

# TECHNOLOGY MATURATION PROCESS IMPROVEMENT

*AER 1601 - Aerospace Engineering and Operations Management*  
**University of Toronto**



**Team 2 - Final Report**

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## 1. EXECUTIVE SUMMARY

Pratt and Whitney Canada (P&WC) is an aircraft engine manufacturer based in Canada. Its headquarters are in Longueuil, Quebec just next to Montreal. This is a division of the larger US based Pratt and Whitney, a business unit with a world mandate for developing and maintaining small, medium and large aircraft engines. Furthermore, the company makes gas turbines and propellers for marine applications as well. It has a strong presence in both the civil and military aviation industry.

The aviation industry is growing rapidly. As the demand for air travel is constantly rising, more planes are being built to accommodate the expanding customer base. These planes need to be more fuel-efficient and economical to stay relevant in the highly competitive market. There is a race to net zero emissions by 2050 within the aviation sector. Thus, innovation has become a necessity now, to advance technology for green and sustainable aviation.

Innovation means management of change. In terms of technology development during the research phase, innovation refers to developing a novel technology or new way of applying existing technology. It also includes upgrading the existing products and services for better results. The Research and Technology (R&T) division of Pratt and Whitney Canada located in Toronto is responsible for looking into these matters.

This project is a collaboration effort between Pratt and Whitney Canada and University of Toronto as a part of the *Aerospace Engineering and Operations Management* course offered at University of Toronto Institute of Aerospace Studies (UTIAS). The project looks into the internal processes at Pratt and Whitney Canada regarding strategic management of innovation, to find opportunities for improvement.

P&WC are aware of the fact that they are lagging behind the industry leaders in terms of speed to deliver innovative solutions to the market. This directly affects the partners and loyal customers of the company. In a fast growing industry, the leaders of the future will be made by their actions in the present. Hence, to survive and maintain the status and reputation of the company, P&WC must adhere to the philosophy of Kaizen by identifying and resolving their internal issues before it's too late.

This project begins with understanding the core issues behind P&WC's technology maturation processes. A kaizen journal is maintained by the company, which was used as a starting point. Further, a root cause analysis helped the team to pin-point and prioritize issues.

A work breakdown structure was created to define the approach as well as roles and responsibilities of all the team members based on 5 major areas of improvement recognized as Technology Transfer, Software Tools, Technology Development, Resource Management and Design Space. Creative solutions and industry wide best-practices were researched and discussed with the company in several meetings held online as well as in-person.

The findings of the project are ideas researched and brainstormed by the team to improve internal P&WC management policies. For each of the aforementioned topics, the team formulated recommendations inspired from the findings but tailored to resolve P&WC's concerns. These include suggesting technology transfer strategies like Techtran, integration of Machine Learning and AI for prediction and analysis, digitization of resource management as well as well-defined product data management practices, developing master test plans for software tools and considering their development simultaneously with hardware, and a guide to rigorous technology development and assessment steps during technology maturation process. The problem of innovation funnel was also dealt with by recommending various options to create and manage an innovation platform.

In theory, there are many potential benefits in the long term that the proposed strategies can produce, but we recommend P&WC to first look deeper into the bureaucracy of the organization and its influence on the internal processes.

Finally, the team concludes that a big transformation needs to be made in the company culture to implement, support and sustain the recommended practices.

## 2. INTRODUCTION

The aerospace and defense industry constantly needs innovation and technological advancements. It facilitates safe and effective air travel, improves communication and knowledge transfer, and supports rising consumerism and worldwide supply chains. It also plays a crucial role in the national security of the country [13].

Pratt & Whitney is an American aerospace manufacturer with global service operations. It belongs to Raytheon Technologies as a subsidiary. Aircraft engines made by Pratt & Whitney are frequently utilized in both civil (particularly airline) and military aviation. In addition to producing aircraft engines, Pratt & Whitney also produces gas turbines for power plants and marine applications. A wide range of products, including turbofan, turboprop, and turboshaft engines, are offered by Pratt & Whitney Canada (P&WC), formerly known as Canadian Pratt & Whitney Aircraft Company and later United Aircraft of Canada. Their products are aimed at the markets for regional, business, utility, and military aircraft as well as helicopters. Additionally, the company develops and produces engines for industrial and auxiliary power applications.

To remain competitive in the market, follow the trends in the industry and sustain the growth of the company, it is essential to follow principles of continuous improvement. Pratt and Whitney Canada have created and maintained a Kaizen Journal to keep track of the company's status in terms of identified problems, current developments, and innovation strategies.

The team worked with Pratt & Whitney Canada towards gaining a deeper understanding of and experience with the strategies for improving the technology maturation process. The objective of this project was to review existing internal P&WC processes for technology maturation and provide input for improvements based on existing trends within the industry. This includes defining the company technology strategy and agreements on which technologies are to be pursued. Based on our analysis and findings, the team developed a set of recommendations that were most promising in speed, quality, and cost benefits then presented them to P&WC on project conclusion.

### 3. BACKGROUND

Technology maturation process details the steps necessary for developing technologies that are less mature than desired to the point where they are ready for project insertion. This kind of strategic management of innovation and technology helps to reduce risk and choose the right group of technologies that may be included in a complete system. Each project's precise technology maturation plan may vary, but the essential steps all have the same final objectives. They share the same fundamental methodology of prototype iteration to test designs and budget projections while guaranteeing that project specifications are satisfied, and the product is fully functioning [14].

The goal of the Research and Technology (R&T) organization at P&WC is to provide technology innovation. The benefits of this technology can often extend throughout the entire company and often includes engineering, manufacturing, and the aftermarket of all its products. The plan was to focus on technology readiness levels (TRL's) 1 through 6. This covers everything from a concept in the form of an idea or technological need, to a promising physical or software prototype which is validated to work within a realistic in a test environment.

TRL	VALIDATION STATUS	TOOL DEVELOPMENT	STANDARD WORK
TRL 1	Basic principles observed. Scientific research transitions to applied R&D		
TRL 2	Technology concept and / or application formulated.	If applicable, are simulation tools available for part family manufacturing process, performance and/or compatibility?	
TRL 3	Proof-of-concept analysis and / or test in laboratory environment.	Basic design tool modifications identified. Initial simulations for part family manufacturing process, performance and/or compatibility completed (if applicable).	Impacted elements of Standard Work identified (e.g. Material Specs, Process Specs, Design Manuals, Lab Manual Sections, Mat. Eng. Checklist, CPDs, Inspection Specs, PDDs, and ESA vs. Lab Control considerations)

