A PMBoK Extension Proposal for Data Visualization in Software Project Management

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Abstract: Although the human brain stores images more easily than text, most of the tools adopted for software project management are based on textual reports. The number of software projects that fail is huge, and the lack of understanding of the project complexity by the stakeholders is among the reasons for project failure. Data visualization techniques and tools can help to identify the project issues and reduce misunderstandings. In this paper, we investigate how project management can benefit from data visualization. To do so, we adopted a hybrid research approach composed by a systematic mapping study, a survey, and three focus group sessions. As a result, we identify a set of the 16 visualization techniques and tools that can be used to support software project management and we propose a PMBoK extension that provides a reference for practitioners who are planning to use data visualization to support software project management.

1 INTRODUCTION

People process information differently, and data visualization (DV) is a great way to help people literally get the big picture. According to Roam (2009), 75% of our sensory neurons are dedicated to visual processing. Furthermore, there are other studies that confirm the picture superiority effect in regard to words in the human brain (Kirkpatrick, 1894; Stenberg, 2006).

In project management, visualization techniques and tools allow the mapping of large amounts of data to visual patterns that aid human information processing (McDermott, 2019) and help in reducing cognitive bias. The use of visualization can help support project decisions (Geraldi and Arlt, 2015), improve the relationship among the team members and achieve project's success (Lu et al., 2020).

Visualization techniques and tools can bring many benefits to software project management (SPM) such as enabling people to view large amounts of data quickly and efficiently. DV can help people obtain insights from a problem, as well as discover a new point of view on the data. Furthermore, it can help people to have a shared vision in a particular situation, and help to choose the actions to take (Sviokla, 2009).

In this paper, we investigate how SPM can benefit from using DV. We adopt the PMBoK Guide (Project Management Body of Knowledge) (PMI, 2017) as our main reference since it has been largely used in the software industry to support project management. To do so, we first performed a systematic mapping study (SMS) to identify the visualization techniques and tools for project management. Next, we performed a survey and three focus group sessions to collect expert opinions on the techniques and tools we found in the literature. Then, we combined the results to propose an extension for the PMBoK guide.

Our main contribution is a set of 16 visualization techniques and tools to support software project management, and a PMBoK extension proposal with two new processes named 10.4 Plan Data Visualization and 10.5 Implement Data Visualization. We follow the PMBoK process standards to detail each process, describe inputs, tools & techniques, and outputs.

The remainder of this paper is organized as follows: Section 2 provides the background on this study while Section 3 discusses the related work. Section 4 details the research method, and section 5 presents the results. Section 6 provides our proposal and section 7 discusses our results. Finally, we draw our conclusions and future research directions in Section 8.

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2 BACKGROUND

2.1 Project Management

Project management is defined as the application of techniques, tools, skills, and knowledge to enable a project to run smoothly. A project is a temporary enterprise to create a unique product, result or service (PMI, 2017). In SPM, the product is the working system that is delivered at the end of the project.

In the software industry, the PMBoK guide is a standard in the field of project management. According to Singh and Lano (2014) the PMBoK guide is adopted in more than 75% of the projects, including software projects. PMBoK splits the management process into five groups: Initiating, Planning, Executing, Monitoring and Controlling, and Closing. PMBoK also presents 10 Knowledge Areas (KA) named Integration, Scope, Schedule, Cost, Quality, Resources, Communications, Risk, Procurement, and Stakeholder. In this paper, we focus on Communications KA because DV techniques and tools are inserted in the communication context. In addition, PMBoK presents 49 processes, each one has inputs (all things that are essential to the process), tools and techniques to help in processes execution, and the resulting outputs.

2.2 Data Visualization

Data visualization (DV) refers to the representation of information and data. Visual representations arose even before writing, when people used to draw daily situations and objects on cave walls, aiming to transfer the knowledge to future generations. Visual representations depend on the type of data in which they originate. To Ward et al. (2010), DV is a way of communicating information using graphics. Their book is adopted as the basis for visualization classifications, according to their type. The authors separate the types of visualization according to the data that originate them, as shown in Figure 1.

3 RELATED WORK

In the Visuals Matter book (Geraldi and Arlt, 2015), the authors discuss several views for visual representations that support the decision in projects and portfolios. They propose visualizations and recommendations for designing and using visual tools in projects and portfolios.

Abad et al. (2016) performed a review on visualization in requirements engineering (RE). Their paper presents 18 usage patterns, which discuss visualization techniques developed for three dimensions of RE: activities, stakeholders and domains.

Shahin et al. (2014) investigated software architecture visualization techniques. They found techniques, tools, types of visualization, activities, and the purpose and domain of visualizations. They also classify the visualization techniques in four groups: graph-based, notation-based, matrix-based, and metaphor-based. In the same direction, Grainger et al. (2016) proposed a framework to improve visual communication, to be used in a non-scientific context.

Lemieux and Salois (2006) and Baum et al. (2017) investigated visualization techniques for a better understanding of the software. They show the generation of visualizations based on code lines.

There are at least three known proposed extensions on the PMBoK subject. The oldest one is for government projects (PMI, 2006), which brings good practices for public sector projects. Another extension is related to SPM (PMI, 2013), developed with the Institute of Electrical and Electronic Engineers, and it uses prescriptive and adaptive approaches. The most recent extension is for the construction sector (PMI, 2016) and the proposal deals with specific domains of projects of that nature, such as integrity, safety, protection, environmental management, financial management, and claims.

