



Industrial qualitative diagnosis support system

Anthony Fouqué

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THÈSE

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Anthony Fouqué

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ABSTRACT

Over the past several years, industrial companies have been under unprecedented pressure to adapt to different variations in demand, supplier problems or simply their own intrinsic changes. This need for adaptation requires the ability to be able to quickly and effectively analyze the current state of health of the company. However, the collecting, processing and reporting of the data and the quantitative information necessary for such diagnoses is much slower than the speed of change now challenging companies. This is why the aim of this research work is to propose a rapid industrial diagnostic methodology, which is based on a semi-automated approach and qualitative information.

After having carried out a state of the art on the existing methods in terms of industrial diagnosis in the first chapter, we chose to focus our scientific and technical proposal on the Thinking Processes method from the Theory of Constraints. This method, which inherits the theoretical foundations associated with graph theory and Bayesian networks, has many potential advantages for conducting a qualitative diagnosis of a production system of goods or services. Unfortunately, it also has many pitfalls, such as the high level of expertise and experience required to implement it, or the excessive amount of time required for its deployment. Thus, in order to benefit more widely from the presumed strength of this method, the present research work has developed the following contributions.

The second chapter thus focuses on the formalization and structuring of an original approach to industrial diagnosis inspired by the Thinking Processes method. It also develops an original functional architecture and a technical architecture to structure a decision support system capable of supporting the developed approach. Finally, it defines and develops a software prototype called DOSSARD to concretize the elements defined in this decision support system.

The third chapter formalizes, in the form of a graph-oriented knowledge base, the validation and enrichment of a generic Current Reality Tree adapted to the characterization of production systems that use manufacturing to stock (MTS). It also develops a generic Current Reality Tree (knowledge base) that is completely new, adapted to production systems that use manufacturing to order or project (ETO). The final achievement is the implementation of a technical solution to instantiate the two previous knowledge bases as part of the DOSSARD decision support system.

The fourth chapter describes how these contributions were tested and validated on about fifty industrial cases in order to demonstrate their added value and also identify their limitations. The proposed approach and the associated decision support system were successful in achieving the expected results. In particular, they made it possible to significantly accelerate the speed of diagnosis while improving the relevance and robustness of the final product.

In the concluding chapter, the manuscript offers a set of promising research perspectives. First, while many field experiments were conducted as part of this research work, most of the cases concerned stock production systems (MTS). The proposal made therefore remains to be validated more widely on cases relating to production to order or project (ETO) and above all, it could be extended to the many other existing systems, such as assembly to order (ATO), configuration to order (CTO) or distribution, for example. Finally, even though the number of industrial cases mobilized for this study was high, it was still too limited to consider an in-depth testing of the knowledge bases and associated inference rules. Also, additional work aimed at multiplying the number of experiments in a real or simulated way could make it possible to consider developing ad hoc learning rules in order to make the approach and the associated decision support system even more robust.

Key words: Supply Chain, Diagnosis, Industry, Theory of Constraints, Thinking Processes.

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RESUME LONG THESE EN FRANÇAIS

La quasi-totalité des secteurs industriels fait aujourd'hui face à de nouvelles tensions : réduction des délais, limitation des marges, risques accrus de non-qualité, défaillances fournisseurs, etc. Dans cet environnement agressif, les objectifs des entreprises pour maintenir leur performance sont notamment :

- L'optimisation des schémas d'implantation et d'organisation des flux ;
- La réduction des stocks et la gestion des approvisionnements ;
- La mise en place d'outils de pilotage pilotés par la demande.

Pour atteindre ces objectifs, les métiers de l'amélioration continue et du Supply Chain Management sont dès lors devenus incontournables. Afin de garantir un développement durable de l'économie d'un territoire, et notamment des PME plus fragiles, il est indispensable que tous les acteurs maîtrisent au mieux leurs flux internes et externes en dépit des aléas, nombreux, et crises, tout aussi nombreuses, auxquels ils sont soumis. Parvenir à gérer cette complexité grandissante tout en maintenant des niveaux de performance élevés constitue le challenge des années à venir pour nombre d'organisations (petites, moyennes ou grandes). Cet enjeu repose sur la capacité des acteurs à améliorer continûment leurs organisations de façon à minimiser les délais et les coûts tout en garantissant la qualité, le service et la sécurité. Les entreprises, et notamment les entreprises de production de biens ou de services qui nous intéresseront dans ce manuscrit, se doivent d'identifier et d'exploiter des sources d'amélioration internes ou externes, qu'elles soient quantitatives ou qualitatives. Elles doivent également se donner les moyens de mieux gérer la variabilité inhérente à tout système de production. C'est l'enjeu adressé par les démarches de progrès permanent, tels que le Total Quality Management, le Lean Management ou le Six Sigma.

Dans un tel contexte, on comprend combien la capacité d'une organisation à maintenir un bon niveau de performance, indépendamment des aléas auxquels elle est soumise, est une question saillante. En d'autres termes, il s'agit pour les systèmes concernés de disposer de capacités à répondre de manière adéquate aux changements qui font désormais partie de leur quotidien (Christopher et Peck, 2004). Ce nouvel objectif de performance s'appelle l'agilité et constitue pour les entreprises qui parviennent à l'atteindre un véritable atout vis-à-vis de leurs concurrents. Agilité est un mot-clé pour beaucoup d'articles de recherche de cette dernière décennie. Elle est habituellement définie comme étant l'habileté à répondre à des changements à court terme (Sheffi, 2004). Selon Lee, les objectifs des organisations agiles sont de répondre rapidement aux changements et de gérer en douceur les perturbations extérieures (Lee, 2004). Pour Peck et Christopher, les deux ingrédients clé de l'agilité sont la détectabilité et l'adaptabilité (Christopher et Peck, 2004). Dès lors, la question qui se pose est de savoir comment cette agilité peut se mettre en œuvre concrètement.

Des auteurs tels que (Benaben, 2012) ou (Lauras, 2013) indiquent que la résolution de cette équation difficile doit forcément profiter de l'ère du tout numérique. Les entreprises actuelles n'ont en effet d'autre choix que de s'appuyer sur les nouvelles possibilités offertes par le numérique pour faire face aux exigences et contraintes que nous avons évoquées précédemment. Si sur un plan technique, l'Internet of Things, l'Intelligence Artificielle ou le

Cloud Computing sont aujourd'hui des réalités très concrètes, il n'en demeure pas moins que leurs utilisations par les organisations de production de biens ou de services demeurent relativement faibles (Benaben, 2012). Ce constat s'explique notamment par la difficulté à analyser globalement les masses de données générées par ces équipements. L'enjeu pour les entreprises n'est plus l'accès à la donnée, mais surtout son interprétation et son exploitation. Cet enjeu est particulièrement criant pour les entreprises dont l'activité consiste à produire des biens ou services. (Atzori et al., 2010) parlent à ce sujet de révolution numérique initiée, selon eux, par l'avènement des smartphones et par le développement exponentiel des objets connectés. De par la variété des équipements existants et à venir, cette révolution numérique transforme progressivement le monde actuel en un vaste système hyper connecté auquel il convient de s'adapter (Sallez et al., 2016). Ainsi, par exemple, l'interaction entre ces objets connectés et les Systèmes d'Information traditionnels (ERP, TMS, WMS, APS, etc.) conduit à modifier la manière dont le traitement et l'utilisation des informations doit être pensée et réalisée (Giusto et al., 2010). Un premier axe de réflexion consiste alors à doter les entreprises de capacités leur permettant de disposer d'une image complète de leurs activités, de leur environnement et des événements qui y sont rattachés. Les Systèmes d'Information traditionnels et les technologies connectées doivent à l'évidence contribuer à l'atteinte de cet objectif. Ces technologies autorisent en effet la collecte et l'émission d'information en temps réels et permettent d'avoir à tout moment une vision précise de l'état d'un système.

Mais au-delà, c'est aussi (et peut-être, surtout) l'expertise métier des acteurs opérationnels et décideurs qui doit être considéré pour comprendre le fonctionnement d'une organisation de production et la faire progresser. En effet, les comportements humains (processus de décisions, règles métiers, etc.) demeurent bien souvent les éléments clés de la performance des entreprises (Dettmer, 2007). Le pilotage d'une activité opérationnelle suppose des arbitrages permanents entre plusieurs alternatives. Chaque entreprise définit alors, consciemment ou inconsciemment, ses propres règles qui influent directement sur les résultats opérationnels et sur la compétitivité de l'organisation. (Smith, 1999) et (Dettmer, 2007) ont montré que les organisations de production de biens ou de services sont systématiquement confrontées à des « conflits » (produire de grands lots versus produire de petits lots, débiter au plus tôt vs débiter au plus tard, etc.) qui impactent directement leur niveau de performance... Devenir plus agile, et disposer d'une performance plus durable, suppose donc de capter ces données « qualitatives », de comprendre les comportements associés et d'adapter au fil du temps la gestion de ces conflits « élémentaires » en fonction des orientations stratégiques poursuivies et des perturbations subies.

L'enjeu de la présente thèse de doctorat est donc de développer une approche innovante d'identification et caractérisation des dysfonctionnements des entreprises de production de biens ou services permettant de rapidement établir un état des lieux de la situation et de soutenir la définition tout aussi rapide, d'un plan de progrès opérationnel.

Le présent projet de recherche adresse ainsi la question du (re-)engineering uniquement par le biais d'une démarche de diagnostic industriel semi-automatisée. Et la question de recherche qui en résulte peut-être résumée comme suit : Comment, à partir de données qualitatives, aider à diagnostiquer objectivement et rapidement les organisations de production de biens ou services ?

Pratiquement, il s'agit de modéliser les processus et comportements existants, afin de détecter les dysfonctionnements ou incohérences existantes dans la situation actuelle. Sur cette base, le projet doit développer une solution innovante capable de faciliter l'identification des axes d'amélioration potentielle concrets. De manière schématique, l'enjeu est de permettre le recueil de données hétérogènes (issues de systèmes d'information ou d'interviews), leur formalisation et leur structuration sous forme de connaissance afin d'établir un diagnostic de l'organisation de façon objectivée et semi-automatisée.

En conséquence, cette thèse de doctorat adresse les objectifs scientifiques (OS) et technologiques (OT) suivants :

- OS1 : Cet enjeu scientifique s'intéressera à la structuration de données qualitatives collectées sous forme d'informations permettant une exploitation cohérente et unifiée par la suite ;
- OT1 : Dans cet objectif technique, le projet s'attachera à développer un composant de Gestion de Base de Connaissances capable de structurer les données afin d'autoriser leur exploitation ;
- OS2 : Cet enjeu scientifique portera sur la formalisation de la connaissance (règles d'inférence notamment) nécessaire à la réalisation d'un diagnostic organisationnel semi-automatisé ;
- OT2 : L'objectif technique associé consistera à définir et développer un composant algorithmique capable de supporter la démarche de diagnostic.

Le projet de recherche comporte donc une forte composante d'intégration de pratiques (méthodologiques) et d'outils (technologiques) afin de garantir son opérationnalité et son acceptabilité. En termes de contribution et de potentiel de rupture, la semi-automatisation de l'étape de diagnostic organisationnel proposée dans ces travaux de recherche, constitue une innovation majeure au regard des outils actuellement disponibles (cf. Chapitre II).

On peut finalement positionner les composantes de l'originalité scientifique et de l'enjeu applicatif du projet de thèse selon deux niveaux :

- Niveau métier : L'originalité scientifique portera ici sur la structuration de la base de connaissances associée et sur la définition des systèmes d'indicateurs adaptés au diagnostic d'entreprises de production de biens ou de services. L'enjeu applicatif concernera donc la capacité des professionnels à envisager des actions ajustées, éventuellement coordonnées, aux caractéristiques connues de la situation. En synthèse il s'agit d'envisager des applications plus « intelligentes », plus « objectives » et plus « globales » des traditionnelles approches de diagnostic organisationnel.
- Niveau technique : Les contributions scientifiques porteront sur les solutions qui permettront de supporter une automatisation de l'exploitation de la base de connaissances et l'exécution des « arbres logiques » (définition de règles métiers et d'algorithmes experts). L'enjeu applicatif sera principalement ici de permettre au plus grand nombre d'accéder aux principes de « Théorie des Contraintes » pour mener des actions de diagnostic organisationnel. Accessoirement, il s'agira de permettre la réalisation de tels diagnostics de façon rapide, objective et exhaustive.

Cette thèse de doctorat est une thèse industrielle réalisée, à temps partiel, entre janvier 2018 et juin 2021, cofinancée par le cabinet de conseil en Supply Chain Management AGILEA (<https://www.agilea-group.com/>) et par la Région Occitanie dans le cadre du dispositif GRAINE (<https://www.laregion.fr/>). L'auteur de ce manuscrit a ainsi été placé en position de consultant métier amené à régulièrement réaliser des diagnostics organisationnels pour le

compte de ses clients. Il a donc ainsi eu l'opportunité de disposer de nombreux terrains d'expérimentations lui permettant à la fois d'alimenter le travail de caractérisation de la problématique industrielle et de tester et valider les propositions faites sur des cas industriels réels et nombreux. Les travaux ont été conduits principalement au sein du Centre de Génie Industriel d'IMT Mines Albi. Ce laboratoire se caractérise par ses objectifs de recherche finalisée. Si on se réfère aux typologies de méthodes de recherche évoquées dans la littérature scientifique, il est possible de dire que notre objectif de recherche est de type appliqué au sens où notre démarche vise à « répondre à un problème actuel de la société, d'une organisation ou d'une entreprise » (Kothari, 2008). L'approche employée s'apparente à la famille des projets de recherche-action au sens où nos recherches ont été mises en œuvre en partenariat avec les agents du milieu d'étude et qu'il existe « une volonté chez ces agents de résoudre le problème et une intention chez les chercheurs de faire avancer les connaissances fondamentales associées à ce problème » (Laurencelle, 2005).

