequently, the process of defining priorities and dividing the objectives for a short, medium and long term is very important, and it allows presenting short-term results that ensure the continuity of the implementation. However it is, necessary once again, to have enough data to make comparisons.

Although the strategy definition is very important, most of the implementation success lies in the monitoring process. Considering that the proposed methodology is focused in SME, a closer surveillance can be easily conducted. However, in order to make the implementation process even easier and more effective, the members of the company which are part of the implementation team can be in charge of part of the process, contributing to reduce the implementation costs. It is important to assure that at least one member of the implementation team is available in the company during the implementation in order to solve the questions and suggestions of the company's people involved in the implementation and to provide fast reactions to the contingences that arise during the process. In the industrial case study the weekly measurement of indicators was suitable for improving the performance of the maintenance members in the suggested methodologies. In these cases it is also useful to customize the PLM platform in order to automate the indicator measuring process, making easier the monitoring process.

It is vital to include in the diagnosis (through activities such as SWOT analysis) and process definition (through the use of proposed tools) most of the company's members that will be affected by the implementation. Their participation will contribute to improve their assimilation and appropriation of the strategy.



Considering that the up-front license cost of the PLM software is one of the most critical issues for the local industry; during the industrial case study it was found that:

- Although Aras Innovator® can be very useful for the local industry because it is Open Source software and a free license is available, it has many limitations such as the lack of connectors for CAD files, dependence of a Microsoft Windows operating System and the long time and difficulty that upgrade it implies. This upgrade process requires a deep knowledge in order to avoid loss of information.
- People trained in the configuration and developments of complex operations in Aras Innovator® are not locally available. However, a proper training process of any member of the company and a proper use of the available forums can be very useful to face this situation, making the implementation viable.

It is important to have a wide knowledge in the use and configuration of ARAS Innovator in order to be able to customize it and solve all problems that could arise during the implementation and that could difficult the regular operation of the company. In this sense, understanding AML language, database management and a proper use of the forums and manuals provided by Aras is compulsory.

Paying an ARAS subscription package could be useful in order to receive direct support from the company; however it is important to analyze its cost and determine how viable it is for local applications.

In conclusion, and based on the last mentioned items the main results of this project can be analyzed in two main context. First in academic environment, due to the experience gained through the Research cycles and second in the local industry, based on the results obtained through the case study. The further paragraphs briefly describe the project contribution:

- In the academic environment PLM has shown a wide applicability. However a properly infrastructure for performing the system administration and support is required. This infrastructure should assure the right system execution, adapt the system to the academic requirements and facilitates the projects monitoring through customized reports and graphs. Additionally an extensive training process is required for students in order them to assume the PLM working way.
- For local industry, the PLM implementation methodology proposed provides a detailed process which includes the main aspects to be considered in this kind of strategies:
  - Technical factors: through PLM system considerations and the application of business processes analysis and definition tools.
  - Social: Through the training process definition, job transitions analysis and the inclusion of the company staff in the PLM strategy definition.

- Economical: through the implementation of PLM systems which does not requires investing in license costs and the definition of a strategy which also allows short term results.

Finally, this methodology can be easily implemented in the local context, because all proposed methods are easy to understand and it can be performed by company's members. However, people with experience in PLM systems is required for guiding the implementation team, as well as a system administrator trained in configuring the PLM system and programming customized modules.

The guide in the PLM implementation could be performed by an external consultant (expert in PLM strategies). However the system administrator must be part of the company's system department, in order to manage the platform. This person can be trained during the implementation process in the system management, configuration and programming.

The use of Open Source systems such as Aras Innovator® allows performing this kind of implementations in the local context, because it eliminates the up-front license costs and it meets most of the functions of traditional PLM systems. In this sense, PLM strategies can be already implemented in local context, as long as the initiative comes from each company's top management.

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# Appendix A

*Table 41. Data base Engine requirements*

Software	Database Engine			
	IBM DB2	Oracle	MySQL	SQL Server
ENOVIA V6	IBMDB2 9.1	Oracle 10g Oracle 9i	MySQL	Microsoft SQL Server
PTC Windchill	N/A	Oracle 10g Oracle 11g	N/A	Microsoft SQL Server
TeamCenter	N/A	Oracle	N/A	Microsoft SQL Server
Aras Innovator	N/A	N/A	N/A	Microsoft SQL Server 2005 o 2008