When comparing our study with previous ones, our study further investigates SPM and the usage of DV in the software engineering field. We believe that by extending the PMBoK guide within two new processes, as presented in this paper, we can provide valuable contributions to organizations as well as the academic community.

4 RESEARCH DESIGN

We conducted a hybrid research approach, starting with an SMS to identify visualization techniques and tools used for SPM. Then, we performed a survey to understand how data visualization techniques and tools are applied in the software industry. Finally, we conducted three focus group sessions to collect expert opinions on the techniques and tools we previously found, and consolidate our results. In this paper, we adopted the following IEEE definitions (of the IEEE Computer Society, 1990) for software techniques and tools:

- **Software Techniques:** procedures to help evaluate and improve the software development process. For example, bars graphs and column charts are used to visually present the data.

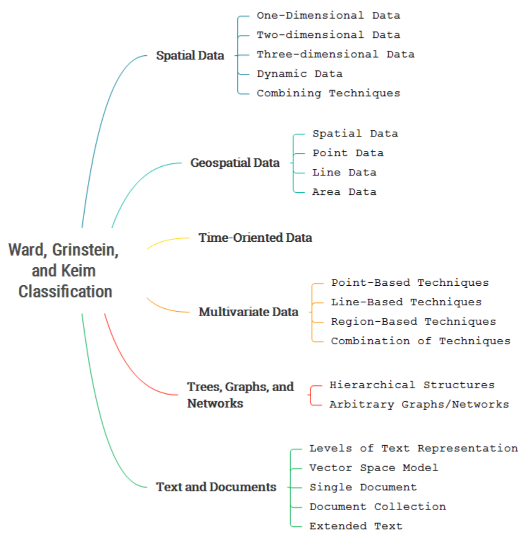

Figure 1: Data Classification according to Ward et al. (2010).

- **Software Tools:** systems for developing, testing, analyzing and maintaining software products or software documentation. Some examples of tools are Microsoft Excel and Microsoft Project.

4.1 Systematic Mapping Study (SMS)

We followed Kitchenham (2007) guidelines to conduct our study. We have split the SMS into three phases: Plan, Conduct, and Document Review. At first, the main researcher created the protocol and then a second researcher validated it. We defined two research questions (RQ):

RQ1: *Which visual management techniques and tools are used for project management in general?*
RQ2: *When are such visual management techniques and tools applied to support project management in the Software Engineering field?*

We applied our search string on Scopus database and adopted by Rauch et al. (2013) to validate our search string. Our search string includes the following terms: *project manage*, information visual*, data visual*, visual management, visual*, tool*, technique*, practice*, method*, challenge*, approach*.* ("*" is a wildcard).

We first applied the search string in November 2018 and then updated the results by applying the search string again in November 2020. We did not specify a period of time for the searching studies. Our results show that the first paper on techniques and tools for project management was published in 1983 by Winsor (1983) and it is focused on the diagonal network analysis technique.

Initially with our search string we got 2278 papers. In the selection step, by reading the title, abstract and keywords, we rejected 1072 papers.

In the extraction phase we first performed a review in the remaining 1206 papers to identify if selected papers were addressing our research questions. Then, we conducted a further the analysis of the accepted ones. At the end, we selected 304 papers to answer our research questions. The list containing the selected papers is available in this link[1]. The papers are sorted alphabetically by the lead author's surname and we have added the letter "R" before the identifier so the references of the paper and the SMS are not mixed (eg.: [R1], [R2], ..., [R282]).

The final set of accepted papers matches the following inclusion criteria: 1) Focused on our research questions; 2) Written only in English; 3) In the case of a duplicate, the most complete version published was selected. The rejected papers include at least one of the following exclusion criteria: 1) Non-English papers; 2) Papers that are not directly linked with the research questions; 3) Papers without bibliographic information; 4) Posters, prefaces, incomplete publications, and duplicated studies.

4.2 Survey

We have conducted an online non-supervised, semi-structured survey composed by open and close questions. The objective of the survey was to understand how DV techniques and tools are applied in the software industry, and the relationship between software tools and visualization techniques. To perform this study, we followed the steps given by Pfleeger and Kitchenham (2001). We validate our survey through face-to-face contact, content validation, and a pilot.

Our questions were focused on the visualization techniques and tools identified in the SMS. For each PMBoK process group (Initiation, Planning, Execution, Monitoring and Control, Closing), we selected the most cited DV techniques and tools during qualitative analysis. Our target audience for the survey was composed of IT professionals with SPM or software development experience. The participants were asked to select techniques or tools that they would use for each process group. We also asked them to provide recommendations on other DV techniques or tools that were not mentioned in our list. We released the survey by e-mail and social media such as Facebook and LinkedIn.