Le document s'organise comme suit. D'abord (Chapitre II) nous nous intéressons, via un état de l'art, aux méthodes existantes dans la littérature vis-à-vis de notre problématique de diagnostic des organisations de production de biens ou de services. Nous développerons ensuite notre contribution théorique en deux temps. D'abord (Chapitre III) nous exposons le processus de fonctionnement et l'architecture générale de notre système d'aide à la décision. Ensuite (Chapitre IV), nous développons le cœur de notre système en décrivant les bases de connaissances autour desquelles notre système d'aide à la décision est bâti. La suite du document s'intéresse à l'expérimentation et à la validation des propositions faites (Chapitre V). Il est notamment question de présenter la plateforme expérimentale développée, de développer un exemple d'application industrielle complet et de discuter les retours d'expérience obtenus par les mises en œuvre réalisées. Enfin, le dernier Chapitre vient clore le propos via un ensemble de conclusions et de perspectives de recherche (Chapitre VI).

Considérant les environnements actuels qui sont particulièrement changeants (cf. le paradigme VUCA), il est important de pouvoir réaliser des diagnostics performants qui tiennent compte de cette caractéristique. Ainsi compte tenu de la volatilité des environnements, et que cette volatilité implique des changements à réaliser dans son entreprise, il est important de noter que le diagnostic doit pouvoir être réalisé rapidement. De plus, ces changements rapides impliquent également que les entreprises vont devoir collecter des informations de plus en plus régulièrement. Ainsi l'origine de ces informations va être importante. Cela peut être des informations quantitatives mais également qualitatives. L'incertitude et la complexité des environnements actuels appellent également à prendre en compte des éléments supplémentaires dans la véracité des diagnostics. En effet, au-delà de la vitesse d'exécution, il est important de voir quel est l'investissement requis en matière de ressources pour réaliser le diagnostic mais aussi les compétences requises pour utiliser ses approches. En effet, si l'approche est rapide mais qu'il faut 2 mois pour former l'équipe à l'utilisation de l'approche, cela aura un impact non négligeable sur la réalisation du diagnostic. Enfin puisque ces diagnostics vont être réalisés de façon plus systématique, il est important que le résultat du diagnostic soit particulièrement explicite et facile à interpréter.

Enfin, il est important que le diagnostic permette d'aboutir à un résultat fiable, i.e. représentatif de la réalité des forces et faiblesses de l'organisation.

Dans ce travail de recherche, nous avons donc étudié les principales méthodes de diagnostic suivantes :

- Les diagnostics organisationnels quantitatifs ;
- Les approches de Lean Manufacturing ;
- La méthode 6 Sigma ;
- Les diagnostics qualitatifs ;
- Les approches de causes à effets (CED) ;
- Les approches des *Thinking Processes* (TP) et notamment les arbres des réalités actuelles (CRT) issus de la Théorie des Contraintes ;
- Les diagnostics mixtes ;
- Le modèle SCOR ;
- La méthode Quick Scan.

Il en résulte que l'ensemble des méthodes de diagnostic précédentes qu'elles soient quantitatives, qualitatives ou hybrides, permet d'aboutir à un résultat plus ou moins fiable mais avec surtout un ensemble de conditions devant être réunis pour pouvoir aboutir à ce résultat :

- Du temps, beaucoup de temps ;
- Des équipes chevronnées ;
- Un devoir de rendre les résultats lisibles si on veut pouvoir exploiter le diagnostic et enclencher l'entreprise dans une démarche d'amélioration continue.

Si les méthodes ne manquent donc pas pour soutenir une démarche de diagnostic organisationnel d'un système de production, aucune ne semble véritablement répondre à la problématique posée dans ce travail de thèse. En particulier, des exigences importantes concernent désormais la capacité à réaliser de tels diagnostics de façon fiable, rapide, et accessible.

Néanmoins trois méthodes semblent plus prometteuses vis-à-vis de notre problématique :

- Les CED avec l'utilisation d'informations qualitatives pour réaliser un diagramme d'Ishikawa ;
- Le Quick Scan qui combine des approches quantitatives et qualitatives ;
- Les CRT qui permettent à partir d'informations qualitatives d'aboutir à de bons résultats.

Dans (Doggett et al. 2004) et (Doggett, 2005), les méthodes CED et CRT ont été comparées de façon objective. Dans ces travaux, les auteurs soumettent plusieurs équipes de diagnostic à un même cas industriel. Certaines équipes sont amenées à utiliser la méthode CED pour conduire leur diagnostic, d'autre l'approche CRT. Il apparaît clairement que l'approche CED bénéficie de plusieurs éléments très positifs : Elle peut combiner de la collecte de données quantitatives et qualitatives, elle ne nécessite pas un haut niveau d'acquisition pour se lancer dans la démarche et elle est rapide à mettre en œuvre. Toutefois son principal écueil est que les 3 groupes ayant utilisé cette approche concluent à 3 diagnostics différents, par ailleurs jugés non pertinents par les acteurs opérationnels de l'entreprise concerné (problème d'identification de la cause racine réelle). Le CRT quant à lui présente plusieurs écueils dans cette expérimentation : sa mise en œuvre est complexe, longue et le résultat final n'est pas facilement exploitable par les équipes. Néanmoins, (Doggett et al. 2004) et (Doggett, 2005) indiquent que les 3 groupes ayant utilisé cette approche aboutissent au même résultat et que celui-ci est validé par les acteurs opérationnels terrain.

L'approche CED elle présente comme avantage sa vitesse et sa facilité de mise en œuvre par les équipes. Toutefois, il est observé dans la littérature deux écueils très significatifs. En effet, les résultats n'aboutissent pas systématiquement à la cause racine du problème (Dogget et al. 2004) et les échanges durant la mise en œuvre du processus sont limités, entraînant une moindre adhésion des parties prenantes à la démarche (Altigan et al, 2011).

Enfin, la méthode Quick Scan qui en dépit de son caractère a priori complet, présente des durées de mise en œuvre très importantes et des difficultés de prise en main significatives. Par ailleurs, même si l'approche se réclame d'une approche mixte qualitative / quantitative, on peut noter que les informations qualitatives sont en réalité déduites de données quantitatives.

La Figure 12 du manuscrit synthétise les principales caractéristiques de ces méthodes. Compte tenu des éléments présentés précédemment, nous avons décidé pour ce travail de recherche d'exploiter et surtout d'améliorer la méthode CRT qui semble disposer du plus large potentiel vis-à-vis de l'enjeu principal du présent projet de recherche, à savoir : développer une approche innovante d'identification et caractérisation des dysfonctionnements des entreprises de production de biens ou services permettant de rapidement établir un état des lieux de la situation pour soutenir la définition d'un plan de progrès opérationnel.

In fine, nos travaux ont consisté dès lors à développer une solution de diagnostic qualitatif robuste et rapide, basée sur les préceptes du CRT et visant à lever ses principales imperfections : Expertise élevée, délais de mise en œuvre longs, faible accessibilité.

L'approche des *Thinking Processes* de laquelle la méthode CRT est issue consiste à :

- Se mettre d'accord sur le problème en identifiant les symptômes, conflits pour construire l'arbre des réalités actuelles ;
- Se mettre d'accord sur la solution en trouvant les différentes solutions, les testant à travers l'utilisation de l'arbre des réalités futures ;
- Se mettre d'accord sur la séquence des actions à réaliser pour mettre en œuvre les différentes solutions imaginées.

Les utilisateurs de cette méthode ont souvent constaté (Smith, 2019), (Scheinkopf, 1999), (Dettmer, 2007), qu'à l'intérieur d'un même système de production de biens ou de services, même s'il y a des segments de marché différents, il y a une certaine homogénéité dans les conflits déduits des symptômes (Smith, 2019). Cette communalité de conflits a été modélisée par (Smith, 2019) et est reprise dans la Figure 17 de ce manuscrit.

L'auteure (Smith, 2019) propose ainsi 8 conflits génériques qui seraient inhérents à toutes les entreprises de production de biens ou de services :

- Augmenter ou non les tailles de lot de fabrication afin d'un côté d'augmenter l'efficacité des ressources mais de l'autre de réduire les cycles ;
- Autoriser ou non les heures supplémentaires afin d'un côté de satisfaire la demande client mais de l'autre de protéger les dépenses de fonctionnement ;
- Expédier des commandes complètes ou non afin d'un côté de minimiser les dépenses de transport mais de l'autre côté de réaliser des ventes plus rapidement ;
- Travailler avec la ressource la plus efficace ou non afin d'un côté de maximiser la marge produit mais de l'autre de minimiser le cycle ;
- Fabriquer sur stock ou à la commande afin d'un côté de proposer des cycles plus courts mais de de l'autre de minimiser les stocks ;
- Maintenir les prix de vente ou non afin d'un côté de protéger sa marge mais de l'autre d'augmenter ces ventes ;
- Acheter en volume ou non afin d'un côté de réduire les coûts d'achat mais de l'autre côté de minimiser les stocks et la consommation de cash ;
- Réaliser de la maintenance préventive ou non afin d'un côté de prévenir les pannes majeures mais de l'autre côté de maximiser l'utilisation des machines.

Ainsi, nous avons un début de solution à une des difficultés de l'approche des *Thinking Processes* qui est le manque de catégorisation des causes possibles. Toutefois, le modèle suggéré par (Smith, 2019) relève d'un simple constat expérimental isolé. Il n'avait encore jamais été scientifiquement validé, ni même documenté. Notre travail a donc porté, entre autres choses, cette ambition.

Ainsi, une des contributions de cette thèse de doctorat a été de vérifier cette proposition selon laquelle ces 8 conflits sont inhérents à tous les systèmes de production. De plus, nous avons souhaité créer un outil d'aide à la décision qui permettrait à n'importe quel utilisateur de tirer bénéfice de la méthode sans avoir à acquérir une expertise très poussée en amont d'une part, et sans avoir à consacrer trop de temps à la mise en œuvre d'autre part. Nous avons donc développé (i) une architecture fonctionnelle globale de l'outil, (ii) une architecture technique et enfin (iii) un processus de mise en œuvre.

Le processus de diagnostic que nous avons développé est le suivant :

1. Clarifier l'organisation étudiée ;

2. Collecter les symptômes ;
3. Vérifier la cohérence des conflits ;
4. Analyser les résultats ;
5. Partager les résultats.

Ce processus est représenté en détail dans la figure 21 du manuscrit et supporte cinq contributions majeures :

1/ La première contribution de nature scientifique porte sur la définition d'une architecture fonctionnelle et une architecture techniques originales permettant de structurer un système d'aide à la décision capable d'accompagner une démarche de diagnostic semi-automatisé inspirée de la méthode des *Thinking-Processes*. Cette contribution répond à l'objectif scientifique OS2.

2/ La seconde contribution de nature technique cette fois porte sur la définition et le développement d'un prototype logiciel appelé DOSSARD permettant de concrétiser les éléments définis dans le système d'aide à la décision précédent. En particulier, ce prototype permet de collecter les symptômes, de créer des liens avec l'arbre générique (voir Chapitre IV) afin de proposer un diagnostic sous forme de graphes. Cette contribution répond à l'objectif technique OT2.

3/ La troisième contribution de nature scientifique porte sur la formalisation sous forme de base de connaissances orientée graphe, la validation et l'enrichissement d'un arbre des réalités actuelles générique adapté à la caractérisation des systèmes de production de type Make-To-Stock. Cette contribution apporte un premier élément de réponse en référence à l'objectif scientifique OS1.

4/ La quatrième contribution de nature scientifique également consiste en l'élaboration d'un arbre des réalités actuelles générique adapté aux systèmes de production de type Engineer-To-Order. Cette seconde base de connaissances est totalement inédite et entreprend de compléter la réponse apportée à l'objectif scientifique OS1 du présent travail de recherche.

5/ La cinquième contribution de nature technique cette fois consiste en la mise en œuvre d'une solution technique permettant d'instancier les deux précédentes bases de connaissances dans le cadre du système d'aide à la décision développé pour ce travail de recherche. Cette contribution s'inscrit en réponse à l'objectif technique OT1.

Dans le cadre du programme industrie du futur développé par la région Occitanie (<https://www.laregion.fr/parcours-industrie-du-futur>) et dans le contexte de crise économique liée à la COVID-19, nous avons pu tester et valider notre approche sur un nombre de cas significatif. En effet, ce programme a pour but de permettre aux entreprises industrielles de la région d'évoluer vers un environnement plus digitalisé de leurs activités. Ainsi, le programme se décomposait en 2 étapes :

- Un diagnostic industriel d'une durée de 3 journées. Ces 3 journées pouvaient être réalisés à distance ou en présentiel. Ces 3 journées pouvaient être ou non consécutives. Le livrable du diagnostic étant un état des lieux qualifié et un plan d'action associé ;
- Un accompagnement, optionnel, post diagnostic pour réaliser la mise en place de ce qui aura été relevé durant la phase de diagnostic.