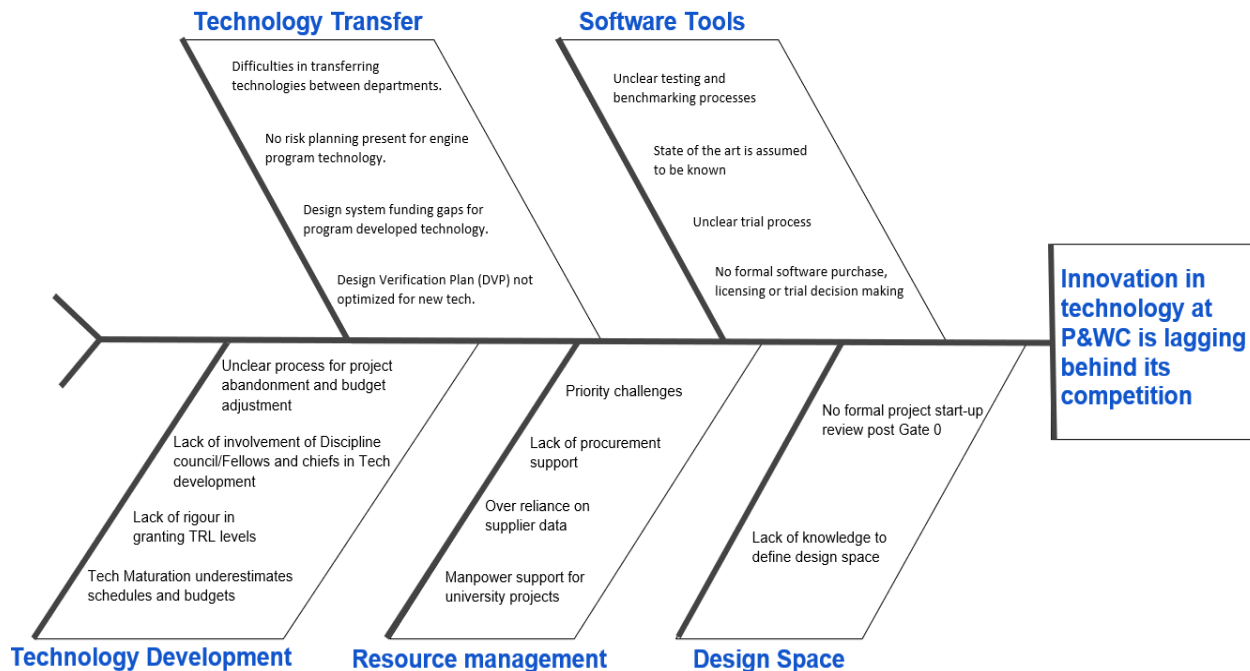
TRL 4	Representative parts tested in laboratory environments. Explore design space. Component or module prototype mfg schedule risk identified and mitigated.	Initial tool validation with predicted / actual comparison. Production process or product simulation approach identified and required inputs are available in simulation tool (if applicable).	Identified revisions used in validation plan. Product inspection and acceptance testing strategy identified. (e.g. capability, capacity, personal training, standard work and throughput)
TRL 5	Component or module level testing in a relevant environment. Module or system prototype mfg schedule risk mitigation initiated.	Component level design tool validation with gap analysis. Production process or product simulation approach used to determine constraints (if applicable)	Standard Work revisions drafted, scope of application defined.
TRL 6	Standard Work for technology validated. System level test in relevant environment completed.	Design tools validated to level consistent with Standard Work.	Standard Work revision text complete.

**Table 1: TRL for hardware**

P&WC are lagging behind in innovation because of issues with technology maturation. They are unable to keep up with aerospace industry leaders and consider their processes inferior to R&D leaders like SpaceX and Google. This project looks into problems affecting all TRLs, especially the lower levels past gate 0. Hence, the major attention is devoted to issues at TRLs as low as 1 and 2.

## 4. ANALYSIS

The root cause analysis has identified five main areas that contribute to a slower pace of innovation in technology at P&WC. The issues of P&WC in terms of innovation in technology are illustrated in the Fishbone diagram in Figure 1.



**Fig 1: Fishbone diagram**

For **technology transfer**, there is a lack of standardized process for technologies to be transferred between different departments. There is no risk planning to bring alternative plans for engine program technology with lower technology readiness levels (under TRL 6). There are design system funding gaps for program developed technology. The current design verification plan (DVP) is not optimized for new technologies and should not be mixed up with a larger module.

In terms of **software tools**, there is an unclear testing and benchmarking process, and an unclear process for bringing in new software for trial. The state-of-art is assumed to be known for software buy or make decisions. There is no formal software purchase, licensing or trial decision making processes.

As for **technology development**, the process for project abandonment and budget



adjustment is not defined. There is no robust method of assessing TRL levels for technologies. There is a lack of involvement of discipline council/fellows and chiefs in technology development. Hence, the technology maturation process always experiences schedule delays and cost overruns. The company is looking for ways to set up an innovation platform to try new suppliers and products.

Regarding **resource management**, there is undefined criteria for resource allocation. The procurement department support is lacking and the whole department is outsourced. Manpower support for university projects is not sufficient. There is an overreliance on supplier data for polymer composites. The IT department is also mostly outsourced.

For **design space**, there is a lack of knowledge to define boundaries of a new technology. There is no formal project start-up review post Gate 0.

The above mentioned points are clear reasons for the slow developments of the company. Thus, new companies like SpaceX and many start-ups are also challenging and threatening Pratt and Whitney Canada's position in the market today.

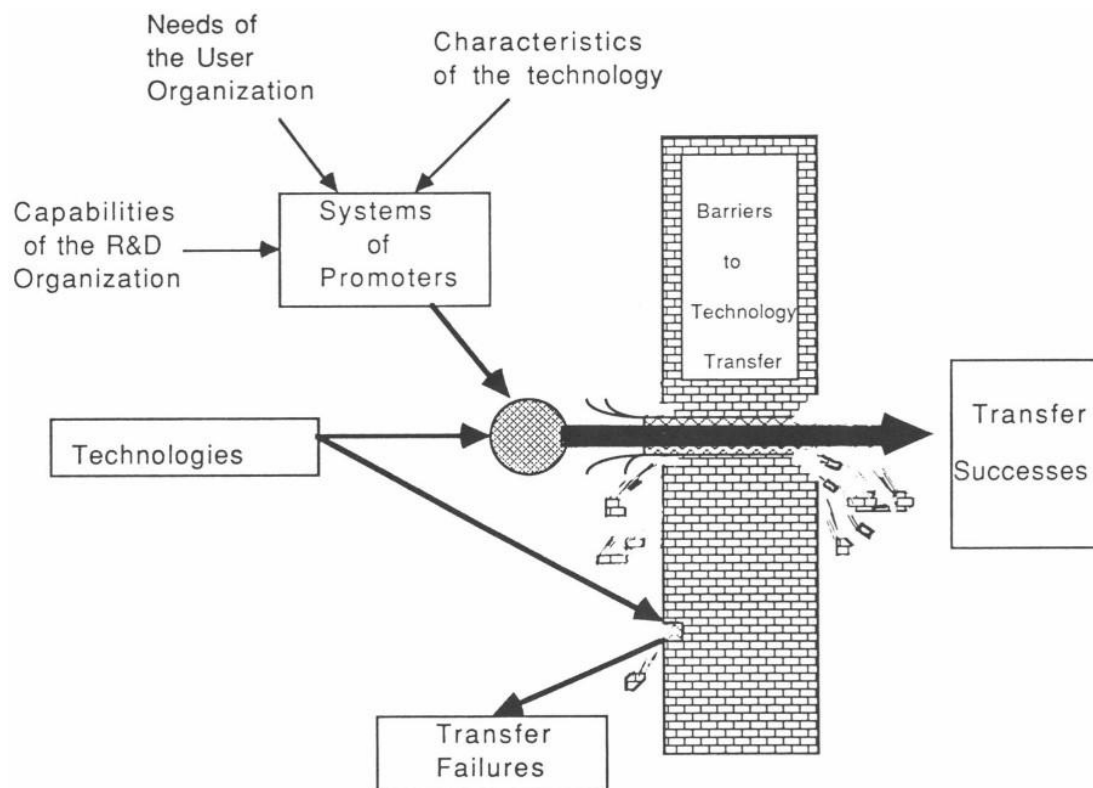
The next section of the report looks into the industry wide best practices and ideas from literature that can be adopted and modified to P&WC's culture, for solving the issues described here.