Up to 1675 people may have had access to the survey, but only 101 members of the target audience an-

[1] https://bit.ly/2J7BAp1

swered. Participants have 7.5 years of IT experience on average, ranging from 0 to 28 years of experience in IT projects. The average age of the participants was 36 years, and approximately 75% identified themselves as male. 85% of the respondents hold some postgraduate degrees, such as MBA, Master or PhD. Most of the participants were located in Brazil (92%), while 5% were located in the United States. Most participants in the survey hold positions directly related to project management such as project manager (28%), project analyst (18%), or director (7%). The remainder (47%) includes coordinator, consultant, engineer, architect, and software developer. 89% of the participants have already worked with software development or deployment projects. Almost half of the participants have worked with prescriptive and agile methodologies, 25% only with prescriptive methodologies and 21% only with agile methodologies.

4.3 Focus Group

We developed the activities based on Morgan's guidelines (Morgan, 1997) to conduct the focus group study. We also adopted the four phases proposed by Kirk et al. (1986) for qualitative research execution: Planning, Observation, Analysis, and Report. Our target audience was software project experts and software development process experts. We elaborated the dynamics to follow during the sessions, and then we conducted a pilot so we were able to simulate, check and improve the process.

We had 13 participants in this study, divided into three sessions (S1, S2, and S3). Hereby we refer to the participants as P1, up to P13. The majority was male, with 12 years of experience in PM and 36 years old, on average. We asked participants to answer an online survey in advance to the sessions. During the sessions, in the main activity, we present the 19 proposed techniques to the participants, and then we asked them about their applicability in SPM. We had a group of research volunteers helping us to take notes on the topics discussed during the sessions.

When the group agreed that a particular technique is useful, they were asked to give examples of contexts in which it could be applied. For the techniques the group found not be suitable for SPM, they were asked about the reasons that drive them. At the end of each session, participants were asked to cite other techniques and tools that had not been mentioned during the sessions. We compiled data from answers to the previous survey, the annotations the assistant researchers made, a compilation one of the members of each session made, and the video and audio we captured during each session.

5 RESULTS

5.1 Systematic Mapping Study Findings

RQ1: *Which visual management techniques and tools are adopted in project management in general?*

We found a set of 16 tools and techniques for PM such as boxplot, dashboard, network diagram, fishbone diagram, scale, spectrogram, focus + context, GIS (Geographic Information Systems-based visualization), pie chart, radar chart, kanban, timeline, linkograph, augmented reality-based, virtual reality-based, 3D, 4D, tree structures, bars or columns chart, scatter plot, Gantt chart, line chart, graph, heatmap, and matrix. These techniques and tools are applied for different types of projects.

We categorized tools and techniques according to the process group defined by PMBoK. We observed that bars and columns chart, dashboards, line chart, and scatter plots are used in all process groups, except the Closing process. However, boxplot, GIS, matrix, and virtual reality-based appears just in one phase each. Most visualizations are made for monitoring and controlling projects. We also found that Scope, Schedule, and Cost are the KAs where visualization techniques and tools are used more in PM. We did not find studies focused on visualization for project Closure.

Our findings show region-based techniques, 3D models, and line-based techniques, followed by time-oriented data to generate the most visualizations in project management. Visualization techniques developed for engineering, architecture, and construction use up to five dimensions to show their project's data. For example, papers with 5 dimensions can present 3D visualization plus time and cost [R253], or emissions of pollutants and accidents identification [R258].

The majority of techniques and tools (46%) are developed to support DV for Engineering, Architecture or Construction projects, and Software Engineering (SE) projects (46%). The remaining (8%) support DV in the Education [R14], Scientific Research [R94], NASA (National Aeronautics and Space Administration) ([R70], [R194]) and Industry ([R219], [R249]) fields. Other report techniques or tools are found in generic projects such as those to generate visualizations of geospatial data. This is a reflection of the predominance of construction projects.

RQ2: *When are such visual management techniques and tools applied to support project management in the Software Engineering field?*

We found 140 papers discussing DV for software engineering (SE) project management. Multivariate data (45%), region-based techniques (32%), and tree structures, graphs, and network diagrams (31%) form the most used data sets in Software Engineering (SE). In these projects, data come from configuration or code repository, source code, e-mail, .xml files, Microsoft Project or Primavera P3. These results make sense because these techniques are used to understand the interaction between developers, monitor and control project scope, and visualize changes the frequency in code snippets.

Our results also show that some visualization techniques and tools use lines of code [R59], [R71], [R72], [R182], [R232]. They are based on metrics obtained from code repositories, e.g., commits, amount of rows, developers information and their contribution in a certain code. The most cited goal for these code-based visualizations is to understand the interaction between developers, monitor and control project scope, and figure out which code snippets have changed frequently.

In SE projects most of the visualizations are meant to display information about the KAs as Scope (51%), Schedule (43%), Stakeholders (23%) and Quality (21%) instead of Cost, most common in general projects. In fact, software quality indicators, for instance, the number of bugs, are important information about project progress.

5.2 Survey Findings

The most commonly adopted DV tools reported are Microsoft Project (59%), followed by Trello (31%), and Microsoft Excel(15%). Other tools mentioned were: Jira (12%), Office Package (8%), WBS Chart Pro (7%), EPM (6%), Microsoft Team Foundation Server (4%), Slack (4%), Microsoft Sharepoint (3%), Redmine (3%) and SAP PS (3%). Basecamp, Google Drive, Kanbanflow, Kanbanize, OpenProj, Primavera P6, and Trace GP hold 2% or less. Participants usually cited more than one tool and sometimes mentioned techniques not listed: pie chart, network diagram, fishbone diagrams, scale, spectrogram, timeline, focus + context, linkograph, and augmented reality-based.