Le but du diagnostic est d'évaluer la maturité industrielle et digitale de l'entreprise. Via ce diagnostic, l'entreprise cherche à mesurer l'état de ses pratiques industrielles par rapport aux bonnes pratiques et à la concurrence. La maturité digitale est évaluée à travers les outils informatiques et les technologies en place au sein des entreprises.

Pour que l'entreprise bénéficie de ce programme, elle doit répondre à 3 critères :

- Avoir une entité basée dans la région ;
- Être une entité de moins de 3000 salariés ;
- Remplir un dossier de subvention auprès de la région.

Pour réaliser les diagnostics et la mise en place des actions d'accompagnement optionnelles, la région Occitanie a fait appel aux acteurs suivants :

- 10 entreprises de conseil, parmi lesquels le cabinet AGILEA ;
- 57 consultants indépendants.

Tous ces acteurs sont des experts du domaine du management des opérations, de la Supply Chain ainsi que de l'amélioration continue.

Le cabinet AGILEA, qui faisait partie des acteurs mobilisés, dispose d'accords avec 13 des 57 consultants indépendants qui peuvent intervenir pour son compte. C'est donc avec les consultants AGILEA et son réseau de 13 consultants indépendants que nous avons pu procéder à une expérimentation large de DOSSARD.

Par ailleurs, il est à noter que l'auteur de cette thèse n'a, à titre individuel, réalisé aucun des diagnostics associés à cette opération. Son seul rôle a été d'accompagner les utilisateurs dans la prise en main de l'outil et de la démarche associée.

Enfin, il faut noter qu'à l'issue de l'étape de diagnostic, chaque entreprise pouvait choisir de ne pas valider la proposition de plan d'actions, la valider et décider de la mettre en œuvre par elle-même, ou bien la valider et se faire accompagner par un des cabinets conseil partie prenante de l'opération.

De façon opérationnelle, l'outil DOSSARD a été mis à disposition des consultants d'AGILEA et de ses 13 partenaires afin que ces derniers puissent réaliser, en toute autonomie, les diagnostics industriels relatifs à l'opération menée par la Région.

Les personnes concernées avaient les caractéristiques suivantes :

- Aucun des consultants ne connaissait la méthode des *Thinking Processes* préalablement ;
- Leurs connaissances en *Théorie des Contraintes* étaient basiques ;
- Nous les avons formés 2h à l'utilisation de DOSSARD ainsi qu'à la construction et l'interprétation d'un nuage de conflits comme mentionné dans les premiers chapitres de cette thèse.

Par ailleurs, nous avons laissé libre choix aux consultants d'utiliser ou non l'outil DOSSARD pour la réalisation de leurs diagnostics. Nous avons simplement collecté les résultats afin d'en tirer des leçons. En particulier, nous avons vérifié si les livrables demandés par les clients étaient tenus, i.e. réalisation d'un diagnostic ainsi qu'un plan d'action associé. Nous avons surtout noté si les entreprises étaient enclines à poursuivre la phase post-diagnostic avec le consultant. En effet, si l'entreprise poursuit, nous pouvons en conclure qu'elle est satisfaite du diagnostic (pertinence) et de la manière dont il a été mené.

Le projet a duré 8 mois d'avril 2020 à décembre 2020 :

- 73 diagnostics ont été réalisés par l'ensemble des cabinets et des consultants indépendants ;
- 25 diagnostics ont été réalisés par AGILEA ou son réseau de partenaires ;
- 18 de ces diagnostics ont été faits avec DOSSARD.

Au regard des résultats présentés précédemment, nous pouvons résumer et comparer l'utilisation du système de diagnostic avec l'approche traditionnelle des *Thinking Processes* comme évoqué par la figure 95.

La plupart des enjeux identifiés dans les Chapitres I et II de ce manuscrit semblent trouver une réponse satisfaisante dans la proposition DOSSARD développée. C'est particulièrement le cas pour les environnements MTS/MTO et cela semble prometteur aussi sur les environnements ETO même si pour le moment, nous manquons encore de résultats applicatifs. En particulier, nous notons que le système proposé permet de rendre accessible au plus grand nombre la méthode des *Thinking Processes* traditionnellement réservée à des experts chevronnés.

Au final, en réponse aux questions de recherche posées dans le cadre de cette thèse de doctorat, plusieurs contributions ont été développées dans le cadre de ce travail de thèse de doctorat :

- D’abord nous avons conçu, structuré et développé un système d’aide à la décision permettant de réaliser des diagnostics organisationnels de systèmes de production à partir de données qualitatives. Ce système d’aide à la décision, inspiré directement de la logique de constitution des arbres des réalités actuelles (CRT) des *Thinking Processes*, comprend une dimension fonctionnelle, un processus de mise en œuvre et une architecture technique complète, instanciée dans le cadre d’un prototype logicielle.
- Ensuite, afin de donner corps à notre système d’aide à la décision, une base de connaissances spécifique a été conçue afin de supporter les mécanismes de raisonnement proposés dans le cadre du système d’aide à la décision. Cette base de connaissance développe plus spécifiquement un arbre générique des réalités actuelles permettant d’identifier et lier les principaux symptômes et conflits généralement existant dans les systèmes de production. Plus exactement, deux versions de cet arbre sont proposées, l’une dédiée aux environnements dits de Make-to-Stock et Make-to-Order, l’autre dédiée aux environnements dits Engineer-to-Order.
- Enfin, un riche plan d’expérimentations a été mené afin d’évaluer la validité, la portée et les limites des propositions théoriques faites. Des dizaines de cas industriels ont ainsi été conduits dans le cadre du programme Industrie du Futur de la Région Occitanie. Il en résulte des gains significatifs vis-à-vis des méthodes traditionnellement employées, tant en matière de temps, productivité (coût), qualité que de service. Ces résultats sont particulièrement positifs pour les environnements Make-to-Stock et Make-to-Order.

CHAPTER I. INTRODUCTION

“If you don’t try, you can’t fail.”

Dr. House

a. Context and problem statement

Almost all industrial sectors are currently facing new tensions: reduced deadlines, limited margins, growing risks of non-quality, supplier failures, etc. In this aggressive environment, the objectives of companies to maintain their performance include:

1. The optimization of system layouts and the organization of flows;
2. Inventory reduction and supply management;
3. The implementation of demand-driven piloting tools.

To achieve these objectives, the professions of continuous improvement and Supply Chain Management have therefore become essential. In order to guarantee the sustainable development of the economy of a territory, and in particular the more fragile SMEs, it is essential that all the actors have the best possible control over their internal and external flows, despite the numerous hazards and crises that they must face. Managing this growing complexity while maintaining high levels of performance is the challenge for many organizations (small, medium or large) in the coming years. This challenge is based on the ability of actors to continuously improve their organizations in order to minimize delays and costs while guaranteeing quality, service and safety. Companies, and in particular the companies producing goods or services that will be of interest to us in this manuscript, must identify and develop internal or external sources of improvement, whether quantitative or qualitative. They must also provide themselves with the means to better manage the variability inherent in any production system. This is the challenge addressed by the steps of permanent progress, such as Total Quality Management, Lean Management or Six Sigma.

In such a context, it is understandable how the ability of an organization to maintain a good level of performance, regardless of the hazards it is subject to, is a salient issue. In other words, the systems concerned must have the capacity to respond adequately to the changes that have become part of their daily business (Christopher and Peck, 2004). This new performance objective is called agility, and those companies that manage to achieve it find it to be a real asset in facing their competitors. Agility is a keyword for many research articles over the last decade. It is usually defined as the ability to respond to short-term changes (Sheffi, 2004). According to Lee, the goals of agile organizations are to respond quickly to change and to manage external disruptions smoothly (Lee, 2004). For Peck and Christopher, the two key ingredients of agility are detectability and adaptability (Christopher and Peck, 2004). Consequently, the question that arises is how this agility can be implemented in practice.

Authors such as (Benaben, 2012) or (Lauras, 2013) indicate that the solution to this difficult equation must necessarily take advantage of the digital age. Indeed, today's companies have no choice but to rely on the new possibilities offered by digital technology to meet the requirements and constraints mentioned earlier. If, on a technical level, the Internet of Things, Artificial Intelligence or Cloud Computing are today very concrete realities, the fact remains that their use by organizations producing goods or services remains relatively low (Benaben, 2012). This is explained in particular by the difficulty of globally analyzing the masses of data generated by this equipment. The challenge for companies is no longer access to data, but above all its interpretation and utilization. This issue is particularly acute for companies whose activity consists in producing goods or services. (Atzori et al., 2010) speak on the subject of a digital

Context and problem statement

revolution initiated, according to them, by the advent of smartphones and by the exponential development of connected objects. Due to the variety of existing and future equipment, this digital revolution is gradually transforming the current world into a vast hyper-connected system to which it is necessary to adapt (Sallez et al., 2016). Thus, for example, the interaction between these connected objects and traditional Information Systems (ERP, TMS, WMS, APS, etc.) leads to changes in the way in which the processing and use of information must be thought about and carried out (Giusto et al., 2010). A first line of thought thus consists in equipping companies with the capacity to have a complete picture of their activities, their environment and the events related to them. Traditional Information Systems and connected technologies must clearly contribute to the achievement of this objective. These technologies support the collection and transmission of information in real time and make it possible to have a precise vision of the state of a system at any time.

But beyond this, it is also (and perhaps, above all) the business expertise of operational actors and decision-makers that must be considered in order to understand the functioning of a production organization and to advance it. Indeed, human behavior (decision-making processes, business rules, etc.) often remain the key elements of company performance (Dettmer, 2007). The management of an operational activity involves permanent trade-offs among several alternatives. Each company then defines, consciously or unconsciously, its own rules that directly affect the operational results and the competitiveness of the organization. (Smith, 1999) and (Dettmer, 2007) have shown that organizations producing goods or services are systematically confronted with "conflicts" (producing large batches versus producing small batches, starting earlier versus starting later, etc.) that directly impact their level of performance. Becoming more agile, and having a more sustainable performance, therefore requires capturing this "qualitative" data, understanding the associated behaviors, and adapting over time the management of these "elementary" conflicts according to the strategic orientations that have been chosen and the disruptions that can occur.

b. Research question and expected contributions

This research project aims to contribute to the development of the toolbox (methods and techniques) necessary for the optimization of industrial organizations and for the improvement of their performance. This includes developing an original and effective approach to better understand the complexity of companies producing goods or services, the new realities on the ground (uncertainty, variability, increasing digitization, etc.) and the new economic challenges facing companies. **The main focus of this project is to develop a decision-support system capable of assisting managers and/or consultants in the establishment of a relevant organizational diagnosis.** The underlying assumption of R&D programs is that any company that does not evolve dies and that, therefore, companies must constantly evaluate themselves in order to undertake progressive action. However, the current complexity of companies often makes the organizational diagnostic exercise difficult, uncertain, time-consuming and tedious. And this is the case whether it is carried out by an expert consulting firm or by the company itself.

The challenge of this doctoral thesis is therefore to develop an innovative approach for identifying and characterizing the dysfunctions of companies producing goods or services in order to quickly establish an inventory of the situation and to support the equally rapid definition of an operational progress plan.

Ultimately, there are many changes to be made to production organizations to guarantee sustainable competitiveness. To clarify the positioning of the work of this doctoral thesis, we can consider the following three complementary phases for developing the agility of a company:

- Re-engineering phase: these are activities that make it possible to characterize and diagnose the processes and flows of a logistics system (local or extended) in order to deduce potential malfunctions and margins of progress;
- Anticipatory management phase: these are activities that make it possible to define the processes and flows to be executed to manage the logistics system according to the known and planned elements;
- Reactive management phase: these are activities that make it possible to detect hazards that disrupt the production system and to adapt, in real time, the processes and flows to be implemented to achieve the expected results.

This research project addresses only the question of (re-)engineering. And the resulting research question can be summarized as follows: How, from qualitative data, can we help to objectively and quickly diagnose organizations producing goods or services?

In practical terms, it is a question of modeling existing processes and behaviors in order to detect existing malfunctions or inconsistencies in the current situation. On this basis, the project must develop an innovative solution capable of facilitating the identification of concrete areas for potential improvement. Schematically, the challenge is to collect heterogeneous data (from information systems or interviews), to formalize and structure them in the form of knowledge in order to establish a diagnosis of the organization in an objectified and semi-automated way.

Consequently, this doctoral thesis proposes to address the following scientific (SO) and technological (TO) objectives:

Research question and expected contributions

- SO1: This scientific challenge will focus on the structuring of generic qualitative data in the form of a or several knowledge-base(s) to provide a coherent and unified utilization afterwards;
- TO1: With this technical objective, the research project will focus on developing a Knowledge Base Management component capable of structuring the data in order to authorize its utilization;
- SO2: This scientific challenge will focus on the formalization of an original decision support system and an ad hoc business-process necessary for the realization of a semi-automated organizational diagnosis;
- TO2: The associated technical objective will be to define and develop a software component capable of supporting the diagnostic process.