## 5. FINDINGS

### 5.1 Technology Transfer

#### Major Barriers and the Most Powerful Promoters

Experiences of 12 firms in transferring 34 new process control technologies from R&D to their point of use in manufacturing are studied using a continuing research program, leading to a methodology called TECHTRAN (figure 2).



**Fig 2: Successful Technology Transfer**

TECHTRAN takes the viewpoint that several barriers often block successful transfers from R&D to users, i.e., manufacturing departments [8]. These barriers can be overcome by a system of promoters derived from an analysis of the user's needs, the R&D organization's capabilities and the characteristics of the technology being transferred.

In this way, successful technology transfer is viewed as a matter of identifying the prevailing barriers in each transfer situation, defining the appropriate system of promoters, and then manipulating these promoters to overcome the barriers [11][12].

### Statistically significant barriers

- **Inadequate staffing by the manufacturing department:** If the plant does not commit to having staff who are properly trained or does not give them the necessary slack time to work with the new technology, new technologies cannot be easily implemented.
- **The technology was perceived as too fragile:** Technologies that were perceived by the manufacturing personnel as too fragile for their plant environments were rejected outright by them. Note that it is the perception of fragility that is the barrier here.
- **The technology was perceived as too complex:** The perception that a technology is too complex often influences R&D's credibility. This barrier highlights the necessity for R&D to constantly interact with their counterparts in other departments.
- **Manufacturing management feared disruption of plant schedules:** Any downtime that occurs while a more productive technology is being installed cannot be recompensed by higher outputs at a later time from that new technology.
- **Manufacturing management was preoccupied with other problems:** Most plant personnel are so preoccupied with their day-to-day problems that they do not feel they can spare the time to try any new technology.

### Statistically significant promoters

- **Counterpart top-level champions (bilateral championship):** Now coming to the promoters, the more the promoters present in the presence of barriers, the higher the chances of a successful technology transfer. The first point states that when managers and vice presidents from both departments, say R&D and manufacturing, assisted in the transfer by promoting it through their actions and collaborative measures, the transfer more often succeeded. When the upper-level management of both R&D and manufacturing jointly advocates the adoption of new technology, it alone becomes a very powerful promoter.
- **Manufacturing involvement at the design stage:** Involving manufacturing in the design of the technology is another powerful promoter. Based on the research done, it was found that many times other departments show reluctance in participating with the R&D as their subjects and topics are of lesser interest to them. An early involvement fostered strong partnerships between R&D and manufacturing, affording them an opportunity to jointly define a form and shape

of the new technology that satisfied both parties.

- **R&D and manufacturing jointly selected the vendors:** R&D is in the best position to select the most technically competent vendor. Manufacturing is in the best position to select the most responsive and experienced vendor. Thus, a joint agreement on the most satisfactory vendor ensures both the long-term integrity of the technology and its continued successful use.
- **The vendor provided the training:** If either R&D or manufacturing provides training, there is a likelihood that in case of difficulty in training with the new technology, one is likely to blame the other. However, a competent vendor who conducts the training will be selfishly motivated to devote whatever effort is required to competently train the personnel, without blaming either R&D or manufacturing when problems arise and hence can lead to a successful implementation of the technology. Selection of vendors problem.
- **Vendor early involvement:** Early involvement of the vendors helps generate positive relationships from the start. There are many different approaches to this, which can be discussed if and when needed. Invite many vendors if you aren't unsure of whom to go forward with or carefully select one at the beginning and jointly develop the technology with that vendor.
- **In-plant demonstration by an R&D/manufacturing team:** Demonstrating the technology in the plant with a team comprising of both R&D and manufacturing can lead to longer-term collaborations between R&D and manufacturing, and a sense of close partnership and dedication to success can be fostered among the team members.
- **The plant dedicated an experienced engineer:** The assignment of an experienced manufacturing engineer within the plant to monitor the transfer has many benefits. It provides a focal point for communication and a dedicated expert within the user's environment who can champion the technology and resolve floor-level details.

### Overwhelming the Barriers

Based on the analysis, it was found that there is a direct relationship between barriers and promoters. The analysis included failure and success transfer cases wherein when the number of barriers faced by a technology was say 9 and promoters were 2, the cases failed and when the barriers were 4 and promoters 10, the cases succeeded. Hence, barriers can be overwhelmed if there are enough promoters.

## Neutralizing Barriers

The approach of overwhelming the barriers with promoters can usually be replaced with a more efficient approach of eliminating barriers by matching them with specific promoters. This is called "neutralizing" the barriers.

## TECHTRAN Results

Situation	Number of		Degree of	
	Promoters	Barriers	User's Willingness to Adopt	Technology Transfer Success
Best of All Worlds	High	Low	High	High
Managed Success	High	High	Low	High
Success Lottery	Low	Low	Low or High	Low or High
Worst of All Worlds	Low	High	Low	Low

**Table 2: TECHTRAN Results**

The results obtained from the TECHTRAN approach are shown in table 2 above. Because there are few barriers and many promoters, there are no issues with technology transfer in the Best of All Worlds. It's possible that many R&D managers believe they have it all, however, this is not a very common situation. More frequently than not, there are numerous hidden barriers, and by using this strategy (TECHTRAN) and conducting a thorough study, transfer success rates can be significantly increased [8].

If the promoters are properly selected to overcome the prevalent barriers, as shown by TECHTRAN, a cost-effective Managed Success is feasible in conditions where the user's willingness to adopt new technologies is low. Technology transfer becomes a kind of Lottery situation when both the number of promoters and barriers are low, it becomes the Worst of All Worlds situation when the number of promoters is low and barriers are high, this case being the most common [8].