Some techniques were mentioned to be useful in all process groups in projects: kanban, bar chart or columns, line chart, and dashboard. 3D, tree structures and Gantt chart are used in all groups except the Initiation group. Scatter plot and graphs are used at all stages, but not at the end of projects, while heatmaps are not used in the Planning phase. By process group, in **Initiation**, the line charts, bars or columns chart, and dashboards are used more; in **Planning**, Gantt chart, tree structures, and line charts are most commonly used; in **Execution**, the Gantt chart again appears as the most used, followed by kanban and line chart; and for the **Monitoring and Control**, the most cited was the Gantt Chart, line charts, and bars or columns chart.

For **Closing**, as no specific technique was identified during the SMS, we asked for a textual answer. 30% of the participants reported they do not use any visualization technique at this stage. 18% reported using dashboards, and 18% used only textual reports. We also asked about tools that participants would recommend to SPM. The three most cited tools were Microsoft Project (59%), Trello (31%) and Microsoft Excel (15%). One-third of them suggests DV techniques are more useful in Monitoring and Controlling. Finally, 19 tools and techniques compose the final set (see Table 1). Based on the SMS and survey results, we classified the techniques and tools into the PMBoK process groups, so that it could be evaluated by the experts.

5.3 Focus Group Findings

Figure 2 presents a heatmap, where we compiled the focus group results, based on the information we obtained from each session (S1, S2, and S3). We calculated the score as follows: 1) Each participant's (P1, P2, ..., P13) previous response in the online survey was worth 1 point; 2) When a consensus is achieved in S1 or S5 it is worth 5 points (each had 5 participants); 3) When a consensus is achieved in S2 it is worth 3 points (each had 3 participants); 4) We sum the score for each technique in each phase.

For this study, the maximum score that a technique could have in each question would be 26 points, i.e. when all the participants and all sessions informed that they would use the technique in a certain group of processes. To divide the techniques into process

Technique	Proccess Group					Not useful
	Initiating	Planning	Executing	Mon. and Controlling	Closing	
3D	4	10	5	4	1	14
4D	3	11	10	8	0	14
Bar or Column	15	17	19	25	18	0
Boxplot	1	5	8	11	1	14
Canvas	26	25	14	9	8	0
Dashboard	12	15	24	26	17	0
Flowchart	15	26	21	17	10	0
Gantt	12	25	24	25	12	1
GIS	9	13	18	12	2	2
Graph	7	15	3	9	1	7
Heatmap	2	13	18	12	2	2
Kanban	10	15	26	24	8	0
Lines	8	17	19	26	15	0
Matrix	17	24	3	11	0	1
Pie	13	19	17	22	20	0
Radar	10	15	2	12	1	7
Scatterplot	2	5	17	21	5	4
Timeline	22	23	13	20	10	1
Tree	14	24	16	17	5	0

Figure 2: Heatmap representing Focus Group analysis.

Table 1: Techniques identified by research method: Systematic Mapping Study, Survey, and Focus Group.

	SMS	Survey	FG
3D, 4D, Boxplot	X	X	
Bars or columns	X	X	X
Canvas, Pie chart, Timeline		X	X
Dashboard	X	X	X
Flowchart		X	X
Gantt chart	X	X	X
GIS	X	X	X
Graph	X	X	X
Heatmap	X	X	X
kanban	X	X	X
Lines	X	X	X
Matrix	X	X	X
Radar chart	X	X	X
Scatter plot	X	X	X
Tree structures	X	X	X
Virtual reality-based	X		
Count	16	19	16

groups, we used 10 as the cutoff criterion. Thus, we reached a consensus in the three sessions, among all participants, that 3D and 4D should be removed. Additionally, two bigger sessions (S1 and S2) also agreed the boxplot should be removed. This way, 3D, 4D, and boxplot will not be part of the final set of techniques. The final version of the proposal would consist of 16 techniques, as shown in Table 1. In it, we can observe that some techniques were found in more than one research method.

6 AN EXTENSION PROPOSAL FOR THE PMBoK GUIDE

Based on our results, we built two processes within the PMBoK Communications Management KA. To do so, we analyzed each PMBoK process, especially the Project Communications Management, then we mapped its inputs, tools and techniques, and outputs. Next, we selected the items that would be useful to help plan and implement DV in project management. The PMBoK extension proposal systematize and emphasize the use of DV in software development projects.

We propose the following processes: 1*0.4 Plan Data Visualization* and *10.5 Implement Data Visualization*. Figure 3 shows an overview project communications management processes. The original figure comes from the PMBoK guide, and we extend it adding two new processes at the end. All the data representation is based on the process presentation model used in the PMBoK guide. The following sections detail our proposal.

6.1 Process: 10.4 Plan Data Visualization

The 10.4 Plan Data Visualization process defines how, which models and which visualization techniques will be used as a complement to the project's communication planning, i.e. those that are suitable for displaying related data.