Table 42. Operating system server side requirements

Software	Operating System - Server Side					
	AIX	HP-UX	Macintosh	Linux	SUN Solaris	Microsoft Windows
ENOVIA V6	-AIX 5.3 TL04-02 OS Patch or higher	HP -HP-UX 11i, 11iv2 (PA-RISC)	Macintosh 10.4 (Non x86)	Red Hat Enterprise Linux 4 x86	SUN Solaris 10 (SPARC & Opteron x86)	-Microsoft Windows Server 2003 SP2 (32-bit & 64-bit x86) -Microsoft Vista (32-bit & 64-bit x86) -Microsoft XP SP2 (32-bit & 64bit x86) -Microsoft XP SP2 (32-BIT & 64-BIT X86)
PTC Windchill	-AIX 5.3 TL04-02 OS Patch or higher	-HP-UX 11i V2 (Itanium) -HP-UX 11i V1 (PA-RISC)	N/A	Red Hat Enterprise Linux 4 (64- bit)		Windows 2003 or higher Server, 32- bit & 64-bit (Except Itanium) Windows XP 32- bit
TeamCenter	AIX	HP-UX		SUSE Linux	Sun Solaris	Microsoft Windows
Aras Innovator	N/A	N/A	N/A	N/A	N/A	Microsoft Windows 2008 Server

Table 43. Software requirements

Software	Client/server	Client		
		Internet Explorer	Safari	Firefox
<b>ENOVIA V6</b>	Yes, with Web browser as client	Microsoft Internet Explorer 7/JRE 1,5	N/A	Firefox 2.0.x/JRE 1.5
<b>PTC Windchill</b>	Yes, with Web browser as client	Internet Explorer 6,0 or higher	N/A	Mozilla Firefox 2.0 Both with Java plugging
<b>TeamCenter</b>	Yes, according to the configuration. Web browser as client	Internet Explorer	Safari	Mozilla Firefox
<b>Aras Innovator</b>	Yes, with Web browser as client	Internet Explorer 6,0 or higher with .Net framework security policy configured	N/A	N/A



Table 44. Additional requirements

Software	Technologies	Additional Software	Architecture
ENOVIA V6	JRE JDK	N/A	SOA Centralized database with distributed file stores
PTC Windchill	TOMCAT JAVA JDK	Aphelion Windchill Directory Server (powered by OpenDS) Active Directory Any LDAP v3 compliant corporate directory service Info Engine Info Engine Adapter for Windchill	SOA Common schema database, business objects and processes models
TeamCenter	Depending on configuration it could be: JRE .Net	If Teamcenter 8 is used, for integrations with other software products it is required to install them before the TeamCenter installation. Some integrations requires additional software: -TeamCenter's lifecycle visualization -NX integration -SCM ClearCase for Rich Client -TeamCenter's Client for Microsoft Office -TeamCenter's Extensions for Microsoft Office -TeamCenter's Integration for Microsoft Office -TeamCenter's Network Folders	SOA
Aras Innovator	XML SOAP JavaScript .Net languages	.Net Environment	SOA

## APPENDIX B

The design process of each company considered in the local survey is shown ahead in Figure 80 to Figure 89.