## **5.2 Software Tools**

### **Software Testing and Benchmarking**

Software testing and benchmarking is a heavily explored topic in the software development industry. Industry practices here would be a great place to look for inspiration for P&WC's own testing and benchmarking processes. As the processes originate primarily from companies that specialize in software development, these processes should be sufficient for P&WC's needs. These processes could apply to testing or benchmarking purchased, licensed or in-house software.

In the software development industry, the first step to verifying software is typically a master test plan, which is written as a framework for software testing. These often include defining [2],[3]:

- The scope of both the software functionality and the intended scope of testing. Of interest is where these scopes overlap
- The risks of various types of software tool failure
- The testing methodology used. For example, it could be based on covering a percentage of total code.
- Testing logistics such as personnel and hardware requirements.

### **Agreement on Purchasing or Licensing Software**

P&WC already has a process to evaluate suppliers for suitability before purchasing software. This qualitative information could be saved and referenced later to inform a decision on purchase versus license. To decide suppliers, P&WC already compile the following information:

- The technical references the supplier has.
- The training services provided by the supplier.
- The documentation provided.
- The tech support provided.

Along with this qualitative information, a quantitative cost benefit analysis could also be useful to inform the purchase or license question. Doing such an analysis would include [4]:

- Estimating the direct, indirect and intangible monetary costs of using a piece of software.
- Comparing these costs with benefits calculated the same way, to determine an estimate of project return on investment.

These quantitative and qualitative factors can then be compiled into a report for review, with the goal of informing a decision about whether to purchase new software. Also, typically licensing works with a different payment model which would be reflected in the cost benefit analysis and can include different tech support, documentation, or training services. These specific factors could be included in a separate report, or a complementary report contrasting the differences between purchase and license [5].

TRL	Definition	Software Description	Exit Criteria
1	Basic principles observed and reported.	Scientific knowledge generated underpinning basic properties of software architecture and mathematical formulation.	Peer reviewed publication of research underlying the proposed concept/application.
2	Technology concept and/or application formulated.	Practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture. Basic properties of algorithms, representations and concepts defined. Basic principles coded. Experiments performed with synthetic data.	Documented description of the application/concept that addresses feasibility and benefit.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Development of limited functionality to validate critical properties and predictions using non-integrated software components.	Documented analytical/experimental results validating predictions of key parameters.
4	Component and/or breadboard validation in laboratory environment.	Key, functionally critical, software components are integrated, and functionally validated, to establish interoperability and begin architecture development. Relevant Environments defined and performance in this environment predicted.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of relevant environment.
5	Component and/or breadboard validation in relevant environment.	End-to-end software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system, tested in relevant environment, meeting predicted performance. Operational environment performance predicted. Prototype implementations developed.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.
6	System/sub-system model or prototype demonstration in an operational environment.	Prototype implementations of the software demonstrated on full-scale realistic problems. Partially integrate with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.	Documented test performance demonstrating agreement with analytical predictions.

**Table 3: TRL for Software**

### State-of-the-art Software Tool Research

The purpose of a research and development department and the technology readiness level system is to find, develop, categorize and critically analyze state-of-the-art technologies. The frameworks to do this already exist in the industry and are already implemented at P&WC for hardware technologies. Integrating the research and

development software tools seamlessly into the R&T and TRL systems already in place has the potential to greatly alleviate issues with finding state-of-the-art software tools.

Even considering the need for new software tools throughout any TRL process, hardware projects included, could have benefits. Considering a technology's need for a complementary software tool would provide ample opportunity for research into the potential to make new software or research if anything is available on the market.

Finding state-of-the-art software on the market could pose a challenge, but encouraging networking and communication with software suppliers, leading experts, researchers, and industry experts in-house or otherwise would help.

Additionally, more effort could also be put into the software tool specific projects during the TRL process. P&WC already has a TRL checklist for software tool projects but further effort may be needed especially during the early TRL stages to ensure that due diligence is done regarding the relevant state-of-the-art in software tools available. NASA conceived the idea of technology readiness levels and they have clear definitions for both hardware and software projects [1].

Their guide for software tool projects would require the consideration of the following early in the TRL process (TRL's 1 and 2):

- Identifying a research topic based on software needs or ideas.
- Reviewing existing literature on the topic. This could include scientific publications, patents, and other literature.
- Creating an in-house proposal for the development or implementation of a software tool as an exit criterion of the first TRL.

### **5.3 Resource Management**

There are two main issues identified in the procurement system. First, the company **bureaucracy** creates extra complexity and excess paperwork on decision making. A single decision involves multiple departments' approvals, and some of them are unnecessary, so much time is wasted in sending emails back and forth, and little effort is spent on continuous improvements of the processes and investment on strategic procurement. Based on the TIM WOODS model [16], the waste and non-value-added activities in procurement are the following.



- *Transportation*: excess paperwork and transporting materials and component inventory
- *Motion*: walking, bending, or searching. Includes manual inventory tracking and control, having internal material not directly located close to where it is needed
- *Waiting*: personnel, material, system, and tool waiting or delay. This includes employees waiting for deliveries, approvals, data, or correct materials and services to arrive. This also can include waiting for supplier performance measurement results, or the processing of purchase orders and contracts
- *Overproduction*: excess paperwork in process due to purchase order processing bottlenecks. Ordering materials without internal customer need, as well as having more work-in-process or finished goods inventory than necessary to meet demand adequately
- *Over-processing*: This can often be found in developing quotations, purchase order processing, order acknowledgements, and invoicing. It can result in information being held up; for example: guidelines that require too many competitive bids, more approvals required than necessary to proceed with issuing purchase orders
- *Defects*: This waste refers not only to the quality of materials, but also to paperwork errors requiring rework and supplier errors. This also includes information from a material or service requester not efficiently received or processed (e.g., missing or wrong standards and no confirmation from supplier on purchase orders), or incorrect, or of poor quality.
- *Skills*: Staff spending too much time on administrative tasks rather than on continuous improvement, and thereby missing opportunities to increase the supply chain surplus through collaboration with internal and external supply chain partners. This would include unsynchronized processes resulting from frequent changes to decisions already made, long lead-times, and wrong material delivery schedules.

Another issue is the location of the procurement department. P&WC places the procurement in a different country from the rest of the R&D team, this increases the communication cost and time is wasted due to the different time zones and working cultures.

There is the need to implement a more **agile procurement** system, which requires a

procurement process being lean and digitized at the same time [15]. It is important to work on a lean process before digitizing it, otherwise, there is the tendency of digitizing a bureaucratic process, which would undermine the full potential and benefits of digitization.