Our data flow diagram (see Figure 4) shows the relationship between the process' inputs and outputs. We can see that there is another process as input: the 10.1 Plan Communications Management. The process 10.1 generates the communication management plan, which together with all project documents, and taking into account the characteristics of the enterprise/organization, they create a solid base for the Plan Data Visualization process. As a result of this process, the communication management plan and project documents must be updated to include data visualization techniques.

6.1.1 Inputs

There are four inputs that have to be considered to define the data visualization plan:
1. Communications Management Plan: it aims to understand how, when, and by who the information will be administered and distributed during the project.
2. Project Documents : all documents used during the project, such as the ones listed in the PMBoK guide. The PMBoK lists 33 documents that may be affected by DV planning processes, e.g. risk report, activities list, quality reports, requirements document, lessons learned, test and evaluation documents, schedule.
3. Enterprise Environmental Factors (EEF): are events that cannot be controlled by the project team and they can influence the project outcomes. Such factors can have a positive or negative impact on the project. EEF that may influence the Plan Data Visualization process include:

- Published material, including papers about applicable DV techniques;
- Academic studies;
- Benchmarking results;
- Global, regional, or local trends, practices, or habits;
- Organizational governance structure;
- Organizational, stakeholder, and client structure and culture;
- Geographic distribution of facilities and resources;
- Specific project document standards;
- Guidelines and criteria for defining the set of visualization techniques and tools to be used;

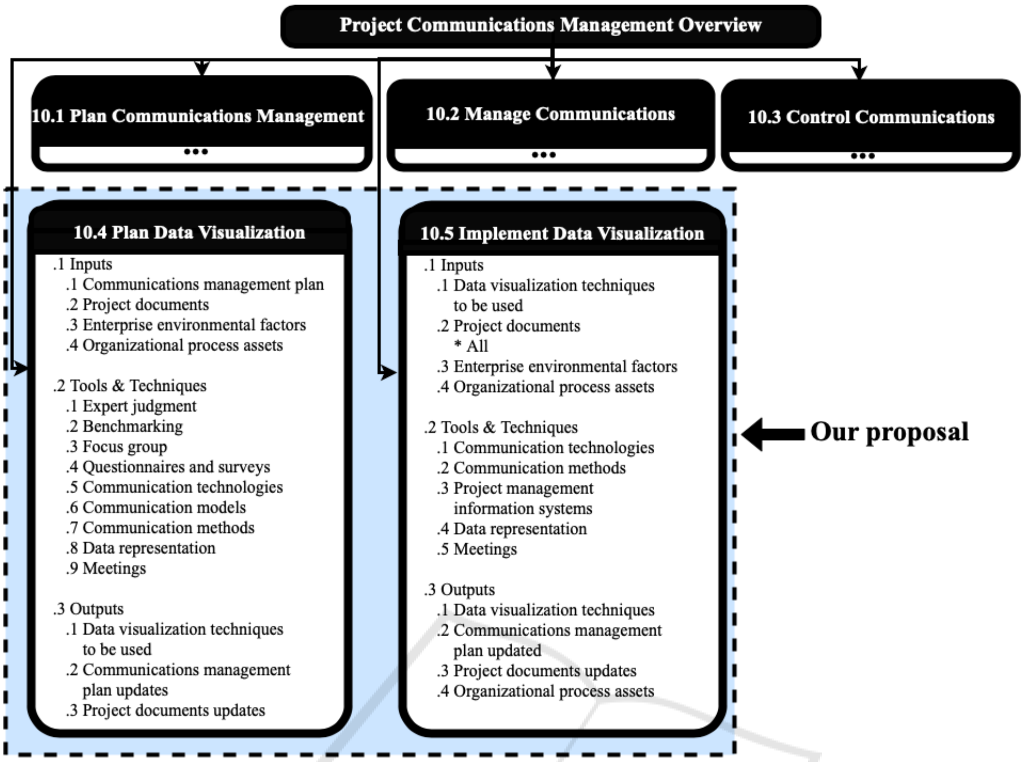

Figure 3: Project Communications Management Overview - Extension proposal.

- Established channels, tools, and communication systems;
- Project management information systems.

4. Organizational Process Assets (OPA): are composed of the processes, plans, procedures, knowledge bases, and policies from the organization where the project is being executed. OPAs that may influence the Plan Data Visualization process include:

- Standard organizational policies, processes, and procedures;
- Project governance structure, portfolio, and program (governance functions and processes to provide guidance and decision making);
- Standardized guidelines for the development, exchange, storage, and retrieval of information;
- Organizational communication requirements;
- Communications management plan template;
- Formal procedures for sharing knowledge and information;
- Document and forms templates;
- Configuration management knowledge base containing versions and baselines of all organizational standards, policies, and procedures.

6.1.2 Tools & Techniques

The tactics used to achieve the expected process outcomes by using the inputs to achieve the outputs:

1. Expert Judgment: The opinion provided by a person or a group of people who have expertise in a specific area of application related to the performed activity. In this case, the people do not have to meet and achieve a consensus, we can consider individual opinions. In the DV planning process, the opinion of individuals with experience, empirical knowledge or specialized training is essential for the project's success. The following topics related to the project should be considered to plan the project DV:

- Knowledge of SPM;
- Knowledge of tools and visualization techniques that can be used to support the communication of information;
- Data interpretation and contextualization;
- Organization communication technologies;
- Organization policies and procedures on legal requirements for corporate communications;
- Communications with the public, community, media, and in a global environment - between virtual groups;
- Project and communications management systems.