The present research project therefore includes a strong component of integration of practices (methodological) and tools (technological) in order to guarantee its operability and acceptability. In terms of contributions and the potential for groundbreaking change, the semi-automation of the organizational diagnostic stage proposed in this research work is a major innovation in view of the tools currently available (see Chapter II). The proposed approach thus develops a true holistic vision of the company in order to clearly identify its areas of progress, with a view to better agility and more sustainable performance.

We can finally position the components of the scientific originality and the application challenge of the thesis project according to two levels:

- Business level: The scientific originality will focus here on the structuring of the associated knowledge base and on the definition of indicator systems adapted to the diagnosis of companies producing goods or services as mentioned in SO1. The application challenge will therefore concern the ability of professionals to consider actions that are adjusted, possibly coordinated, to the known characteristics of the situation (TO2). In summary, it is a question of considering more "intelligent", more "objective" and more "global" applications of traditional organizational diagnostic approaches.
- Technical level: The scientific contributions will focus on solutions that will support automation of the exploitation of the knowledge base and the execution of "logic trees" (definitions of business rules and expert algorithms as described in the TO1). The application challenge here will mainly be to allow as many people as possible to access the principles of the "Theory of Constraints" to carry out organizational diagnostic actions (SO2). Incidentally, it will be a question of allowing such diagnoses to be carried out quickly, objectively and exhaustively.

c. Research method and means

This doctoral thesis is an industrial thesis carried out, part-time, between January 2018 and June 2021, co-financed by the supply chain management consulting firm AGILEA (<https://www.agilea-group.com/>) and by the *Occitanie* region of France as part of the GRAINE (<https://www.laregion.fr/>) program. The author of this manuscript was thus placed in the position of business consultant who regularly carried out organizational diagnoses on behalf of his clients. He therefore had the opportunity to have many fields of experimentation allowing him to both contribute to the work of the characterization of the industrial problem and to test and validate the proposals made on real, and numerous, industrial cases. The work was carried out mainly within the Industrial Engineering Center of IMT Mines Albi. This laboratory is characterized by its objectives of targeted research. If we refer to the typologies of research methods mentioned in the scientific literature, it is possible to say that our research objective is of the applied type in the sense that our approach aims to "respond to a current problem of society, an organization or a company" (Kothari, 2008). The approach used is similar to the family of action research projects in the sense that our research was implemented in partnership with the agents of the study community and that there was "a desire in these agents to solve the problem and an intention in the researchers to advance the fundamental knowledge associated with this problem" (Laurencelle, 2005). Finally, we must mention that our developments were based on work of a qualitative nature (i.e., literature reviews, undirected interviews, etc.) as well as of a quantitative nature (i.e., surveys, databases, etc.) in the sense of (Panneerselam, 2004) or (Kothari, 2008).

Regarding the literature review, we had to look at an extensive quantity of references. Consequently, the manner in which this information was selected and sorted was critical. The articles were selected through the combination of publishing dates and how many times the articles were quoted in other articles. This approach helped us to select and classify the main articles for building our knowledge base.

Our approach is ultimately mainly inductive and can be summarized according to the principle described in the following figure (from (Benyoucef, 2008) and (Lauras, 2013)).

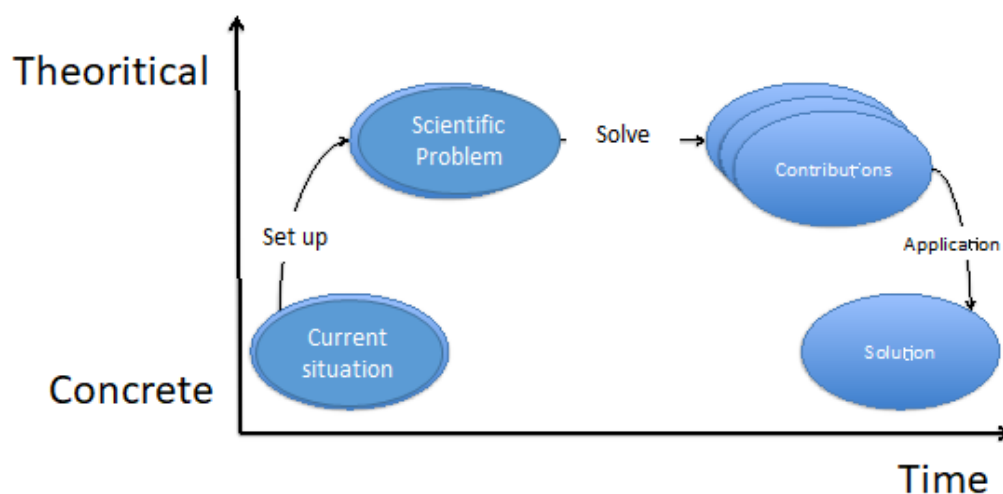


Figure 1. Research methodology (from (Benyoucef, 2008) and (Lauras, 2013))

The preceding figure shows that our research methodology is based on three major steps:

1. Formalization, which consists in characterizing an industrial problem in such a way as to formulate it as a scientific problem. This step includes the modeling and characterization of the studied system on the one hand, and the formalization of the data necessary for the solution to the problem on the other hand;
2. Resolution, which consists in developing original methods (for those problems not referenced in the literature) or in using existing methods (for scientific problems already referenced in the literature). In all cases, the lines of research chosen are developed in depth in order to produce added value compared to the bibliography;
3. Application, which consists in implementing the proposals made on one or more application cases (the targeted research idea). The idea remains to demonstrate the potential contribution of the proposed solutions compared to existing ones. This contribution can then be compared with the effort required to make these solutions accessible.

In our work, we have dealt with the whole cycle (formalization, resolution and application) and have considered the possibilities of applying our proposals in the short, medium and long term, as well as the scientific perspectives that our contributions could generate.

From a practical point of view, the development of this project was done by iteration, as shown in the following figure:

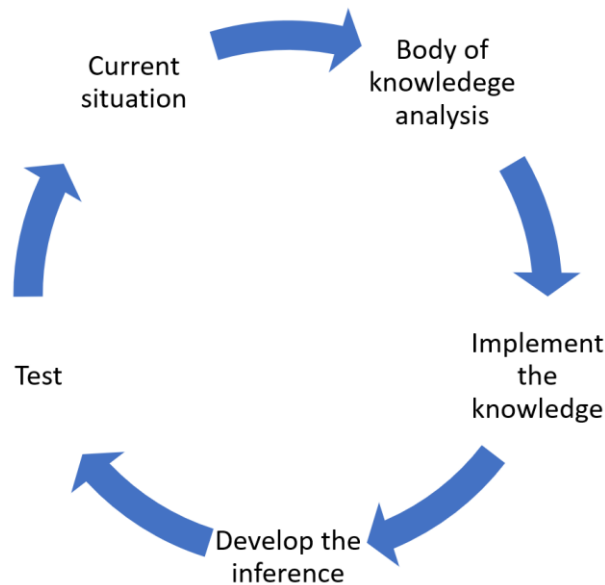


Figure 2. Research approach

Initially, we noted the different symptoms present within industrial organizations. Then, we linked these symptoms with the different elements of knowledge present in the literature. This connection allowed us to build an original knowledge base and to develop the associated inferences. Once this stage had been completed, we were able to carry out the test and thus verify the relevance of our proposals and contributions.

d. Content structuring

The rest of the document is organized as follows. First, (Chapter II), we will explore, via a state of the art, the methods existing in the literature with regard to our problem of the diagnosis of organizations of production of goods or services. We will then develop our theoretical contribution in two stages. In the first stage, (Chapter III), we will explain the operating process and the general architecture of our decision support system. In the second stage, (Chapter IV), we will develop the heart of our system by describing the knowledge bases around which our decision support system is built. The remainder of the document will focus on the testing and validation of the proposals made, (Chapter V). In particular, this will be a question of presenting the experimental platform, then developing an example of a complete industrial application and discussing the feedback obtained by the implementations carried out. Finally, the last chapter will close the subject with a set of conclusions and research perspectives, (Chapter VI).

CHAPTER II. STATE OF THE ART

“I'm smart enough to know what I don't know.”

Dr. House

The first objective of this chapter is to position our research work regarding the main existing organizational diagnostic approaches. In order to carry out this analysis, we must first clarify the different types of environments in which an industrial diagnosis can be carried out and then describe the different approaches to evaluation that exist (section 1). Then, we will analyze the different organizational diagnostic approaches in order to determine what their strengths and limitations are in the context of our problem (section 2).

The second objective of this chapter is to identify and select, among all the existing methodologies, the one which might serve as a backbone of our future proposal. Based on the analysis presented in section 2, we conclude that the *Thinking Processes* approach from the Theory of Constraints has immense potentiality regarding our scientific and technical objectives, despite its numerous current limitations. As our research work makes the bet that it will be possible to build a relevant decision support system from this approach, section 3 will describe in depth the initial methodology and its features. This part of the work will also discuss the proximity of this approach with other causal analysis methods, such as Bayesian networks.

1. Strategies for the production of goods or services

According to (Günlal et al., 2011) and (Barbosa et al., 2017) the industrial environment is composed of three main flow families. They are defined by the ASCM (Association for Supply Chain Management) in the APICS Dictionary (2020) as follows:

- The Make to Stock (MTS) environment: “A production environment where products can be and usually are finished before receipt of a customer order. Customer orders are typically filled from existing stocks, and production orders are used to replenish those stocks.” (APICS dictionary)
- The Make to Order (MTO) environment: “A production environment where products can be and usually are finished after receipt of a customer order.” (APICS dictionary)
- The Engineer to Order (ETO) environment: “In ETO environments, customer specifications require unique engineering design, significant customization, or new purchased materials. Each customer order results in a unique set of part numbers, bills of material, and routings.” (APICS dictionary)

From a theoretical point of view, these definitions are very clear. Nevertheless, a number of articles (Beemsterboerf et al., 2016; Rafei et al., 2016; Barbosa et al., 2017) reveal that these strategies are not always distinct from one another but are often hybrid. For example, (Beemsterboerf et al., 2016) suggest that some environments must have combined approaches to meet specific market needs, particularly between MTO and MTS. In addition, these same ideas are developed in (Rafei et al., 2016) and (Amrani et al., 2017). In particular, they mention the very strong connections between MTO and ETO flows to "satisfy specific customer requests". For example, some products that are manufactured in ETO mode are certainly unique in terms of finished products but they still belong to certain macro-families of technology. At the scale of this macro-family of technologies, the company can detect market needs, especially in the short cycle, and create an MTO activity from certain technological building blocks developed in ETO. Thus, the physical flow of the products is a mixture of a pure ETO flow project and an MTO flow that contains a specific part and is defined by the ETO building blocks of the company.

In (Beemsterboerf et al., 2016), (Rafei et al., 2016), and (Barbosa et al., 2017), it is clearly stated that industrial issues are often common. It is a question of making deliveries on time while minimizing the associated expenses. Moreover, as suggested by (Rafei et al., 2016), "hybrid solutions often face choices to be made between the fundamental characteristics of combined flows to meet specific market demands."

These choices, or trade-offs, include several types:

- What technologies do we offer for a shorter cycle?
- What technologies do we not offer?
- How much are customers willing to pay to get this shorter cycle?

For example, in a hybrid MTO/ETO environment, the company is often forced to choose certain stocks of raw materials to meet specific ETO needs while offering a manufacturing cycle close to an MTO logic. For example, since material A is cheaper and faster to produce, the company can choose to offer only this material. In these same types of flows, the MTO sometimes has to update technical elements of the product as well as the specific customizations that are actually characteristics of the ETO. As we have seen in (Beemsterboerf et al., 2016),

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(Rafei et al., 2016), and (Barbosa et al., 2017), it is difficult to say that there are only 3 types of production strategies. There is in fact a sum of possible combinations to meet increasingly specific needs. Indeed, production strategies can be combined within an organization among:

- MTO/MTS strategies;
- MTO/ETO strategies;
- MTS/ETO strategies, etc.

In such different environments and with so many possible combinations, and given the VUCA (Volatile, Uncertain, Complex, and Ambiguous) environment of organizations, the analysis of an organization's current situations has become increasingly complicated (Bennett and Lemoine, 2014). Thus, we could question the diagnostic methods that are most widely used today.

2. Diagnosis, Audit and Evaluation

Before starting this document, it is important to provide some definitions. Indeed, the field of the analysis of company performance is full of possibilities. Conventionally, diagnoses, audits or evaluations can be used. It is therefore important to define these terms to clearly distinguish their nuances.

A diagnosis of a system is based on the analysis of a set of symptoms (Mitchell, 1988). In practice, as part of a diagnosis, this will be a question of identifying the root cause(s) of the non-performance of a system from the identification and analysis of a set of negative observations.

An audit refers to the procedure for analyzing a system on the basis of an established reference system (Dun et al, 1981). Generally, this reference is determined by a body independent of the system but associated with the field studied. A typical example is ISO certification. Companies subject to ISO certification are thus required to be audited to verify their level of compliance with the standards established by ISO. It is important to note that the concept of audits can be applied to many areas, but not all auditing bodies are state-owned enterprises. They may also be private organizations. However, in some areas (such as accounting and finance), auditing rules are strictly regulated and defined by the state.