The idea of lean is to focus on the value adding of a process and eliminate the wastes associated with it. This can be achieved by applying the value stream mapping of a process [16], which identifies and separates the value-added and the non-value added activities, where different kinds of wastes were illustrated above in the TIM WOODS model.

Therefore, for an agile procurement, the non-value-added activities can be automated so that physical paperwork handling can be minimized. Also, by digitizing the procurement process and increasing the visibility of information in an integrated manner, staff from different departments can view the necessary information and documents on the same platform, so it improves communication and collaboration between them. Once time is saved from non-value added activities, staff can spend more time on strategic and value-added activities of the procurement.

#### **5.4 Technology Development**

##### **Schedule delays and cost overruns [7]**

It is observed that the schedules developed, and the allotted budget is always insufficient. The research phase itself takes 6 to 7 years before entering production.

Reasons for Cost increments and Schedule overruns:

- Schedule overruns lead to cost rise
- Lack of proper documentation at every step of technology development
- Lack of involvement of discipline chiefs. This Company has to provide proper incentives and empower program managers, while also holding them accountable to solve problems and reduce risks by effectively addressing issues early.
- Lack of support from Pratt and Whitney (Longueuil plant, HQ) for procurement. Most of the funding is diverted to Quebec.

### **IPTs restructuring [18]**

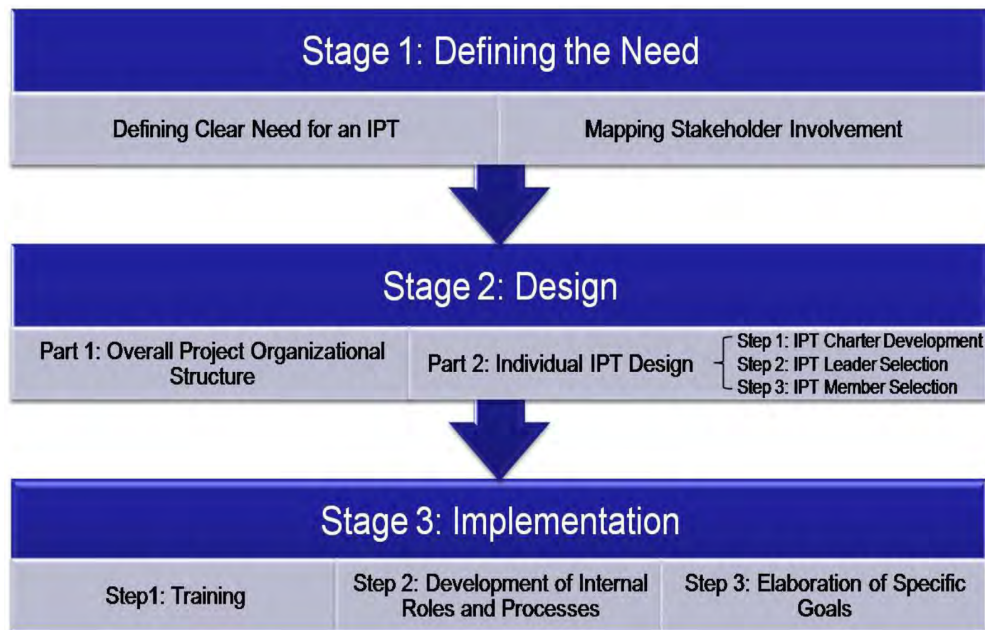
Research phase IPTs and Production phase IPTs are independent and isolated. This leads to loss of information and opportunities for misunderstanding and assumptions.

Research has consistently demonstrated that IT projects fail more often because of organizational and personnel reasons than because of technological failure. Even the most skillful execution of standard project management disciplines still may not address these organizational and human factors enough to avoid ultimate project failure.

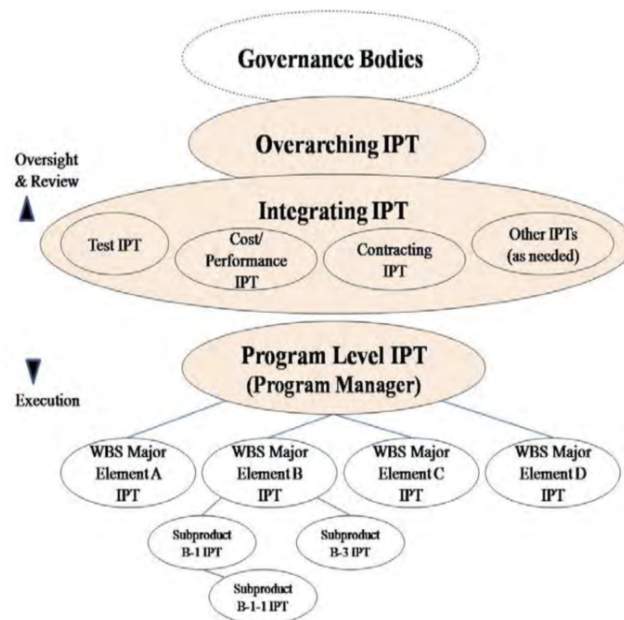
The classic example of this – which happens all too often – is of a system that has been well designed and executed but is ultimately rejected by the larger organization. The very reason that integrated project teams are so popular is because management recognizes that a key – perhaps The key – to ultimate project success involves somehow bringing together a complete diverse and often complex assortment of stakeholders and get them to work together effectively enough to define, design, implement, and operate IT systems (or policies or business processes) that will serve the actual needs of the larger organization once the system is ready for deployment.

Yet, despite this widespread recognition of this key to project success, the very tool used to ensure that this diverse stakeholder engagement happens – the IPT – is often itself poorly understood, defined, designed, and implemented.

Just as there are a series of well defined stages of requirements definition, design, and implementation of an IT system or business process, there should be a similarly mature process to define the need and design and implement an IPT. These stages are summarized in the following diagram:



**Fig 3: IPT creation and execution [18]**



**Fig 4: Importance of Integrating IPT and Overarching IPT [18]**

The steps given in figure 3 make up the best practice to run an IPT from start to finish.

For Pratt and Whitney Canada, there is a need to develop an **Integrating IPT**. This team will be responsible for communication with all the independent IPTs to ensure documentation of every bit of information produced and prevent loss of data as the product development moves from one stage to the other, as shown in figure 4.

This Integrating IPT will report directly to an **over-arching also called the master IPT** which contains all people with authority from various departments. This master IPT will make decisions and communicate with the governing bodies and stakeholders.