2. Benchmarking: for instance, a search to know the most used best practices in project management. It is used to identify best practices that could be adopted by the institution. Benchmarking can be conducted by reviewing or mapping the literature.
3. Focus Groups: it is an expert meeting, made to share information about visualization techniques applicable to SPM. We conducted focus group sessions as part of this study, where we present DV techniques from a SMS and a survey, and three experts groups evaluated it in software development projects context. As a result, we identified the main techniques that can be used to support SPM (see Section 5.3).
4. Questionnaires and Surveys: a questionnaire can be just a data collection instrument, while surveys comprehend an entire research protocol containing all the process to generate and analyze the questionnaire data. Surveys can also be used to know which techniques and DV tools people are using to support communication in their projects. We use a survey as a data collection tool (see Section 4.2).
5. Communication Technologies: communication technologies are those that help communication between different organization parties for displaying project DVs. It includes e-mails, web portals, written documents, social media, databases, and others.
6. Communication Models: representations of how communication will happen over the project duration. Communication models can be established through standard documents adopted by the team. A standard for communication should be always adopted as the starting point to define the communication model for a project.
7. Communication Methods: it is the systematic process, procedure, or technique that is used to transfer information between stakeholders. For instance, it can include a process that indicates who communicates about a problem in the project schedule, who will receive this communication, and how.
8. Data Representation: formed by graphical or textual representations, it indicates how data will be displayed, and are used to transmit data and information about the project among stakeholders.
9. Meetings: project meetings to gather information or discuss the project status. During the meetings, team members can define data visualizations tools that will be used to illustrate project information.

6.1.3 Outputs

The outputs from the Plan Data Visualization process are described as follows:
1. Data Visualization Techniques: Project visualization techniques are used to support SPM. Table 5 presents the set with sixteen visualization techniques found in the SMS, the survey, and the focus groups. Also, examples where such techniques can be applied.
2. Communications Management Plan Updates: The communication strategies available in the project management plan can be updated in order to include techniques selected to show project data in documents.
3. Project Documents Update: All project documents can have its models updated, considering best practices in employing visualization techniques, used for graphical representation of information.

6.2 Process: 10.5 Implement Data Visualization

The 10.5 Implement Data Visualization process ensures that project information will be clearly and easily visualized and understood by all stakeholders, according to the information they need. It involves applying visualization techniques in different contexts of software development projects. For this purpose, we use visualization techniques such as those mentioned in Section 6.1.3.

We also develop a data flow diagram to show the relationship between the inputs and outputs of this process (Figure 4). As input, we use the new process 10.4, Plan Data Visualization, all project documents and characteristics of the enterprise/organization. After applying the process, we expect to produce updates on the communications management plan and in other project documents, to include DV techniques. It also can indicate updates on OPAs.

6.2.1 Inputs

Inputs identified in implementing the DV process are described as follow.
1. Data Visualization Techniques to be Used: Visualization techniques that can be used vary according to the project, and can also be related to KAs. Techniques that may be used include, but are not limited to: canvas, dashboard, tree structures, flow chart, GIS, bars or columns chart, scatter plot, Gantt chart, line chart, pie chart, radar chart, graph, heatmap, kanban, matrix, and timeline.
2. Project Documents: All documents used in a project can be considered inputs to this process.
3. Enterprise Environmental Factors: Environmental factors that may influence the implementation of DV include, but are not limited to:

- Established channels, tools and communication systems;
- Project management information systems;
- Database with project information;

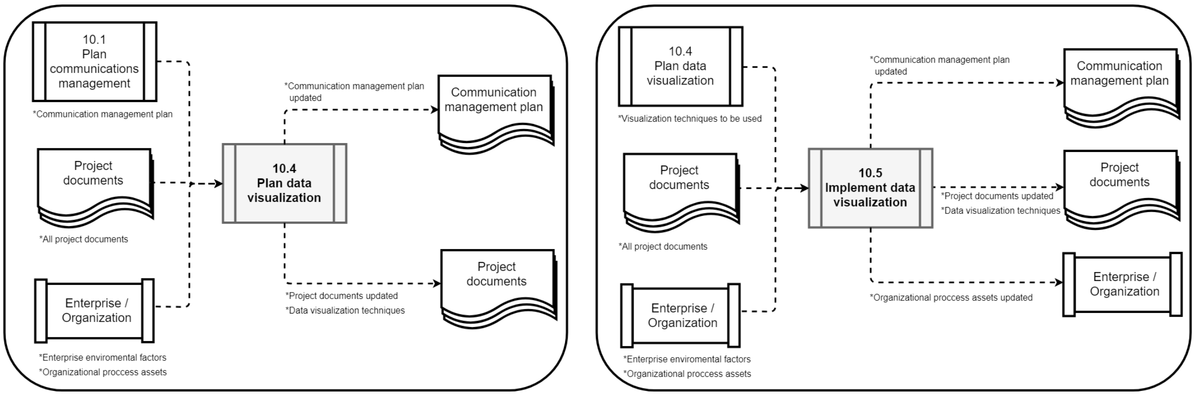

Figure 4: Processes 10.4 and 10.5: Data Flow Diagrams.