An evaluation consists in using a set of tools designed to assess whether the system is achieving the expected levels of performance and whether it has the means required for carrying out its activity (Greenberg and Kramer, 1991). This is not a question of comparing a system to standards, nor of looking for the root causes associated with system malfunctions, but simply of measuring the state of the system's performance and its evolution over time.

In the rest of the document, we will focus on the concept of diagnosis, and specifically on the concept of the diagnosis of industrial systems for the production of goods or services.

3. The main methods of organizational diagnostics

The purpose of this section is to describe the different types of diagnostics that exist in industrial environments. In each of the following subsections, we will also explore how these approaches serve the analysis of MTO/MTS/ETO and hybrid production strategies. We will rely in particular on a state of the art to describe the strengths and weaknesses of its methods in the current industrial context, and thus identify good practices and shortcomings.

Considering the current environments that are particularly subject to change (cf. the VUCA paradigm), it is important to be able to carry out efficient diagnostics that take this characteristic into account. Thus, given the volatility of the environments and that this volatility implies changes to be made to a company, it is important to note that the diagnosis must be able to be carried out quickly. In addition, these rapid changes mean that companies will have to collect information more and more regularly. Accordingly, the origin of this information is going to be important. This can be quantitative as well as qualitative information. The uncertainty and complexity of today's environments also require that additional elements be taken into account for the veracity of diagnoses. Indeed, in addition to the speed of execution, it is important to see what investment is required in terms of resources to carry out the diagnosis, as well as the skills required for using its approaches. For example, if the approach is fast but it takes two months to train the team in the use of the approach, this will have a significant impact on the attainment of the diagnosis. Since these diagnoses will be carried out more systematically, it is important that the results of the diagnosis are particularly explicit and easy to interpret.

Finally, it is important for the diagnosis to succeed in producing a reliable result, i.e., representative of the reality of the strengths and weaknesses of the organization.

1. Quantitative organizational diagnostics

1. The Lean Manufacturing approach

Lean Manufacturing is an approach that was developed by Taiichi Ohono (Becker et al., 1998). Its aim is to improve a system by driving out waste. The founding company of Lean is considered to be Toyota. This company manufactures cars in an MTS environment. In order to identify the areas of improvement of the system, the Lean method uses what is known as a continuous improvement approach. The aim here is to try to identify the various levels of waste present in the system. When waste is identified, it is necessary to propose actions to correct the problem (reduction or elimination). Such an action plan ultimately consists in planning the resolution of the problem, correcting it, verifying it and acting. This approach was notably developed by Mr. Deming in the 1950s and is known as PDCA (Plan Do Check Act) (Dudin et al., 2015). In terms of tools, the continuous improvement approach of Lean is based on logic called Gemba Walk (i.e., walking around the workshops to detect the real problems of the terrain), in order to identify the 7 Muda (i.e., the main areas of waste), in particular by mapping the flows via a Value Stream Map (VSM).

In a VSM, a certain amount of quantitative data must be collected. For example:

- Cycle time;
- Quality level;
- Quantity in stock;

- Quantity in progress;
- Scrap rate.

In the principle of operation, when the VSM has been finalized, the team that built it will then identify the waste. This waste is called *muda*. There are classically 7 types of *muda*:

1. Overproduction: consists in producing a quantity greater than the demand;
2. Overstocking or unnecessary inventory: represents unsold or unused inventory;
3. Transport and travel: represent transfers of physical products. For example, when you systematically walk across the workshop to get tools;
4. Over-processing or unnecessary processing: When the team or the operator performs tasks that have no value for the product;
5. Unnecessary movements: These are movements that are carried out by the operators and that could be reduced if, for example, tools were more accessible at a workstation;
6. Errors, defects and scraps: Represent product retouching or refabrications following quality problems;
7. Wait times and delays: Describe inventory queues of different resources. This immobile stock is considered to be waste.

In practice, the team will carry out a VSM before analyzing each of the steps of the mapping obtained in order to identify the *muda* present on the stations. This list of *muda* will then be converted into an action plan to remove or collapse the *muda* using the principles of PDCA seen earlier. One of the classically used representations is the one shown in the following figure:

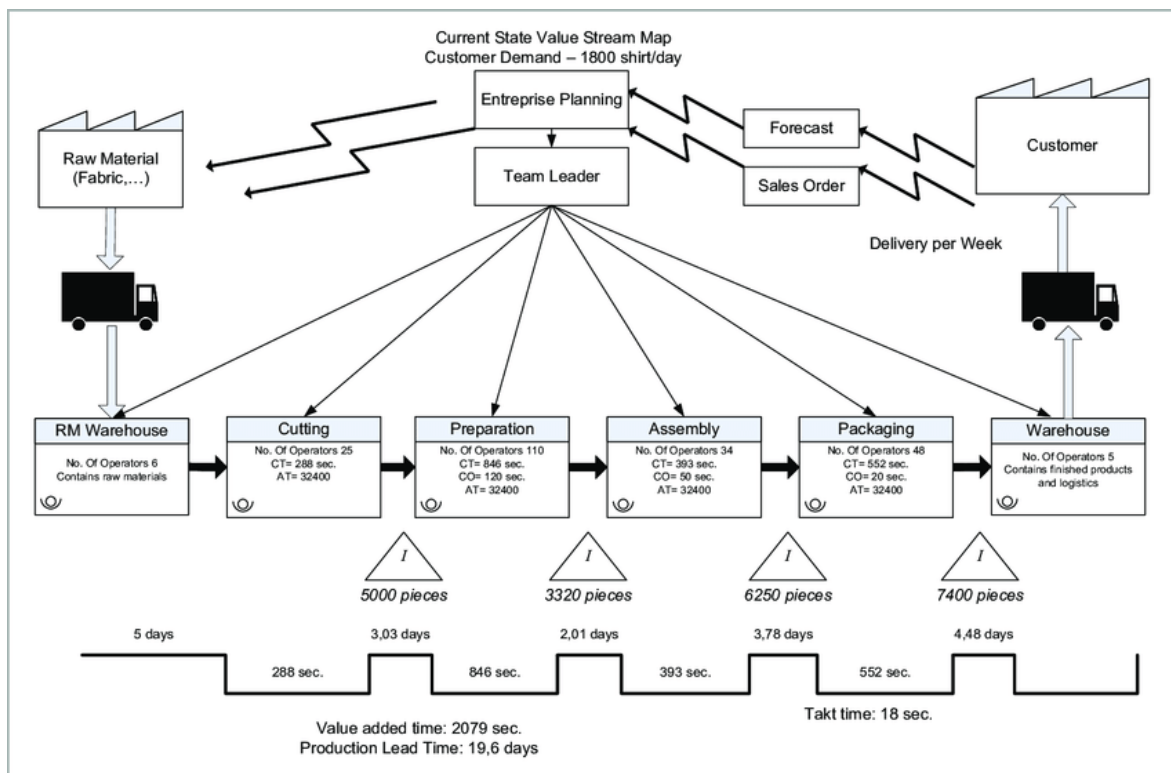


Figure 3. Value Stream Map diagram (Kentli et al., 2013)

The lightning-shaped arrows represent the flow of information, while the rectangular elements represent the subprocesses. From a diagnostic point of view, the Lean approach is intended to be relatively quantitative. Indeed, the information gathering phase is often based on indicators such as Takt Time, Cycle Time, etc. However, it should be noted that *muda* are usually qualitative

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information that is then converted into quantitative data. For example, we see a certain number of displacements and then we will measure what these displacements represent in concrete terms.

In short, we can say that the Lean approach consists of:

- Scanning a specific subsystem;
- Determining a certain amount of quantitative data;
- Identifying *muda* based on qualitative information to convert them into quantitative data;
- Eliminating these *muda*.

Through this approach, we can deduce that the diagnostic part is quite limited. Indeed, simply studying a subsystem does not provide a global view. Moreover, even making a sum of the subsystems is in no way a guarantee of having a realistic vision. In addition, the collection of information takes place in a given setting, the *muda*. Even if the interest of this framework is obvious in allowing a generalized understanding, it does not help in understanding the different mechanics that are hiding behind the *muda*. Indeed, the approach as presented makes it possible only to solve a sum of irritants rather than to go and dig into the root causes of the system. However, it should be noted that this Lean approach is often coupled with a cause analysis tool called the Ishikawa diagram. This Ishikawa diagram will be developed in section 2.2.1.

2. The 6 Sigma approach in diagnostics

The 6 Sigma method was invented by Motorola in the 1990s but was further developed thanks to General Electrics who made it a reference model (Caulcutt, 2001). The principle is to reduce variability within processes, especially with regard to manufacturing processes. The process used is based on DMAIC (Define, Measure, Analyze, Improve, Control/Master). The DMAIC method is represented by Figure 3 below:

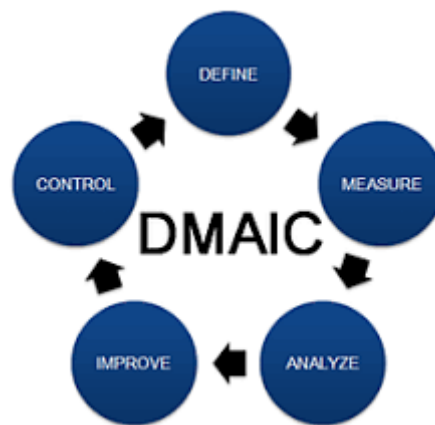


Figure 4. Representation of a 6 Sigma DMAIC diagram

The execution of the 6 Sigma tool is carried out through the same approach as that of Lean Manufacturing: the company will identify a team capable of solving a defined problem. Once this team is established, it will be able to start the DMAIC process as indicated below.

The Define principle consists in characterizing the system that we want to study, notably by identifying the needs of customers through what is known as a Voice of Customer approach.

Customer needs can be defined through the market information from sales functions. They can be derived from market research for analyzing market trends.

In Measure, the approach quantifies the gaps between the current system and the customer's needs. These differences will be the basis for the next step, Analyze. However, it should be noted that it is also during this phase that the team will use other diagnostic tools, in particular the Ishikawa diagram (see section 2.2.1).

In Analyze, the team will use variability deviation measures to observe the various key parameters that are generating these deviations. Again, the method suggests using the Ishikawa diagram to analyze some causes of the problem being studied. The aim here is to take stock of the current situation and to compare the figures with the objectives of the improvement project.

The Improvement phase, on the other hand, consists in designing and implementing a set of actions that will make it possible to ultimately achieve better results. It is therefore a question of taking action. Here again tools are suggested, such as the PDCA (Plan-Do-Check-Act) to carry out this change in a structured way.

Finally, the Control phase verifies that the results measure up to the initial objectives.

In summary, the 6 Sigma/DMAIC approach is very focused on the use of quantitative data to identify problems identified in the system. As in the Lean Manufacturing approach, the method is applied to a given specific subsystem and seems to be difficult to use on the scale of a global system such as a company producing goods or services.

3. Data Mining and Process Mining

Since the emergence of Industry 4.0 two tools have made a strong appearance, providing a significant complementary capacity to quantitative diagnostics. In themselves, these tools do not constitute diagnostic approaches as such. However, they greatly facilitate the processing of data, which are now often massive, and they therefore facilitate the development of diagnostic results.

Data Mining first represents data analysis from different points of view. The idea is to transform a set of data into contextualized and actionable information to support decision-making mechanisms (Perzyk et al., 2014). The principle of Data Mining consists, via ad hoc algorithms, in establishing/proposing/testing links between these data and thus identifying master diagrams (Lithoxoidou et al., 2017). Data Mining can go so far as to include possibilities for predicting future events. Although Data Mining tools make it possible to analyze large amounts of data (Perzyk et al., 2014), the initial collection of this data remains the main issue. It often results in the implementation of simplifying assumptions during the collection phase (Lithoxoidou et al., 2017; Childerhouse, 2011).

Like Data Mining, Process Mining (PM) consists in performing data analysis according to a time dimension. In the case of Process Mining, the tools will analyze data that circulates in an activity flow (Aguirre et al., 2013). Thus, this approach will focus only on events that occurred during the execution of a process. Practically, it consists in collecting data as a log file, event data in our case, and in automatically creating a process model. More information on the Process Mining step is available in (Van der Aalst, 2011). However, Process Mining requires a specific log file: that is to say having enough representative events collected. Consequently, the question is how

to constitute such a representative file? In a significant number of companies, IT systems (such as ERP, APS, WMS, etc.) are now mature enough to produce log files that can adequately feed a PM system. The problem is tracking processes and flows between the companies and the plants, because for a great majority, only a few of the steps are tracked (often limited to the shipment event and the final arrival event). Because of this lack of information, the processes and/or log files are manually established through observations and interviews (Perzyk et al., 2014). However, it is overly complicated and time consuming to manually build such a file. Ultimately, by using Process Mining, the user will be able to (Ingvaldsen, 2012):

- Identify improvement plans for certain steps in the process;
- Find the key elements of its process (non-value-added tasks, bottlenecks);
- Establish future scenarios and measure their impacts on the system.

2. Qualitative organizational diagnostics

1. Cause and Effect approaches

Cause and Effect Diagrams (CED) have their origins in the 1960s, when continuous improvement techniques emerged (Sokovic et al., 2009). The birth of Lean Manufacturing in Japan notably led to the appearance of a widely used and well-documented CED: the Ishikawa diagram.