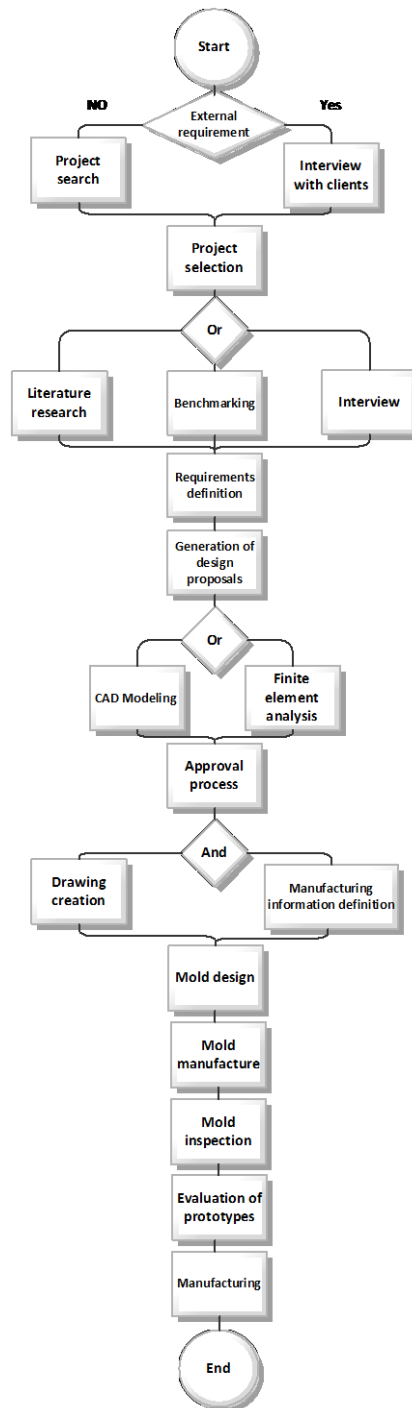


Figure 80. Company 1's Design process

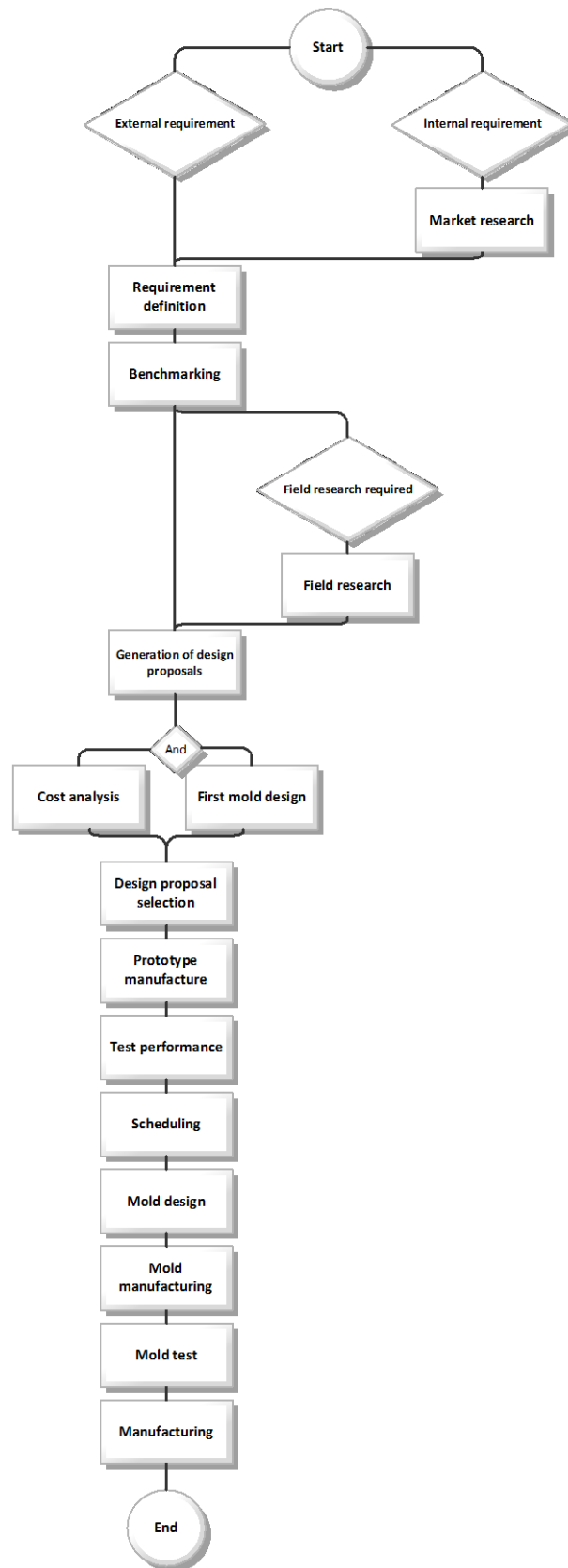


Figure 81. Company 2's Design process