The following chart shows the risk if the given conditions are not met, for structuring IPTs:

		IPT Risk Profile		
		High	Medium	Low
Key Success Indicators	Urgency	<input type="checkbox"/> No urgency	<input type="checkbox"/> Urgent	<input type="checkbox"/> Very urgent
	Authority & Leadership	<input type="checkbox"/> No executive commitment/support <input type="checkbox"/> No decision authority <input type="checkbox"/> Inexperienced leader with no training	<input type="checkbox"/> Some/mixed executive commitment/support <input type="checkbox"/> Some/mixed decision authority <input type="checkbox"/> Trained leader with minimal experience	<input type="checkbox"/> High cross-functional executive commitment/support <input type="checkbox"/> Complete decision authority <input type="checkbox"/> Trained, experienced leader
	Direction, Purpose, & Scope	<input type="checkbox"/> Major disagreement among stakeholders <input type="checkbox"/> No charter or other effective guidance <input type="checkbox"/> No clear measures of success	<input type="checkbox"/> Some consensus among stakeholders <input type="checkbox"/> Somewhat clear charter/guidance <input type="checkbox"/> Some measures clear and others	<input type="checkbox"/> Broad consensus among stakeholders <input type="checkbox"/> Clear charter/ guidance <input type="checkbox"/> Clear measures of success
	Process	<input type="checkbox"/> No planning <input type="checkbox"/> No training	<input type="checkbox"/> Some planning <input type="checkbox"/> Some training	<input type="checkbox"/> Optimum planning <input type="checkbox"/> Optimum training
	Membership	<input type="checkbox"/> No selection criteria/process <input type="checkbox"/> Members are unable to represent their stakeholders <input type="checkbox"/> <5% of members' time allocated to IPT <input type="checkbox"/> Poor incentives	<input type="checkbox"/> Mixed selection criteria/process <input type="checkbox"/> Most members are able to represent their stakeholders <input type="checkbox"/> <50% of member's time allocated to IPT <input type="checkbox"/> Some/mixed incentives	<input type="checkbox"/> Agreed to selection criteria/process <input type="checkbox"/> All members are able to represent their stakeholders <input type="checkbox"/> Members are fulltime <input type="checkbox"/> Strong incentives
Aggregate:				

The following is a good quality checklist, to help formulate and run the IPTs successfully: (Source - MITRE IPT start-up guide [18]). The pages indicated in the table are pointers to the actual guide, if more details are desired.

Stage	IPT Start-up Steps
Definition of Need	Define a clear need for IPT(s) by mapping stakeholder involvement over the course of the project lifecycle (p 9)
Overall Project Organizational Design	<p>Design an overall project organizational structure that optimizes IPTs in the following ways (pp 10-12):</p> <ul style="list-style-type: none"> <li>• Does the complexity of the project require multiple IPTs?</li> <li>• If so, is there an “integrating IPT” that integrates the work of all the other IPTs?</li> <li>• At what points in the project lifecycle do each IPT need to be convened and disbanded?</li> <li>• Is there a good balance between the overall number of IPTs and the number of members on each IPT?</li> <li>• Does the reporting structure simplify and minimize the number of decisions that will need to be elevated beyond each IPT?</li> <li>• Is it clear to which supporting non-IPT work groups (e.g., contractor groups) each IPT can delegate its work?</li> </ul>
	<p>Budget sufficient time and funding for (p 13):</p> <ul style="list-style-type: none"> <li>• Charter Development and Stakeholder Engagement</li> <li>• IPT Leader selection</li> <li>• IPT membership selection</li> <li>• Allocation of IPT members’ time/duties</li> <li>• Co-location of IPT members (where possible)</li> <li>• Travel</li> <li>• On-line support systems</li> <li>• Training in IPT skills and skills specific to the particular work of the IPT</li> </ul>

Stage	IPT Start-up Steps
Individual IPT Design	<p>Develop an IPT Charter with the following elements (pp 13-15):</p> <ul style="list-style-type: none"> <li>• Need, purpose, and scope</li> <li>• Outcomes, outputs, and performance</li> <li>• Authority (including scope/limits, decision elevation, directive authority over other groups)</li> <li>• Key external processes (including oversight process and interface with key external organizations/processes)</li> <li>• Membership (including individual qualifications and decision authority)</li> </ul>
	<p>Engage and obtain full support for the IPT Charter from all key stakeholder organizations (including those represented on the IPT) (p 15)</p>
	<p>Select the IPT Leader and commitment from the Leader's supervisor to the Leader's role and time commitment to that role. Characteristics of the leader should include (pp 15-16):</p> <ul style="list-style-type: none"> <li>• Lack of bias</li> <li>• Technical expertise</li> <li>• Project management skills</li> <li>• Ability to manage external environment</li> <li>• Team engagement skills</li> <li>• Values inclusion</li> <li>• Decisive</li> <li>• Time management skills</li> <li>• Able to effectively elevate/delegate decisions</li> <li>• Commitment to IPT's work</li> </ul>
	<p>Select the IPT members and commitment from the members' supervisors to their role and time commitment to that role. Characteristics of the members should include (pp 16-17):</p> <ul style="list-style-type: none"> <li>• Authority to make decisions on behalf of their constituent organization</li> <li>• Background, knowledge, skills to represent their constituent organization</li> <li>• Open-mindedness</li> <li>• Team skills</li> <li>• Personal commitment</li> <li>• Time Commitment</li> </ul>



Stage	IPT Start-up Steps
IPT Implementation	<p>Conduct training for the IPT members in the following areas (p18):</p> <ul style="list-style-type: none"> <li>• The purpose of an IPT</li> <li>• Why an IPT is being used in this case</li> <li>• How an IPT needs to function</li> <li>• Behavior and skills required of IPT leaders and members</li> <li>• Skills specific to the tasks of this IPT</li> </ul>
	<p>Define and establish internal IPT roles, including (p19):</p> <ul style="list-style-type: none"> <li>• IPT Leader</li> <li>• Facilitator</li> <li>• Lead roles on specific internal processes</li> <li>• Lead expert roles (e.g., SME)</li> <li>• Lead roles with work groups reporting to the IPT</li> <li>• Interfacing roles with external organizations and processes</li> </ul>
	<p>Define and establish internal IPT processes including (p20):</p> <ul style="list-style-type: none"> <li>• Decision-making</li> <li>• Meetings and communications (including around confidentiality, documentation, and document management)</li> <li>• Team dynamics</li> <li>• Team self-assessment (including use of the IPT KSI Model in Appendix A)</li> <li>• Interface with external processes</li> </ul>
	<p>Further define, clarify, and elaborate the goals, outcomes, and performance measures defined in the IPT Charter and obtain concurrence from governing bodies.</p>

### Technology Readiness Assessment (TRA)

The rigor of the TRA depends on the processes defined to conduct such assessments.

For P&WC, currently people are randomly chosen to be on the review panel. The core members from management are fixed and then additional expertise from respective departments has an undefined selection procedure. No proper process to select the panel for reviews into TRL levels.

For the review panel, it is found that external reviewers independent of the organization



would provide good feedback. These can be retired academic professors, experts from sister companies, government funding agency employees, as well loyal customers and consultants. With proper NDAs in place, external reviewers can become a part of the TRA review panel to provide best judgment.