The principle of operation is to identify a particular problem and find the causes that generated this problem. The best-known approach associated with the Ishikawa diagram for identifying these causes is usually the 5Ws, for the 5 Whys. This consists, for the problem of identifying, in asking “‘Why’ did this happen?”, then considering the answer and subsequently asking why this answer happened. The objective is to repeat this cycle 5 times as mentioned in Figure 5.

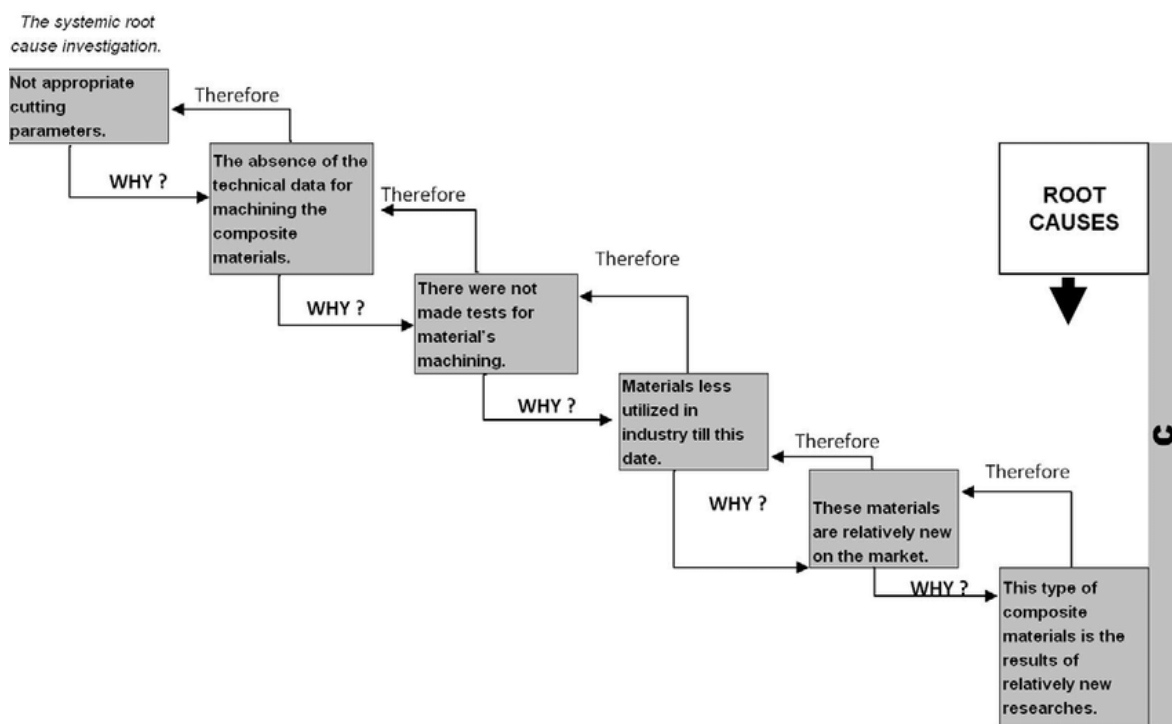


Figure 5. Representation of the 5 Why method (Serrat, 2017)

In practice, the process works as follows:

1. A team with different functions is formed to analyze the problem;
2. The "5 Why" approach is applied;
3. The multi-disciplinary nature of the teams makes it possible to identify different potential causes;
4. The team classifies these cases by families;
5. The team writes the action plan to prevent these causes from reoccurring.

It is notably the phase of the classification of causes that has given rise to another name for the Ishikawa diagram: the Fishbone Diagram (Coccia, 2018). Indeed, one of the challenges of qualitative diagnostics lies in the representation of results. The CEDs suggest using the approach shown in the following figure:

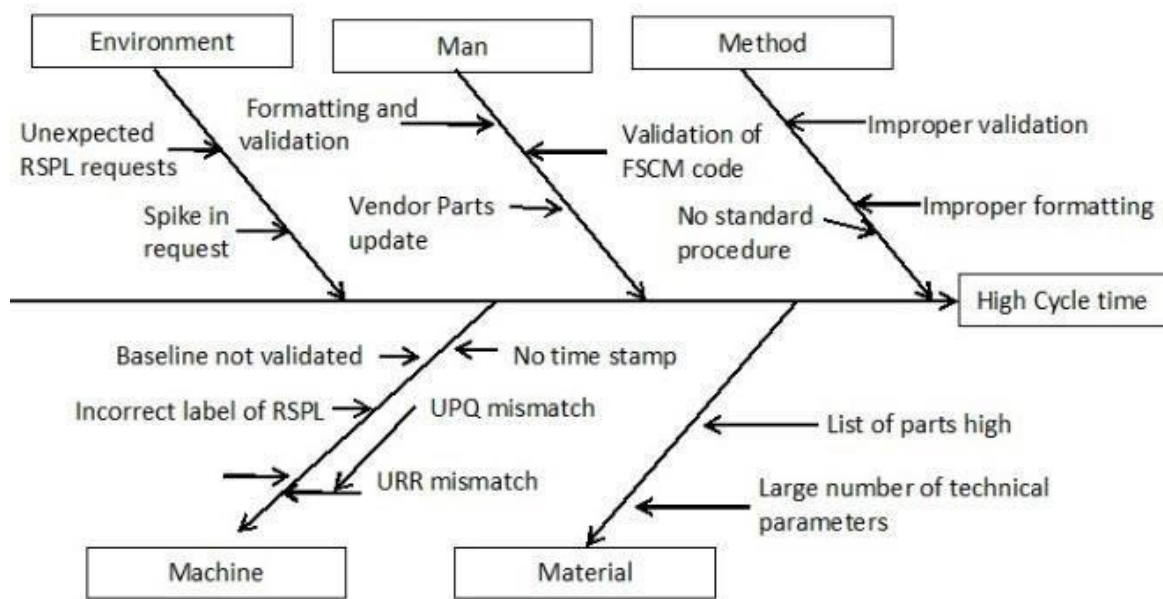


Figure 6. Ishikawa's Fishbone Diagram (Siva and al., 2017)

In this approach, when the team in charge of the project is in the classification phase (Step 4), it will identify categories of causes. Each of these categories will be represented by a branch with the different ideas of the teams. Moreover, as can be seen in the previous figure, some branches may also contain subcategories in order to detail other potential causes.

CEDs, according to (Siva et al., 2017) have the following advantages:

- They are simple to learn and use;
- They are extremely fast to produce: it takes less than 1 hour to make a CED;
- They put the team in a process of continuous improvement because in the case of incomplete or limited results, all that is needed is to start the process again with another team;
- Finally, given its simplicity, it is easily deployable in different areas of the organization.

According to (Doggett, 2005), this tool nevertheless suffers from significant pitfalls. In particular, the following elements are noted:

- There is a team-specific bias. Depending on the functions that are put into the process, it is highly likely that causes associated with people's functions will be found, rather than those related to the problem itself.

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- For the same problem, different teams will find different root causes.
- The principle of diagnosis is to find THE root cause. However, in CED approaches, there is a tendency to find a multitude of root causes. Moreover, Doggett (2005) specifies that the term root causes can be replaced by potential causes.

Ultimately, CEDs are diagnostic methods that are easy to implement, deploy and use. However, from a "pure diagnosis" point of view, this approach does not lead to a common root cause shared among teams. This therefore questions the reliability and relevance of the results obtained with this method.

2. The Theory of Constraints

The Theory of Constraints (ToC) was created and developed by E. Goldratt, notably in his most famous novel entitled "The Goal". Nevertheless, summarizing ToC from this book would be too limiting. Indeed, ToC has developed its approach in areas as varied as:

- Production;
- Distribution;
- Project management;
- Continuous improvement;
- Change management.

It is these last two areas in particular that interest us here. Indeed, the ToC displays a fairly clear strategy on how to proceed with change. The theory holds that there are three types of resistance to change within any system (Kim et al., 2016):

- We do not agree on the problem;
- We do not agree on the direction of the solution;
- We do not agree on how to implement this solution.

From this postulate, the body of knowledge of ToC extends to a set of tools to clarify the problem (diagnosis), to give direction to the solution and to accompany the induced change. ToC proposes a method for diagnosing the functioning and behaviors of a company based on qualitative data (Dettmer, 2007). Where ToC goes further than the others is that this theory has been embellished with a process for generating, managing and executing the diagnosis and the resulting change. These processes are called *Thinking Processes* (TP) (Dettmer, 2007). TPs are composed of five tools, each with a specific objective for supporting the different stages of an organizational diagnosis and also for solving the various problems related to resistance to change (Dettmer, 2007):

- The Goal Tree: this type of tree aims to define the objective of the studied system, to associate the key success factors linked to the objective of the system and to determine the conditions necessary to achieve these key success factors. The idea in this stage is to agree on the final objective to be achieved and to determine in a broad way the means and conditions for achieving it.

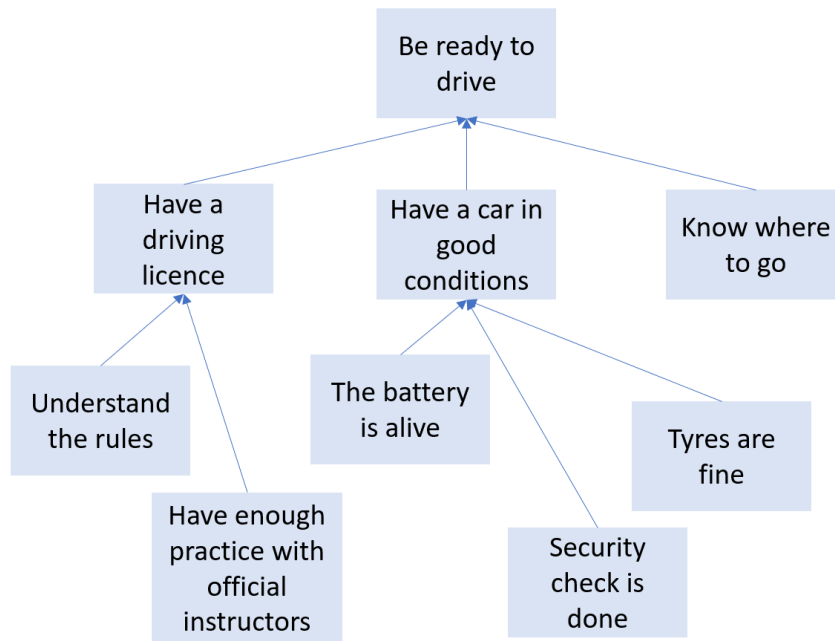


Figure 7. Goal Tree based on the work of Lawrence et al., 2002

As shown the figure above, in order to be ready to drive, you must have your driver's license, a car in good condition and know where to go.

To have a car in good condition, you need to have a working battery, tires in good condition and the various safety elements that have been checked.

- The Current Reality Tree (CRT): Once the Goal Tree has been established, the next step is to establish the differences between what should be done (objectives and key success factors) and what is happening in reality. Deviations are referred to as adverse impacts or symptoms. The idea is then to find the root causes of their symptoms and identify possible links between intermediate effects. Ultimately, this Current Reality Tree makes it possible to agree on the problem and its consequences on the system. Next figure shows an example of a CRT. It can be represented as follows:

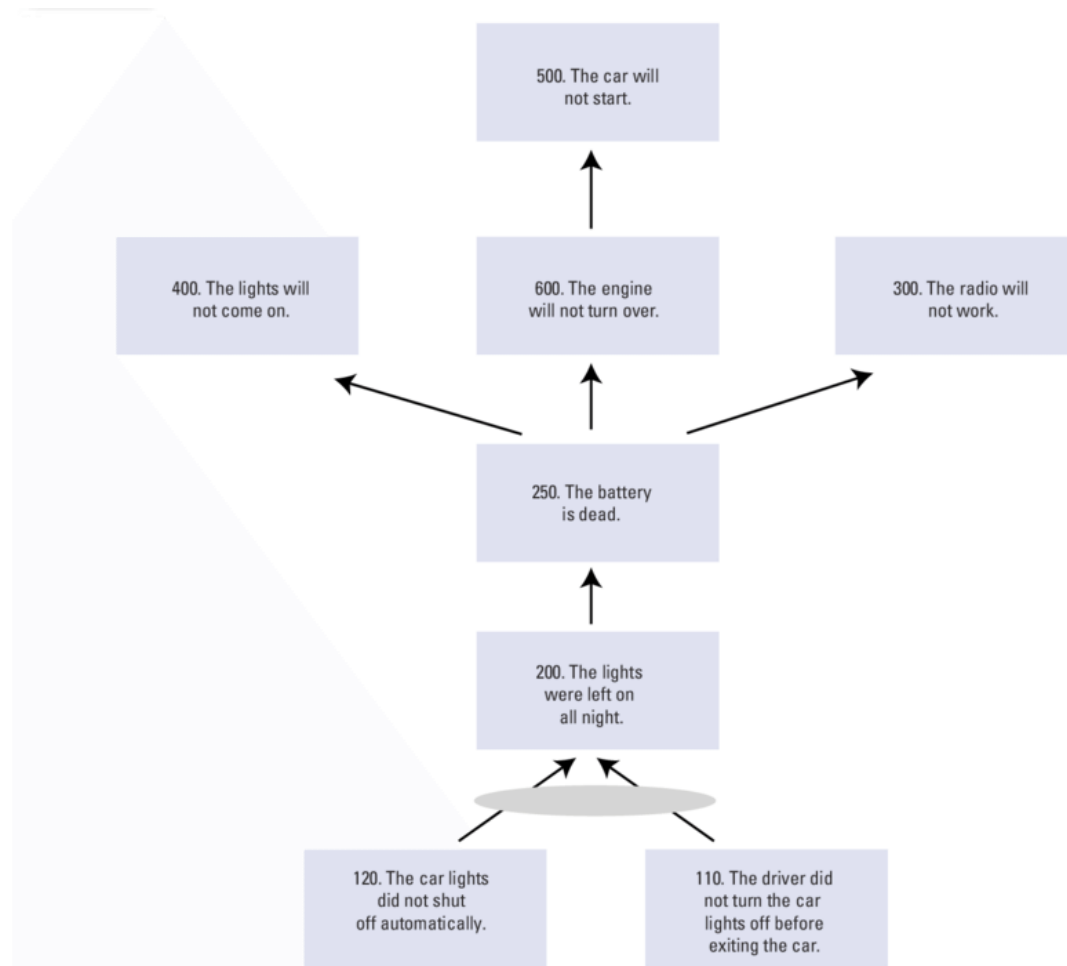


Figure 8. Example of a Current Reality Tree (Lawrence et al., 2002)

In the example mentioned here, the main symptom is that the car will not start. Using the TP method, we can propose the pattern of cause and effect shown in Figure 6: If the driver has not turned off the headlights and the headlights are not automatic, then the headlights have remained on. This has drained the battery. If the battery is no longer operational, then the engine will not start and neither will the car.