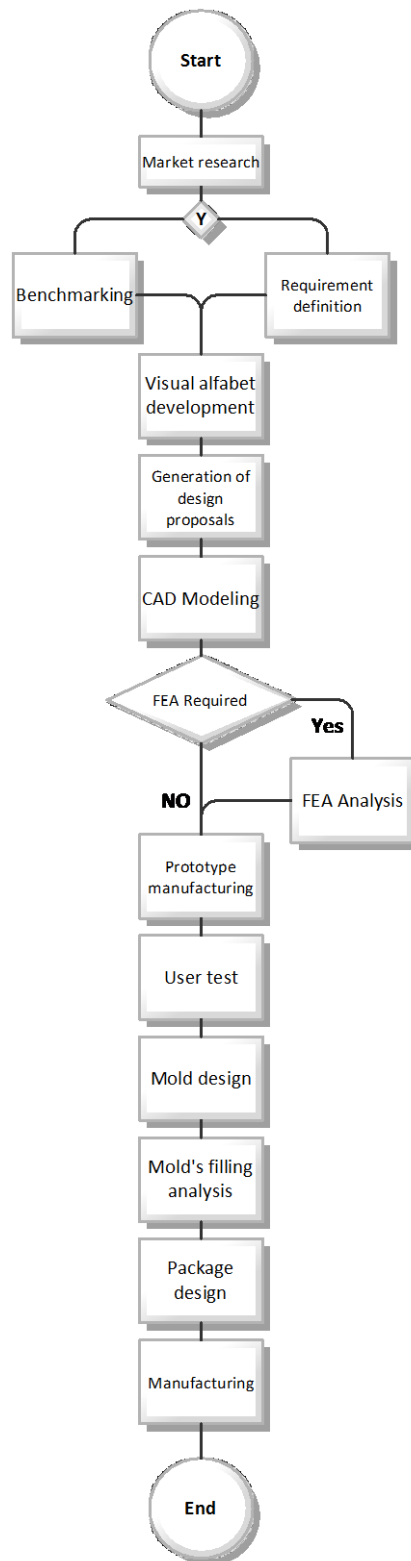


Figure 82. Company 3's Design process

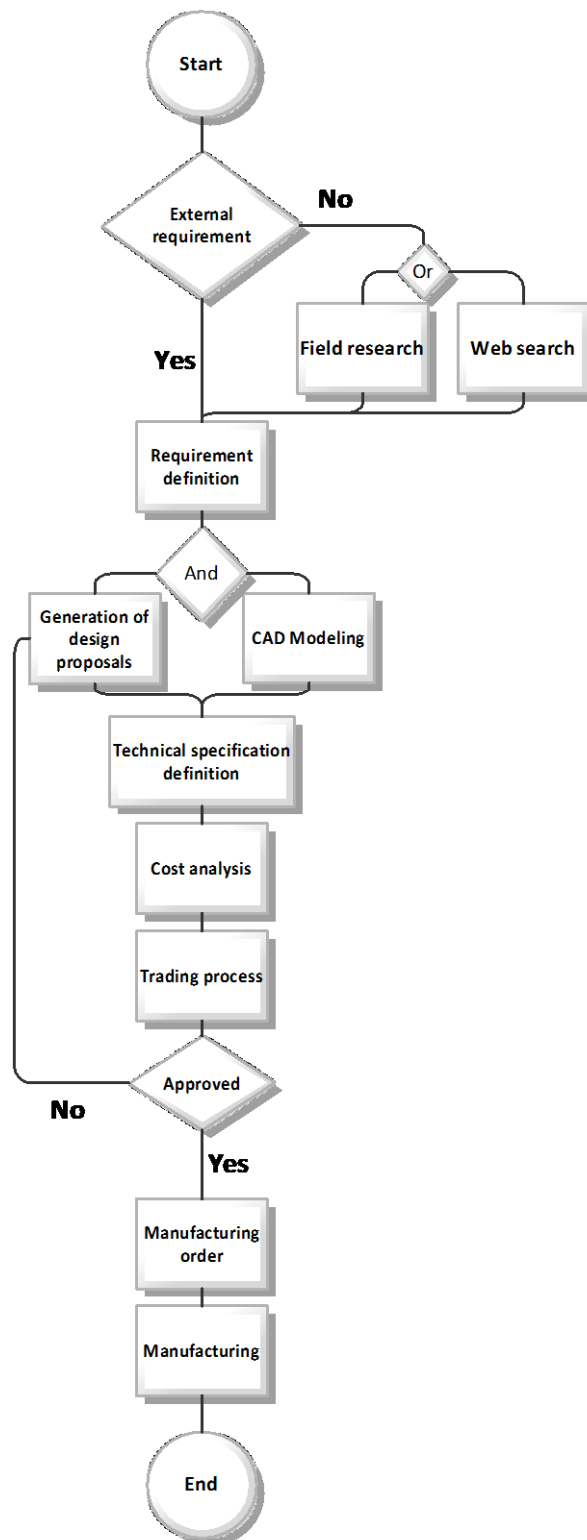


Figure 83. Company 4's Design Process