- Data from published estimates.

4. Organizational Process Assets (OPAs): that may influence implementation of DV include, but are not limited to:

- Document and forms templates;
- Configuration management knowledge base, containing versions and baselines of all organizational standards, policies, and procedures, and any project documents;
- Monitoring and reporting methods;
- Repositories with historical information and lessons learned;
- Databases for managing problems and defects, with historical data from each problem and defect resolution actions;
- Performance measurement database, that are used to collect and make available processes and product measurements;
- Financial databases;
- Source code repositories.

6.2.2 Tools & Techniques

Next, we present the tools and techniques that can be used to implement the data visualization process:
1. Communication Technologies: Tools, systems, and applications used in a project that serve to transfer information between stakeholders. Examples include emails, chats, institutional systems, text messages and online discussion groups.
2. Communication Methods: The systematic process, procedure, or technique, used for the purpose of transferring information between stakeholders. It can be mapped with a flowchart, for example.
3. Project Management Information Systems (PMIS): It is a system that contains tools and techniques used to gather, integrate, and disseminate outputs for project management processes. Examples of PMIS are Microsoft Project, Trello, and Microsoft Excel.
4. Data Representation - Data Visualization Techniques: These are graphical representations used to disseminate project data and information. Graphical representations that can be used include, but are not limited to, those described in Table 1.
5. Meetings: Reunion among stakeholders, usually with specific guidelines, where DVs can be displayed. For example, videos and slide shows can be used to illustrate information related to the project.

6.2.3 Outputs

The outputs expected from implementing DV processes are:
1. Project Data Visualization: Visualization techniques should take into account the type of data, the KA, and the context in which it will be used. Table 5 presents some contexts where techniques can be used.
2. Communications Management Plan Updates: The communication strategies in the management plan can be updated, with the implementation of techniques for visualizing data contained in the documents.
3. Project Documents Updates: All project documents can have their models updated, according to the implementation of visualization techniques for graphical representation of the information.
4. Organizational Process Assets: OPAs that can be updated because of the implement DV process include, but are not limited to:

- Document and forms templates;
- Configuration management knowledge base, containing versions and baselines of all organizational standards, policies, and procedures, and any project documents;
- Methods of monitoring and producing reports.

	Integration	Scope	Schedule	Cost	Quality	Resources	Communications	Procurement	Risk	Stakeholder	All
Bars or columns		Planned x realized, Features by sprint.	Evolution of the project; Hours planned x consumed.	Comparison of indicators; Project cumulative cost; Resource cost per location;	Information about users of the system; System performance: number of access, load, database.	Resource allocation capacity; Number of people per project time.					Project performance.
Canvas		Collaborative planning; Planned x realized; User stories; Product vision summary; Project scope.	Collaborative planning; Planned x realized.				Project kickoff meeting; Status report.				Collaborative design of the project;
Dashboard	Portfolio and program information.	Planned x realized; Track project execution; Project progress bar; S curve; To do list.	Control project evolution; Hours of development; Planned x realized; Sprint planning; S curve.	Supplier information; Project costs; Project budget (pie chart).			Use as input to retrospective meeting.	Supplier information.	SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis.		Sprint progress; project's progress;
Flowchart	Helping the understanding of the business process to elaborate the business case; Design of development processes; Process mapping.	Project macro view; UML activity and state diagram; Expected scope x realized; Plan project phases; Workflow of what was developed .	Plan tasks, like a Gantt chart without temporal information.				Meeting guide; Review information from the project to the operational team.		View information about information security.		Project summary;
Gantt chart		Planned x realized; Activity planning; View scope changes.	Monitor activities; Plan activities; View project timeline.								
GIS	Generation of "attack plan" by area, on a map of a company, in software deployment	Support for business analysis	Software deployment planning and monitoring in geographically distributed teams; Plan the execution of a project by region.	Project cost per location.	Mapping open bug reports by location	Visualizations for distributed team management.	Digital marketing strategy		Monitor in real time some geographically sensitive data.		Project information with features in distributed geographic locations;
Graph		PERT chart (Program Evaluation and Review Technique); User journey.	Network diagram (relationship between activities) PERT chart (Program Evaluation and Review Technique).				Mapping communication channels within a project.		Critical path of project activities; Monte Carlo simulation for risk analysis.		
Heatmap	Management of information related to projects in portfolios;	Visualization of relationships between project phase and task; View requirements criticality.	Timeline analysis (headlights); Plan minimum and maximum range for a given task.	Cost analysis; Costs by period.	View where most users clicked on a web page, for evaluation and page design.	Team members competencies analysis, for training planning.			Follow-up of indicators on critical technologies for the project; Risk analysis; View critical project data.		
Kanban		Backlog; Control micro tasks in short periods; Collaborative planning; Task planning; Activities summary.	Project planning; Backlog; Activities summary.								
Lines		Evaluate data obtained during the project; Project life cycle; S curve; Planned x realized, Burndown chart; Burnup chart.	S curve.	Financial comparison; Statement of income; Added value.							Information comparison.
Matrix	SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats); Selection of projects to start.			Matrix to map where to invest.			Communication matrix.		Technology TIME analysis (Tolerate, Invest, Migrate or Eliminate); Product or project feasibility study; Mapping of competitors; Risk matrix.	Mapping of stakeholders - who is in favor and who is against; who has power and who does not have.	Decision support; Assessment of project aspects.
Pie chart		Hours consumed per feature; Estimated proportion of time at each stage of the project.	Hours consumed per feature; Workload information; Estimated proportion of time by project stage;	Statement of income for the year per phase; Phase information (cost, time, etc.); Proportion of costs of each project stage.	Types of bugs found.	Workload information; Sizing the team.					Comparison of data within a context; Phase information (cost, time, etc.).
Radar chart	BSC (Balanced Score Card); Portfolio management, for prioritization of projects and programs.					Evaluation of teams at retrospective meetings.		Benchmarking-performance comparison between two or more systems; Comparative to choose a technological solution; Supplier comparison.		Stakeholder competency analysis.	
Scatter plot					Bugs per delivery.	Team capacity statistical analysis.					
Timeline		Deliverables (project milestones); Macro planning.	Schedule summary; Temporary outline; Deliverables (project milestones); Macro planning; Deadlines.				Status report; Use as input to retrospective meeting.				
Tree structures		Plan software deliveries; WBS; Project activities and groups structuring; Mind map; Project checklist; Scope view; Critical path map.	Monitoring of the activities evolution; Plan software deliveries.			Project Organization Chart.	Use as input to retrospective meeting		Risk analysis; Critical path map.	Mapping expectations	