- The Conflict Cloud: This is a tool that, once the root cause has been found, determines whether it is in total contradiction with another element of the tree. In (Goldratt, 1996), for example, one of the root causes is the existence of a rule that dictates that all operators must be constantly busy producing so that they lower manufacturing costs. However, another rule that exists in the same system is: "Do not provide work to employees so that the stocks of current and finished products decrease." The Conflict Cloud makes it possible to describe this contradiction, to highlight the hidden hypotheses of conflict management and to propose a solution called injection. In terms of resistance to change, we realize that we are always in the logic of certifying that we understand the problem and the cloud offers the beginning of a solution for this. Below you can find another example of a Conflict Cloud.

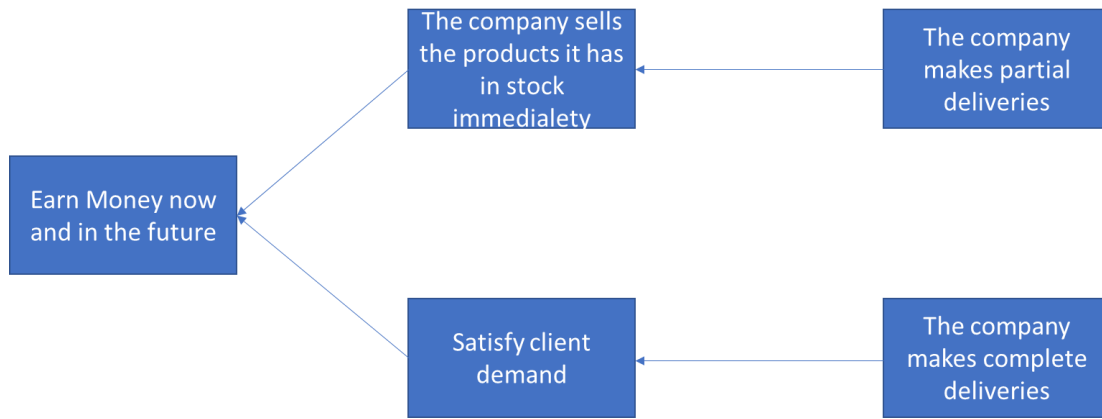


Figure 9. Example of a Conflict Cloud (Smith, 1997)

Injection is the solution that will solve the Current Reality Tree, and it is the starting point for the Future Reality Tree.

- The Future Reality Tree: Indeed, injection is the starting point of the Future Reality Tree. The idea is to verify that the proposed injection will have the opposite effect to the effects observed in the Current Reality Tree. When this is the case, it is possible to verify that the proposed injection is correct. If the injection does not achieve the desired effect, it may be due to the fact that it is incomplete or that a second injection at a higher level of the tree is necessary. It is also at this point that another tool of the Future Reality Tree, called the negative branch, comes into play. This branch makes it possible, from an injection solving a certain number of problems, to determine whether the injection will not have new negative consequences on the system that were invisible at the time of establishing the CRT. In Future Reality Trees, we work on the solution and its direction as well as the risks associated with it. Once this has been done, all that remains is to write the action plan. A Future Reality Tree can be represented as the following figure:

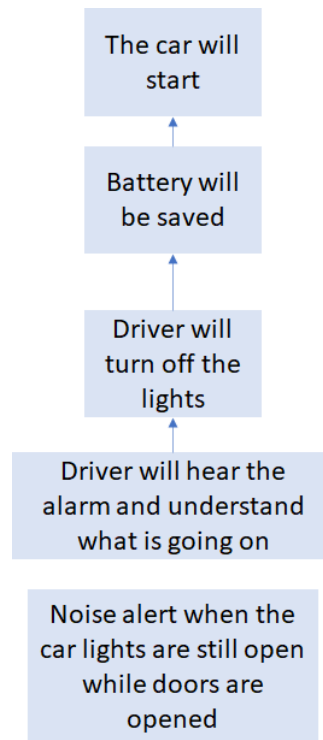


Figure 10. Future reality tree based on Lawrence and al., 2002

- The Prerequisite Tree: This tree takes the injections that have been created and reviewed in the Future Reality Tree. The question here is to determine the obstacles that prevent the injection from existing in reality. Here, the members of the group are invited to make proposals, to imagine what risks are associated with the implementation of the injection and to sequence these risks in the order of execution. The purpose of this tree is to prepare for the smooth running of the plan by writing the milestones of the execution as well as the solutions for bypassing the obstacles that may appear at certain milestones.

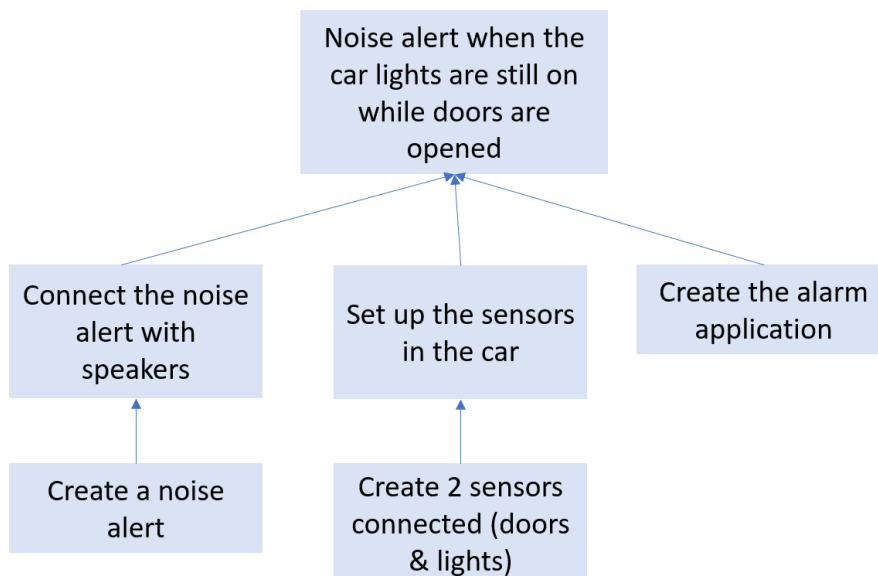


Figure 11. Example of a Prerequisite Tree based on Lawrence and al., 2002.

However, this process would not be effective if it did not provide a logical way to criticize each of the steps inside the trees by anyone constructing or reading the tree. Indeed, the creation of these five tools requires clear and identical rules to ensure that the construction is done in a logical way and is not influenced by personal interests. This method is known as the Categories of Legitimate Reservation (CLR). CLR is used to validate the different entities contained in the trees as well as the links between them. These categories can be used at two moments: during the construction of the tree and also during its proofreading. There are seven types of reservations (Dettmer, 2007):

1. Clarity: the entity is not comprehensible to the user. The solution is to make this entity intelligible by rewriting it. This will help people to better understand a problem or situation.
2. Entity Existence: the entity here is not recognized as existing in the system. The aim here is to validate the problem, or an intermediate effect, as well as the existence of the consequences of the latter.
3. Causality Existence: the two entities exist and are clearly defined but the interlocutors do not see the causal link between the two. Again, it is a question of ensuring that the proposed problem or injection validates the positive or negative consequences on the system.
4. Cause Insufficiency: the entity alone does not achieve the proposed effect. In this case, it is a question of determining whether underlying problems neglected to be mentioned when constructing the tree links.
5. Additional Cause: the link between the entity and the associated effect is correct but there is another entity that produces the same effect independently of the first. Again, the question is whether underlying problems remain.
6. Cause-Effect Reversal: this is to verify that the entity and the effect are in a logical order. For example, if “the lower right side of my abdomen hurts and I have a temperature, then I have appendicitis” is actually an inversion because it is not the pain and temperature that cause appendicitis but the opposite: “If I have appendicitis, then the bottom right side of my abdomen hurts and I have a temperature.”
7. Cause Sufficiency: the entity and its effect exist but this same entity generates other effects independently of the first.

In (Dettmer, 2007), the robustness and relevance of the results obtained by this method are demonstrated. In particular, the author indicates that several teams using this approach to diagnose the same production system systematically led to the same result, which incidentally was correct. However, he also mentions that the teams that have used this approach do not really want to repeat the experience because the method has a number of pitfalls:

- The approach is very time-consuming;
- The approach requires a particularly high level of knowledge to be used. Initially, the training for understanding this method took 20 days. Today, it is possible to train for this approach in 10 days;
- The final rendering is rather inaccessible at first glance. Indeed, the final representation of the tree is rather difficult to read, as mentioned in (Doggett, 2005).

In the end, it can be said that this approach, even though it clearly answers our research question, remains particularly inconvenient and cannot easily be deployed in a company.

We have just seen in the previous paragraphs the main approaches dedicated to organizational diagnosis based on quantitative or qualitative information. There is, however, a third category

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of mixed approaches that needs to be explored. These mixed methods use both quantitative and qualitative information to conduct an organizational diagnostic approach. In particular, we will focus here on the SCOR model and the Quick Scan approach that are now particularly widespread.

3. Mixed organizational diagnostics

1. The SCOR model

The SCOR (*Supply Chain Operations Reference*) model provides a vision of the entire supply chain by facilitating the representation of physical, informational and financial flows from the supplier's supplier to the customer of a company's customer. Its main objective is to be able to offer a benchmark for comparison among companies in the same sector in terms of supply chain management. To do so, it offers analytical tools as well as evaluation tools (Supply Chain Council, 2000). The SCOR approach is divided into three stages:

1. Analysis, which aims to describe a supply chain with the help of a toolbox;
2. Evaluation, which proposes standard performance indicators for supply chains that make it possible to compare themselves with other companies;
3. Improvement, which is based on the good practices advocated by the SCOR model.

Here we will outline the approach and the four levels of granularity proposed by SCOR.

Level 1 models, on the basis of the basic functions (supply, make, deliver, plan and return), the scope of the supply chain that one wishes to study. The work is done here with a very macroscopic vision. The SCOR model offers several indicators, such as:

- The number of complete orders delivered to date, the number of orders shipped in less than 24 hours, the cycle time (between the date of taking of order and the date of delivery);
- The costs of goods, the total costs of supply chain management, the value added per employee, the coverage of stocks;
- The margin, the return on investment, profitability.

Level 2 details, based on predefined process categories, each of the major components of the supply chain. Here again, the SCOR model offers performance indicators associated with each element of the proposed toolbox.

Level 3, on the other hand, describes in more detail each of the processes defined at Level 2. This description is based, once again, on predefined elements. Performance indicators are associated with each of the items in the data library.

Level 4 is not, strictly speaking, part of the SCOR model. The aim here is to descend to the level of basic activities (in essence, specific to each company) that make up each of the processes in the supply chain. The SCOR model does not offer a toolbox or performance indicators here.