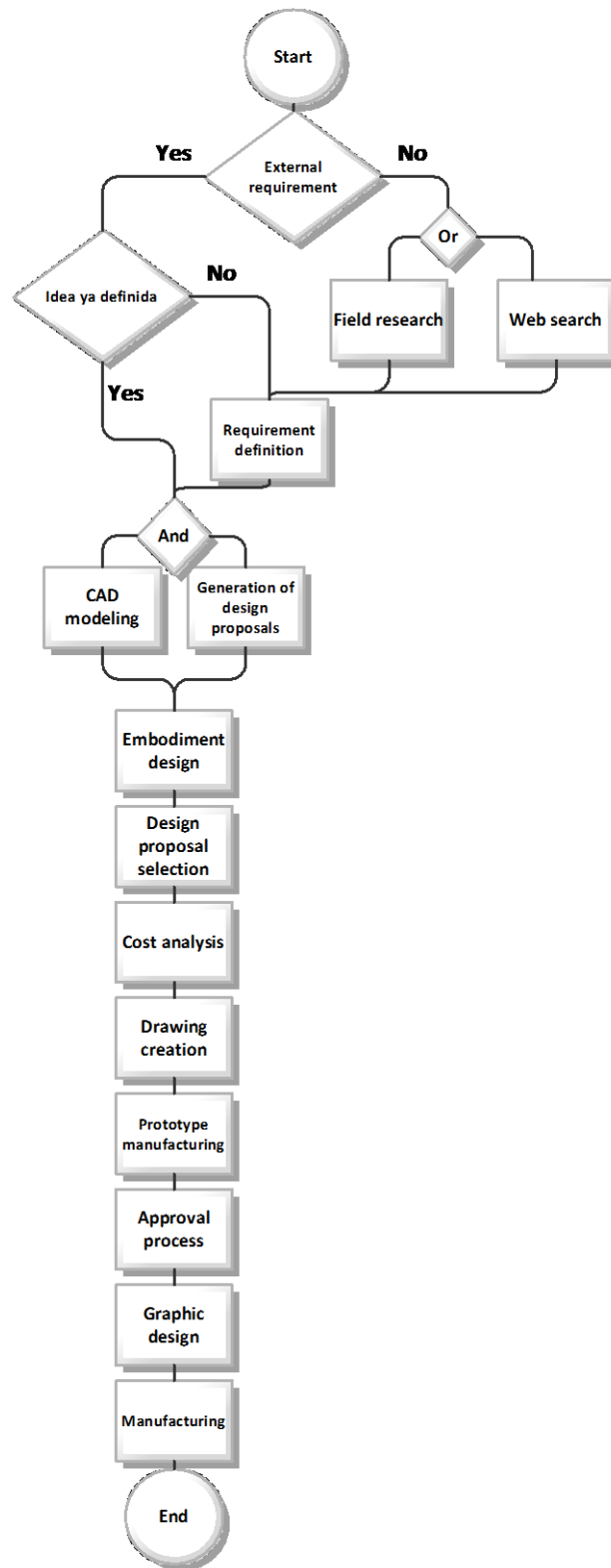


Figure 84. Company 5's Design Process

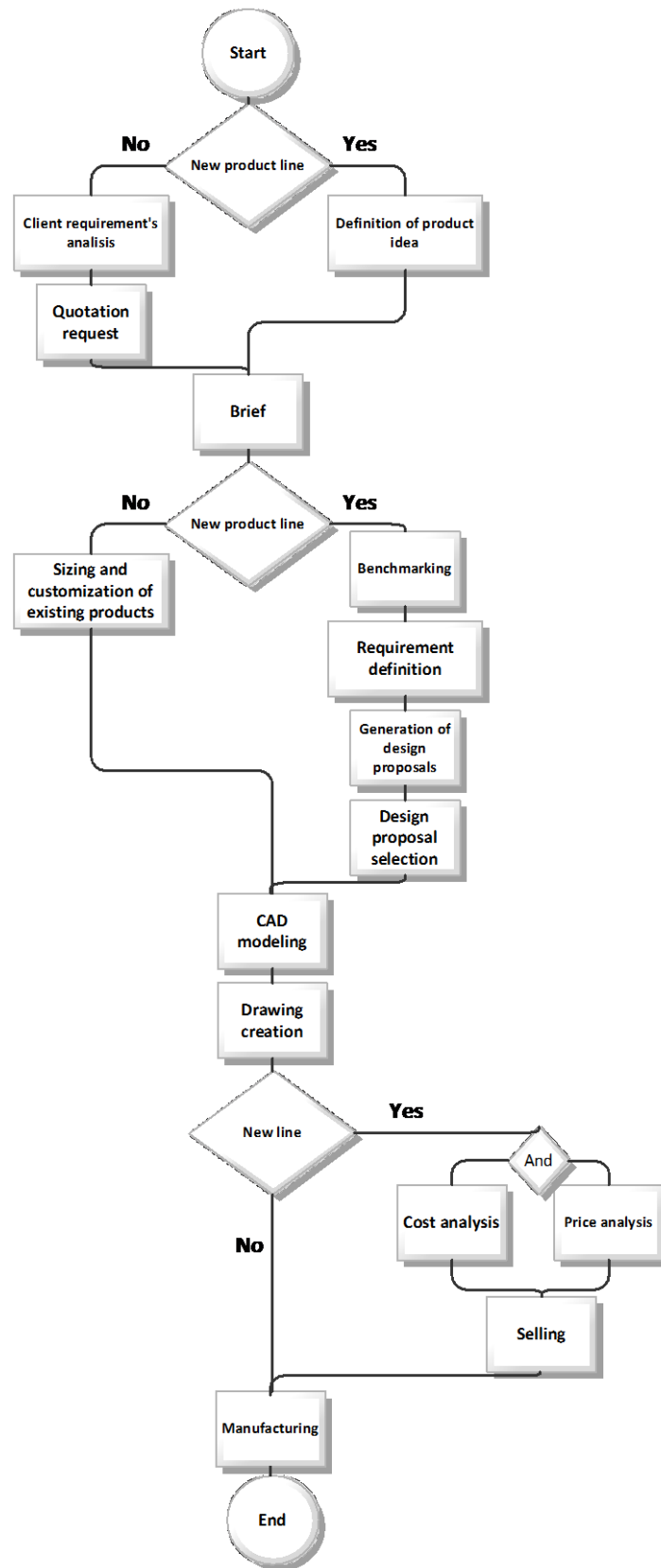
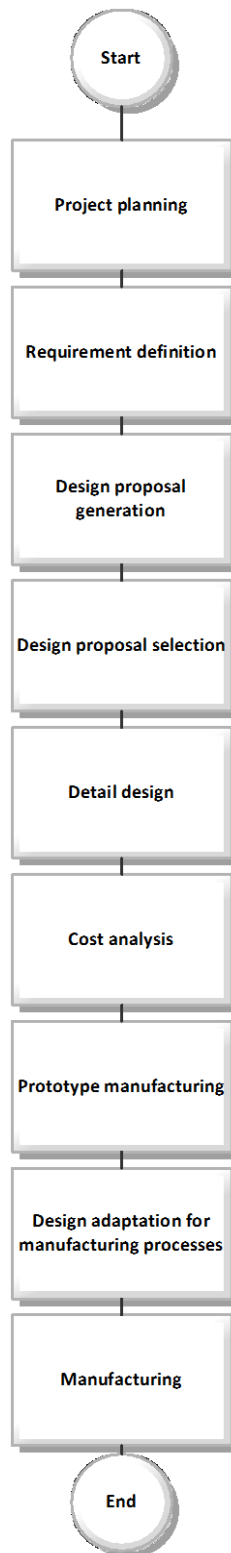