Regarding selection of panel members, it is considered a good practice to document the decisions made by the team as well as the individual members of the team at every stage and gate of the entire process. As the technology matures, rate the quality of decision making for each of the team members and maintain an account of their performance. If the technology gets approved for product development and becomes a success, provide a success rating to all the TRA members. Use this data for future TRA team selection based on the technology under review.

After reviewing **US Government Accountability Office (GAO) guide for TRA**, best practices recommended by US Department of Defence and Department of Energy for:[17]

- Preparing TRA plan and selecting TRA team
- Process to Identify Critical Technologies
- Process to Assess Critical Technologies
- Preparation of the TRA report
- Method to use the TRA report for future findings

would be of great value to P&WC to make their assessments more solid, robust, comprehensive and well documented.

The US GAO provides ideas, suggestions, strategies and methods that can be applied directly by any company. The guide incorporates practices developed at NASA, DOE and DOD after years of experience in the technology development and maturation processes. Hence, it can act as a wonderful reference to help solve P&WC's assessment issues during technology development.

The following is an excellent quality checklist, to make successful assessments: (Source - US GAO TRA guide [17])

There are five steps that, when followed correctly, should result in TRAs that governance bodies or program managers or technology developers can use for making informed decisions.

The following questions correlate to the best practice checklists from the Guide's five steps of conducting a high-quality TRA. These questions can be used by auditors or other independent entities that may be internal or external to an organization to evaluate the extent to which the best practices have been met.

Step 1 –Prepare the TRA Plan,  
and Select the TRA Team

1.1 Does the TRA plan have a comprehensive assessment approach that includes the following?

1. Is the purpose and scope clearly defined?
2. Are the resources, schedule, funding, and personnel needed to conduct the TRA identified?
3. Are the CT definition and TRL definitions identified?
4. Are the evaluation criteria to be used for assessing test results defined? Does it describe the types of evidence that will be collected to perform the assessment? Who will write the TRA report?
5. Is there a written study plan to help each TRA member prepare for conducting the assessment?
6. Is there a plan for handling dissenting views?

1.2 Does the TRA plan identify the recipient(s) of the report, such as a program manager, systems engineer, or a governance body supporting an upcoming decision point, stage gate, or go/no-go decision?

1.3 Does the TRA plan identify the expertise needed to conduct the assessment, and other characteristics of the TRA team, such as

1. Is the composition of the expertise, knowledge, and experience needed to conduct the TRA clearly written to guide the selection of the TRA team members?
2. Is the TRA team defined and properly sized to conduct the assessment? What was the basis for the sizing the TRA team?

3. Are the TRA team members experienced in conducting TRAs? For those team members with TRA experience, what are those experiences, qualifications, certifications, and training?
4. Are the TRA team member profiles documented and do they include signed statements of independence?
5. Did the TRA team have access to or discuss the need for additional subject matter experts from a variety of disciplines as needed or determined by the team? If so, who were those experts and in which disciplines were they experienced?

1.4 Are members of the TRA team independent and objective? Have they signed statements of independence?

1.5 Did the TRA team review the initial TRA plan to ensure it included all the essential information?

1.6 Has the TRA team been allocated adequate time and resources to execute the TRA plan?

1.7 Has the appropriate information been obtained and documented to conduct the TRA, such as the program master schedule, budget documents, test plans, and a technical baseline description of the program's purpose, system, performance characteristics, and system configuration?

1.8 Is the level of detail in the TRA commensurate with the level of detail available for the program?

**Step 2 – Select the Critical Technologies**

2.1 In selecting CTs, was a reliable, disciplined, and repeatable process followed and documented?

2.2 In selecting CTs, was the decision based on consideration of the newness or novelty of technologies and how they will be used?

2.3 In selecting CTs, was the selection based on consideration of the operational performance requirements and potential cost and schedule drivers?

2.4 For each CT is the relevant environment derived based on those aspects of the operational environment determined to be a risk for the successful operation of the technology?

2.5 Did the selection of CTs consider the potential adverse interactions with system interfaces?

2.6 Is the number of CTs selected for assessment based on solid analysis using the WBS, technical baseline description, process flow diagram, or other key program documents?

2.7 Is the selection of CTs confirmed using more specific questions and requirements that pertain to the platform, program, or system in which they will operate, refined and confirmed by the TRA team and others, as appropriate?

2.8 Are CTs selected during early development?

2.9 Are CTs defined at a testable level, including any software needed to demonstrate the functionality?

2.10 Did the TRA team document the reasons why technologies were selected as critical and why other technologies were not selected?

**Step 3 – Evaluate the Critical Technologies**

3.1 Did the TRA team confirm that the TRL measure and definitions selected during the TRA planning phase was appropriate? Did the TRA team reach agreement with the program manager on the kinds of evidence that would be needed to demonstrate that a TRA goal or objective has been met?

3.2 Did the TRA team interview the testing officials and verify that the test article and the relevant or operational environment are acceptable and the results acceptable?

3.3 For the assigned TRL rating for each CT, did the TRA team document and support their decisions with credible and verified evidence, such as test analytical reports, requirements documents, schematics, and other key documents?

Step 4 – Prepare the TRA Report

4.1 Is there a policy or guidance on how TRA reports should be prepared, including a template that identify the elements to report and document; process for submission, review, and approval; how the TRA results should be communicated; and who should be involved?

4.2 Does the TRA report include the following key information: (1) executive summary of the rating, (2) program background information, (3) TRA purpose and scope, (4) process for conducting the TRA, including

the selection of CTs, (5) rating for each CT assessed, (6) supporting evidence for each CT assessed including references to test results and other key documents, and (7) executive staff approval of the TRA report rating?

4.3 Upon completion of the assessment by the TRA team, did management check or attest the factual accuracy of the TRA report?

4.4 Does the TRA report include management's response (i.e., concurrence, or dissenting views with the findings)? Is the response clearly written, logical, and supported by evidence to support the position?

Step 5 –Use the TRA Report Findings

5.1 Was the TRA report used for its intended purpose, such as to inform decision makers about whether a prescribed TRL goal has been met, identify potential areas of concern or risk, or other purpose?

5.2 For CTs that are assessed as immature and did not meet the TRL goal, which of the following actions were taken?

1. Identify alternative or backup technologies?
2. Initiated development of a TMP?
3. Update the program risk management plan?
4. Update the cost and schedule risk assessment?

5.3 For TRA reports used for governance purposes, was the report timely? (e.g., submitted in advance of the decision point or stage gate to allow sufficient time to use the information)

5.4 Does the TRA report document lessons learned?

This checklist will ensure complete and thorough evaluation of all the developments in the company. These five parts of assessment can be applied to any process at any given time, as many times as necessary, to prevent any losses in later stages of the development process when it becomes expensive to make changes.

### **5.5 Design Space**

Unclear about how to define a theoretical design space and project boundaries for new product development. Very large number of design concepts, do not have time and budget to explore them all.