Figure 5: Examples of contexts to use DV techniques for each KA.

7 DISCUSSION

Our paper brings advances in the theoretical field for software project management. As we developed a SMS, we could identify the most cited visualization techniques and tools in project management. The mapping study also allowed us to widely understand visual techniques that have been adopted by project managers in software management projects.

Our results show that the code repository is useful to generate many types of data visualization. It can help visualize all the lineage of the code: who first developed, who updated, tested, etc. It can also help to understand the human relationships among the team, as it can trace the lines of code to show which developers work together, displaying the affinity among stakeholders.

With the survey, we had access to the opinion of a hundred project management experts. We have listened to the experts' opinion about tools and techniques that are useful in software project management. We also identified techniques and tools used by project managers to perform daily tasks and support its activities. We found out that Microsoft Project, Trello and Microsoft Excel are the most adopted software tools for supporting project management. We also found the use of kanban, bar or column chart, line chart, and dashboard during the entire project, since its beginning to the closing - different to what we map during the SMS.

The focus group sessions allowed us to discuss in depth the use of visualization in project management. We had access to the opinion of thirteen experts, who helped us to select the techniques and tools that would be most useful and also describe several project management scenarios where the techniques and tools could be applied. Thus, we could select a set of techniques and tools to be used in software project management.

Our hybrid research approach contributed to the development of an extension proposal for the PMBoK Communications KA, including two new processes. The proposed processes are 10.4 Plan Data Visualization and 10.5 Implement Data Visualization. Our proposal brings advances to both the theoretical and practical software project management field. For the practical software project management, we deliver two detailed processes to help select and implement the most suitable visualization techniques according to the project context. Notice that the *Implement Data Visualization* process is dependent on the execution of the *Plan Data Visualization* process. It means we must plan first, so we can successfully apply the implementation of data visualization techniques in our software project management.

We also present detailed instructions on how to deploy our processes. Starting with the inputs, we present and describe each factor that must be taken into consideration to start the processes. Then, we suggest tools and techniques that can be used to help achieve the expected outcomes for each process. We also present the data flow diagram for both processes. The data flow helps to visualize the connections between inputs and outputs. Then, we present the predicted outputs for each process.

We emphasize that we follow the PMBoK model to design our proposal. Thus, we create processes based on a broadly used template, that are known, easily understood, and broadly followed by thousands of people all around the world. It reduces the learning curve for people that are already acquainted with PMBoK and are interested in learning about how to use DV techniques in their projects. Hence, it makes easier for people to start following two new processes.

8 CONCLUSIONS AND FUTURE WORK

As mentioned earlier, visualization techniques and tools can benefit software development project management since it helps to better understand the project context and how the stakeholders could contribute to project success. PMBoK is one of the most used standards when it comes to project management, but it does not present details about how to plan and implement the use of data visualization tools and techniques within the projects.

In this paper, we survey and present how software development project management makes use of data visualization, identifying data visualization techniques and tools used, or that can still be applied to benefit software project management.

Our research method comprises the adopting of SMS, survey, and focus group. With the SMS we identified sixteen DV techniques applicable to project management. With the survey, we end up with nineteen techniques and mapped the three tools project management specialists use most to visualize their project's data. Executing the focus group, we could refine the suggested techniques to sixteen, and collect information about the context where tools and techniques could be applied.

The extension we developed for the PMBoK can be added to the Communications Management knowledge area, and by following the two processes we created, people could use our extension to help select the best way to represent information alongside the ten

PMBoK knowledge areas. We also present examples of contexts in which they can be applied.

As for directions of future research on DV in the software engineering field, we want to develop a data repository to present the processes and how to implement them in the software development field. For example, selecting a KA and identifying a context in which specific visualization techniques and tools could be applied to better interpret the data. We also plan to perform a case study to evaluate the use of DV for agile projects.

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