Figure 85. Company 6's Design Process



*Figure 86. Company 7's Design Process*



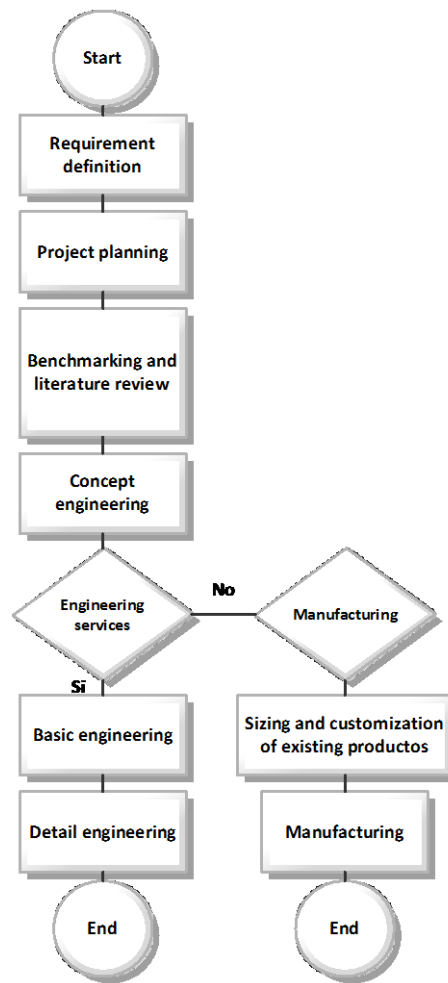


Figure 87. Company 8's Design Process

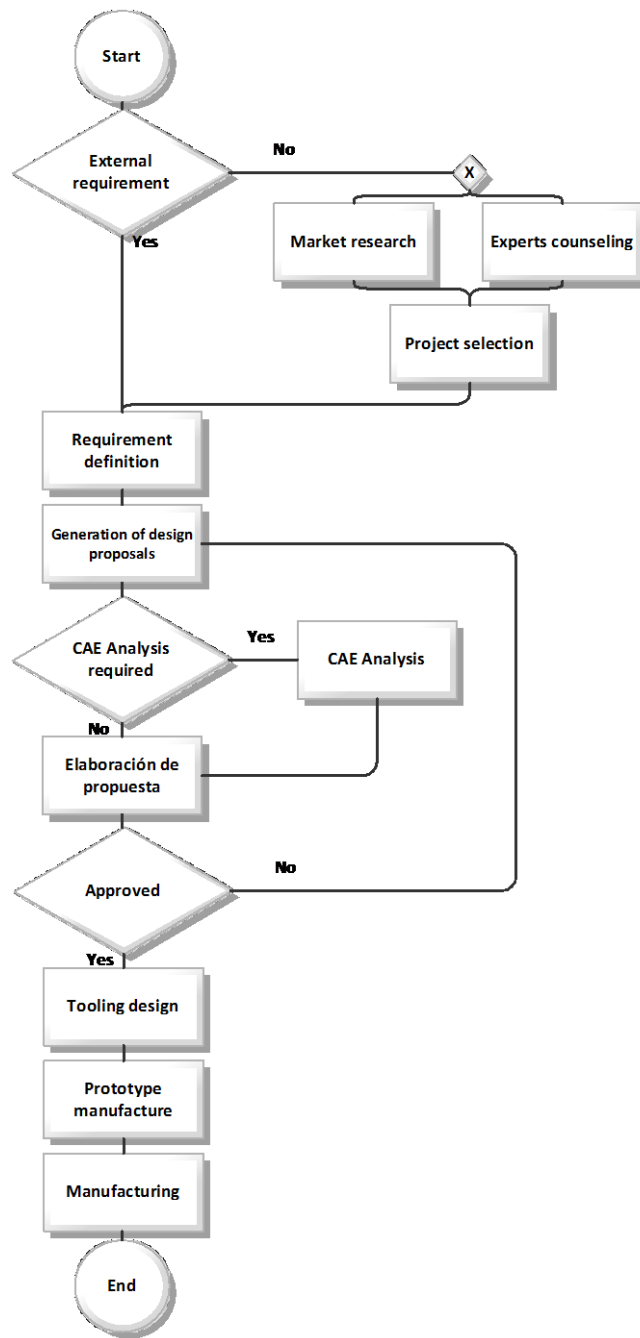


Figure 88. Company 9's Design Process

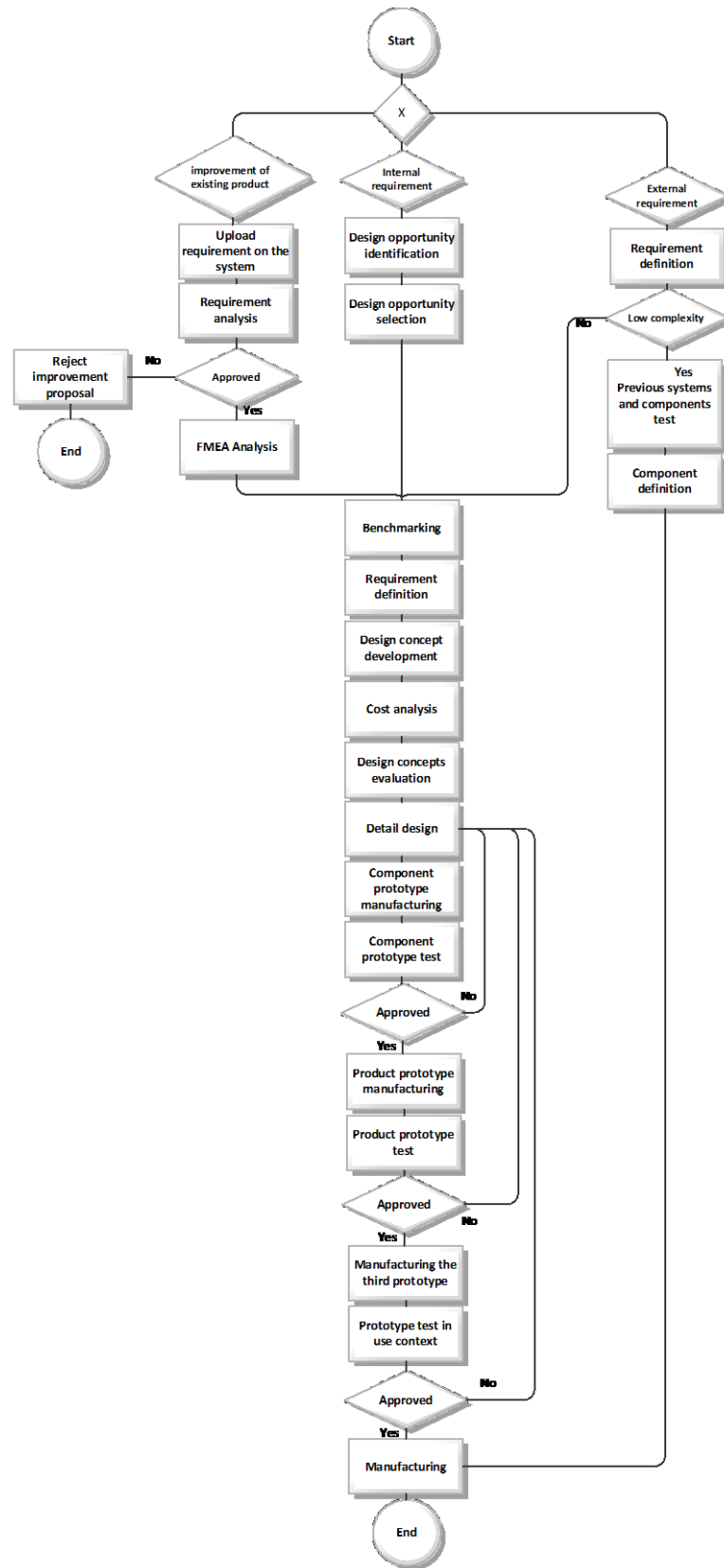


Figure 89. Company 11's Design Process

## APPENDIX C

Table 45. SWOT Analysis table

SWOT ANALYSIS TABLE			
Strengths	Weaknesses	Opportunities	Threats

Table 46. Strategy definition table

STRATEGY DEFINITION TABLE		
Strategy number	Objectives	Activities

Table 47. Effort estimation table

EFFORT ESTIMATION TABLE						
Criteria ( $C_{E_j}$ )	Weight ( $W_{E_j}$ )	Reference ( $R_{ij}$ )	Objective $i$ ( $V_{E_{ij}}$ )	Objective $i$ ( $V_{EP_{ij}}$ )	Objective $i$ ( $S_{ij}$ )	Objective $i$ ( $W_{VE_{ij}}$ )
$C_{E_1}$ : Time						
$C_{E_2}$ : Amount of resources required						
$C_{E_3}$ : Knowledge available						
$C_{E_4}$ : Amount of processes involved						