Explore the use of IDEF methodology (Integrated Definition tool) to define and model design space:

IDEF [19] refers to a family of modeling language, which cover a wide range of uses, from functional modeling to data, simulation, object-oriented analysis/design and knowledge acquisition. Eventually the IDEF methods have been defined up to IDEF14:

- IDEF0 : Function modeling
- IDEF1 : Information modeling
- IDEF1X : Data modeling
- IDEF2 : Simulation model design
- IDEF3 : Process description capture
- IDEF4 : Object-oriented design
- IDEF5 : Ontology description capture
- IDEF6 : Design rationale capture
- IDEF7 : Information system auditing
- IDEF8 : User interface modeling
- IDEF9 : Business constraint discovery
- IDEF10 : Implementation architecture modeling
- IDEF11 : Information artifact modeling
- IDEF12 : Organization modeling
- IDEF13 : Three schema mapping design
- IDEF14 : Network design

In 1995 only the IDEF0, IDEF1X, IDEF2, IDEF3 and IDEF4 had been developed in full. Some of the other IDEF concepts had some preliminary design. Some of the last efforts were new IDEF developments in 1995 toward establishing reliable methods for business constraint discovery IDEF9, design rationale capture IDEF6, human system, interaction design IDEF8, and network design IDEF14

The methods IDEF7, IDEF10, IDEF11, IDEF 12 and IDEF13 haven't been developed any further than their initial definition. These modelling techniques can be used as inspiration to create a method to model the design space for innovative technology concepts.

### **Makerspace - Creating an innovation platform**

P&WC has a reputation and well-developed supply chain with trusted personnel that ensure the Quality standards of the company.

When new and innovative technology is being developed in start-ups and small-size creative companies with no established reputation in the market yet, P&WC is resistant to incorporate them into the trusted partner list and take a risk on the brand value.

There is a need for an innovative platform that can be used to test promising products before incorporating them into the P&WC supply database.

Researched solutions developed and being used by competitors:

- Industry Academia collaborations like DAIR - Downsview Aerospace Innovation and Research Hub, Bombardier and Centennial College partnership etc.
- Investing in promising startups after launching joint venture platforms like Boeing, Lockheed, Airbus does.

Examples:

- Lockheed Martin Ventures and SkunkWorks
- Startup Boeing - Helps airlines launch
- Aerospace Xelerated - Idea portal by Boeing
- AE HorizonX - Funding to get strategic access to disruptive technologies critical to shaping and realizing the future, Joint Ventures between Boeing and AE
- Airbus Bizlab and Airbus Ventures

## 6. RECOMMENDATIONS

Based on the analysis conducted on the Kaizen journal issues, a few recommendations were developed and suggested to P&WC.



**Fig 5: Summary of Recommendations**

### **6.1 Technology Transfer**

There is a lack of standardized process for technologies to be transferred between different departments, leading to unnecessary delays in project completion. After reviewing various promoters to combat a barrier in technology transfer, a systematic procedure can be put in place at P&WC wherein historical data of past organizational and technological circumstances is collected, which was previously not done. This information can then be used to train a Machine Learning algorithm to perform a prediction analysis on the cost-effectiveness of each promoter against a specific barrier or a group of barriers. The program would then give outputs suggesting the best promoters to combat the barriers in question for a particular technology transfer operation.



## **6.2 Software Tools**

P&WC has an unclear testing and benchmarking process for software tools. To alleviate this issue they should write a detailed master test plan which will require compiling and considering many details of software testing and benchmarks. It will also act as a guide to making test cases and benchmarks within the described scope and methodologies.

Currently there is also no formal software purchase, licensing or trial decision making processes. P&WC should combine software supplier assessment data with a detailed quantitative cost-benefit analysis. This would allow project stakeholders to reach an agreement on whether to purchase software, or instead license or trial software based on differences in the quantitative and qualitative analysis.

Another issue is that state-of-art is assumed to be known for software buy or make decisions. Here, P&WC should focus on seamlessly integrating software tools into their technology readiness level framework. This would include determining software needs for any TRL project and researching the potential of software tool ideas.

## **6.3 Resource/Procurement Management**

Currently, P&WC has a long acquisition to PO time, therefore, they need to make investment on agile procurement transformations; this requires both implementing a lean procurement system and digitizing it. They should use the value stream mapping to simplify the procurement process, and digitize the non-value-added activities. By using an eProcurement system, it improves the communication efficiency since staff are exposed to the same information on the platform at the same time. P&WC also needs to create IPT teams to foster collaboration between procurement and key functional areas, so a faster decision-making time can be achieved when selecting vendors and issuing POs.

## **6.4 Technology Development**

The company is dealing with regular schedule delays and cost overruns during their R&T innovative technology development phases. It is recommended that strong support from the discipline chiefs and managers should be obtained by holding them accountable and empowering them with incentives. Proper IPT structure and TRL assessments will also significantly help improve the schedule and cost management. For IPT restructuring, it is



recommended to create an integrating IPT as well as a master IPT to prevent loss of information and risk free decision making. Follow the checklist provided in the finding sections to design and implement the IPTs for maximum benefit. Finally, the TRA and any assessments at Pratt and Whitney Canada can be performed using the checklist and guided steps provided in this report. It will ensure a rigorous, robust and well documented approach to assessments, reporting and use of data for future purposes.

### **6.5 Design Space and Makerspace**

The problem of innovation funnel is common to the entire aerospace industry but many companies have established interesting solutions to create innovative platforms. P&WC should try to analyze these options provided in the findings sections and select the one that best suits their needs. To define design boundaries during initial phases of concept development, modeling strategies like IDEF should be explored by the company.

## **7. CONCLUSION**

A fantastic project with Pratt & Whitney Canada, where the team was exposed to the management related concerns faced by an aerospace giant when dealing with innovation. The team helped the company to analyze the issues in R&T plus provide an external opinion and creative ideas to solve the given issues. A new, fresh perspective is vital to the continued growth of every business. Staying stagnant can cause undesired outcomes. P&WC is well aware of their weakness but it takes a lot of brainstorming, solid decision making and strong internal support, to cultivate a culture of change in a company as old as this one. Founded in 1928, this company has seen major success over the years. But at present, the company is struggling to beat the unicorns and newcomers in the market. Through this final report, the team has provided recommendations to the company inspired from the discussions held with them over the fall term and industry wide best practices researched simultaneously.

## 8. TEAM PROFILE



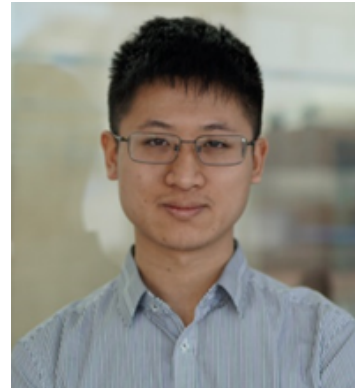
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