Table 48. Rating scale based on percentage table

RATING SCALE BASED ON PERCENTAGE TABLE					
	0-20%	21-40%	41-60%	61-80%	81-100%
$C_{E_1}$ : Time	1	2	3	4	5
$C_{E_2}$ : Amount of resources required	1	2	3	4	5
$C_{E_3}$ : Knowledge available	5	4	3	2	1
$C_{E_4}$ : Amount of processes involved	1	2	3	4	5

Table 49. Benefit estimation table

BENEFIT ESTIMATION TABLE					
		Correlation between the objective and the strategy ( $C_{B_1}$ )	Impact level of the objective over the strategy ( $C_{B_2}$ )	Amount of areas or people that are positively impacted by the accomplishment of the objective ( $C_{B_3}$ )	
Strategy	Objective	$W_{E_1}$ :	$W_{E_2}$ :	$W_{E_3}$ :	Benefit ( $B_i$ )

Table 50. Uncontrollable variable estimation

UNCONTROLLABLE VARIABLE ESTIMATION					
OBJETIVES	DESCRIPTION	UNCONTROLLABLE VARIABLES ( $C_{UV_j}$ )	POSSIBILITY OF AFFECTATION ( $V_{UV_{ij}}$ )	WEIGHTED ( $W_{VUV_{ij}}$ )	Total ( $UV_i$ )

Table 51. Entities table

ENTITIES TABLE				
ENTITY				
TYPE				
STATE OR TRANSACTION				

Table 52. Activity identification table

ACTIVITY IDENTIFICATION TABLE	
<b>Process:</b>	
<b>State's Transition</b>	<b>Activities</b>

Table 53. Roles' characteristic table

ROLES' CHARACTERISTIC TABLE			
<b>Role</b>	<b>Responsability</b>	<b>Knowledge required</b>	<b>Tools</b>

Table 54. Resources table

RESOURCES TABLE									
	Maintenance area				Engineering department		Purchase department	External	
Activity	Maintenance Manager	Mechanics technician	Electronic technician	Assistant	Eng. head	Eng. analyst	Purchase assistant	Supplier 1	Resources

Table 55. R-N-I table

		R-N-I TABLE				
ENTITY						
ACTIVITIES						
AREA	ROLE					



Table 56. Resources correlation table

RESOURCES CORRELATION TABLE					
Entity	Activities	Frequency	Cuenta ETC	Annual labor	Unit cost

Table 57. Process analysis table

PROCESS ANALYSIS TABLE			
Process	High cost processess	Unit cost	Comments

Table 58. Form analysis table

FORM ANALYSIS TABLE			
FORM			
Information contained in the form	Mandatory elements	Fields that can be combined	Fields that can be eliminated

Table 59. Objectives, goals and opportunities

OBJECTIVES, GOALS AND OPPORTUNITIES TABLE		
Objectives	Goals	Opportunities

Table 60. Process benefit estimation table

		PROCESS BENEFIT ESTIMATION TABLE						
		Affected processes (Entities)			Related with goal			Expected benefits
Opportunities	Main process							

Table 61. Process priority estimation table

		PROCESS PRIORITY ESTIMATION TABLE							
		Goals		Resources		Factors			
Processes				Unit time (Min)	Unit cost (COP)	Imp time	Imp cost	Risk of imp	Priority

*Table 62. Career plan design chart*

	Future activity	Future activity	Future activity	Future activity	Future activity	Future activity	
Roles	Weight 1	Weight 2	...	...	...	Weighth "n"	TOTAL
Role 1							
.							
.							
.							
Role n							

Table 63. Permission definition table

PERMISSION DEFINITION TABLE							
ITEM :							
State of lifecycle:							
Questions		People or identity in charge of creating a new instance of the function	People or identity in charge of performing any action over the function or editing it	People or identity in charge of controlling and monitoring the related process or activity	People or identity that requires related information as an input to perform any other activity	People or identity that can delete this information or instance	People or identity in charge of approving, disapproving or promoting the instance or item
ROLES							
	Permission	Can Add	Update	Get	Get	Delete	Promote

## APPENDIX D

	Week	Activities	
Before starting project	11	Monitoring of filling out forms before the PLM implementation	
	12		
	13		
	14		
	15		
	16		
	17		
Before launching	18	S1, S2 and S3	
	19		
	20		
	21		
	22		
	23		
	24		
	25		
	26		
	27		
	28		
	29		
	30		
After launching	31	S4	
	32	S5	Development of documentation
	33		
	34		
	35		
	36		
	37		
	38		
	39		
	40		
	41		
	42		
	43		
	44		
	45		
	46		