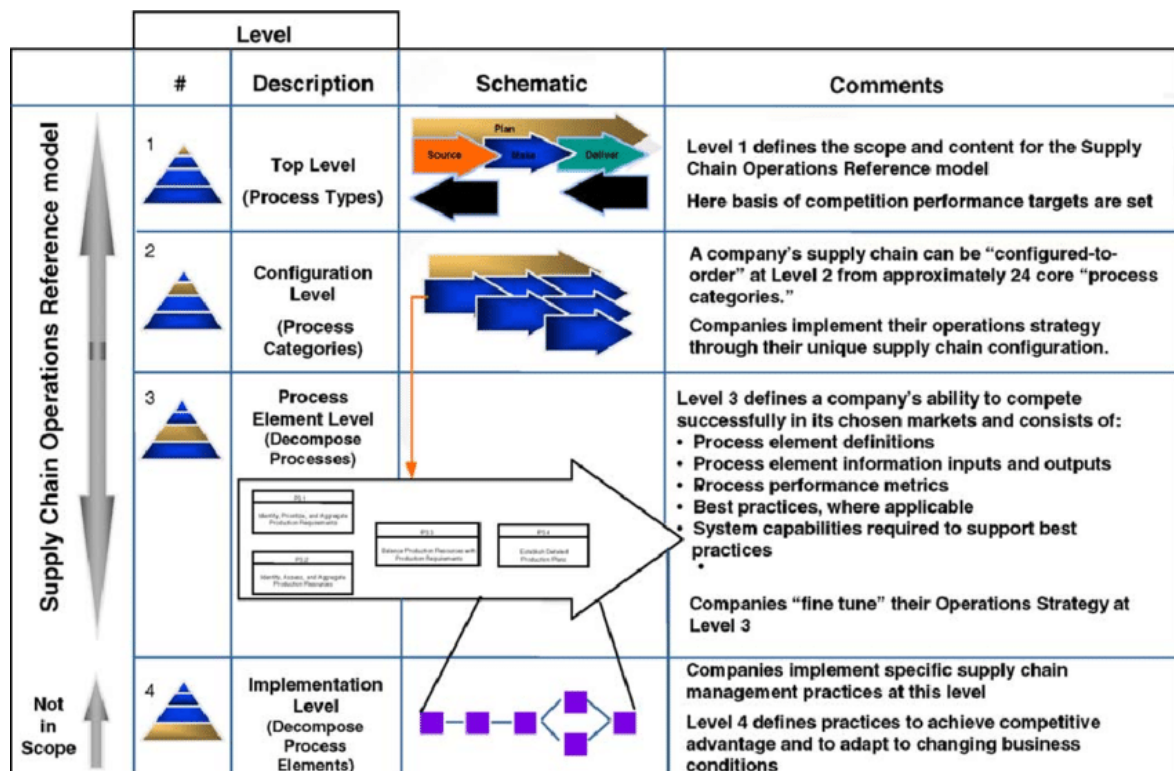


Figure 12. The different levels of the SCOR model (from (Supply Chain Council, 2000))

With regard to the evaluation component of the SCOR model, there are in total three categories of indicators with, for each, three degrees of detail corresponding to the three levels of modeling (Bolstorff, 2002). These are indicators relating to:

- Customer vision: quality of service, flexibility, efficiency-speed;
- Internal process vision: costs and efficiencies;
- Shareholder vision: profitability, return on investments and dividends.

Although the performance indicators here are perfectly defined and formulated, they are still very difficult to deploy within a company. While the breakdown of processes at a macroscopic level is general enough to be applied to any case study, the more detailed levels (level 2 and especially level 3) lead to structures that become difficult to identify compared to what already exists. As demonstrated by (Lauras, 2004), the model is too "ideal". It assumes that the organization in question is already strongly decompartmentalized and that it fits perfectly into the "mold" proposed by the SCOR model. If, in principle, this approach is irreproachable, for many companies it serves more as a target rather than a model of what exists. The proposed reference model is therefore an excellent formalization of the target to be achieved, but its utilization will be difficult as long as the maturity of existing organizations remains low.

In the end, the main strength of this tool lies, without a doubt, in its ability to help in the formulation of performance indicators. On the other hand, it is sorely lacking in flexibility and cannot guarantee the relevance of the chosen indicators. In addition, we can raise the question of the completeness of this target in terms of the integration of the immense variety of industrial configurations.

2. The Quick Scan method

The Quick Scan approach was developed by (Childerhouse et al., 2011) in the early 2010s. It has its origin in the desire to improve the quality of organizational diagnoses, whether quantitative or qualitative. The team that carries out the diagnosis starts from the premise that the two modes of diagnosis (qualitative and quantitative) are incomplete in order to have a real picture of the system studied.

The process as described in (Childerhouse et al., 2011), is as follows: The diagnosis will be divided into two independent parts, one quantitative and the other qualitative. It is represented by the following figure:

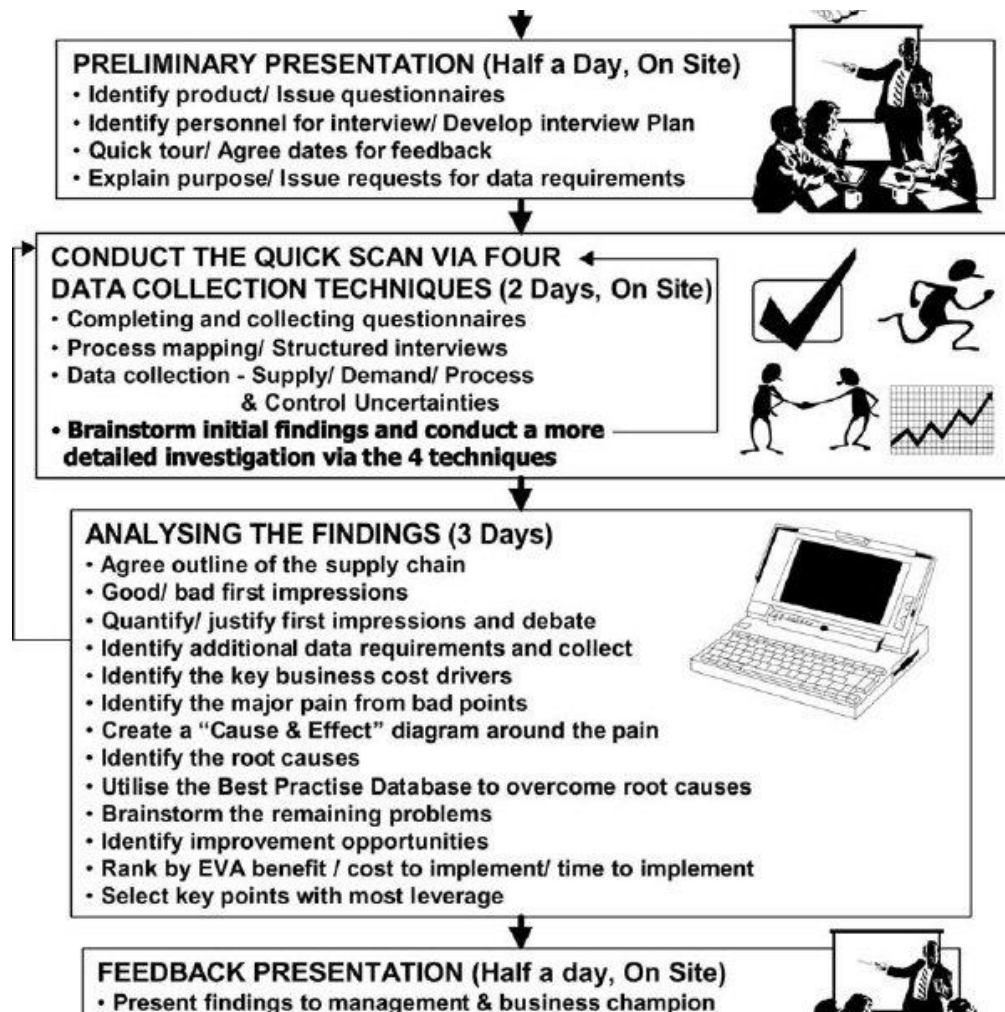


Figure 13. Representation of the process associated with Quick Scan (Childerhouse et al., 2011)

For the quantitative part, the diagnostic team retrieves all the data (cycles, delivery rate per hour, stock level, quality indicators, etc.) to be collected to analyze them and deduce a set of results presented in the form of a dashboard. This dashboard will contain information related to the service rate, stock, quality, etc.

For the qualitative part, paradoxically, the Quick Scan team collects quantitative information to arrive at qualitative information (Childerhouse et al., 2011). From this quantitative information, it will deduce qualitative information on the content of the product. For example, the team reports a service rate of 50%. This is insufficient in relation to market demand, so the following

qualitative information will be deduced: the company does not respect the level of quality of service required by the market.

With this amount of qualitative information, the company will carry out a diagnosis. It should be noted that according to (Childerhouse et al., 2011), the method of utilization of the collected data varies. However, the Quick Scan approach, including the Ishikawa diagram, appears to be the most commonly used.

To summarize, the combination that the Quick Scan approach seeks to make represents a sum of the items to be collected independently of one another. One fact is that we are going to convert quantitative data into qualitative information.

From an organizational point of view, it is mentioned in (Childerhouse et al., 2011) that the Quick Scan approach requires a specific type of organization. A team that will collect and analyze the data is needed, as well as a team that will carry out the qualitative part. In addition, it is worth noting that the team dealing with the qualitative part must have a higher level of experience and expertise in order to be able to fully conduct the process. Finally, in terms of duration, (Childerhouse et al., 2011) mentions a workload of several weeks to fully complete this Quick Scan.

In terms of results (Childerhouse et al., 2011) does not indicate precise results as to the effectiveness of the Quick Scan method but it is noted that companies find the diagnosis particularly complete, albeit sometimes imprecise.

To conclude, the QS method is probably the most complete of all the methods used to carry out a diagnosis because it seeks to aggregate and make the most of other existing methods: CED, indicators from SCOR, etc. However, it can be noted that this completeness accentuates the major pitfalls of these methods when used locally on a smaller scale, such as the level of skills required, the duration of implementation, the imprecision of the result, etc.

4. Synthesis and analysis of diagnostic approaches

Ultimately, all the previous diagnostic methods (quantitative, qualitative, hybrid) make it possible to arrive at a more or less reliable result but with a set of conditions that must be met to achieve this result:

- Time;
- Experienced teams;
- A duty to make the results readable if the goal is to be able to take advantage of the diagnosis and engage the company in a process of continuous improvement.

While there is no shortage of methods to support an organizational diagnosis of a production system, none of them really seems to respond to the problem posed in Chapter I. In particular, important requirements now concern the ability to carry out such diagnoses in a reliable, fast and accessible manner.

Finally, the methods that seem the most promising with regard to our initial problem are:

- CEDs, with the use of qualitative information to make Ishikawa diagrams;
- Quick Scan, which combines quantitative and qualitative approaches;
- TPs with CRTs, which allow qualitative information to lead to good results.

The main methods of organizational diagnostics

In (Doggett et al., 2004) and (Doggett, 2005), the CED and CRT methods were objectively compared. In these works, the authors subjected several diagnostic teams to the same industrial case. Some teams were required to use the CED method to conduct their diagnosis, others the CRT approach. It is clear that the CED approach benefits from several very positive elements: it can combine the collection of quantitative and qualitative data, it does not require a high level of acquisition to embark on the process and it is quick to implement. However, its main pitfall was that the 3 groups that used this approach came to 3 different diagnoses, which were in addition considered irrelevant by the operational actors of the company concerned (due to the problem of identifying the real root cause). The CRT also had several pitfalls in this experiment: its implementation was complex and long, and the final result was not easily usable by the teams. Nevertheless, (Doggett et al., 2004) and (Doggett, 2005) indicate that the 3 groups that used this approach came to the same result, which was validated by the operational actors in the field.

In the CED approach, we have seen that it represents a number of advantages, particularly in terms of its speed and ease of implementation by teams. However, we have seen two very significant disadvantages. Indeed, the results do not systematically lead to the root cause of the problem (Doggett et al., 2004) and exchanges during the implementation of the process are limited, resulting in reduced stakeholder support for the approach (Altigan et al., 2011).

Finally, we have seen the Quick Scan method that offers a mixed quantitative/qualitative approach. We found here that despite its *a priori* comprehensive nature, this approach had significant implementation times and serious handling difficulties. On the other hand, although the approach claims to be a mixed approach, we found that the qualitative information is actually derived from quantitative data.

In the following table, the main characteristics of these methods are summarized according to the criteria mentioned in the articles cited above:

Criteria	CED	Quick Scan	CRT
Ability to make robust diagnosis	Low	Medium	High
Level of experience and expertise required	Low	High	High
Time to perform	Fast	Long	Medium

Figure 14. A comparison of diagnostic approaches

Taking into account the elements presented in the above table, the approach envisaged for the future consists in trying to take advantage of and above all to improve the CRT method which seems to have the greatest potential in regard to the main challenge of the present research project, namely: to develop an innovative approach for identifying and characterizing the dysfunctions of companies producing goods or services, in order to quickly establish an inventory of the situation to support the development of an operational progress plan.

Ultimately, our work therefore consists in developing a robust and rapid qualitative diagnostic solution, based on the precepts of the CRT and aimed at removing its main imperfections: the need for a high level of expertise, lengthy implementation times, and limited accessibility.

4. The Logical Thinking Processes Methodology in Depth

1. General description of the method

The method of *Thinking Processes* was first explained in “The Goal”, (Goldratt, 1998). This is a problem-solving method. The goal is, from a list of symptoms, to lead to the heart of a conflict which is at the origin of all the symptoms mentioned. Then, it is a question of finding the solution and checking that it solves the problem in order to finally construct the action plan.

One of the founding principles of this approach is that it integrates a change management process directly into its resolution process. Indeed, all the tools backed by this method assume that there are 3 levels of resistance to change:

- We do not agree on the problem;
- We do not agree on the direction of the solution;
- We do not agree on how to implement the solution.

Starting from this constant, the method proposes to use a sum of tools, called trees and clouds of conflict, as described in the book “It's Not Luck” (Goldratt, 1998):

- The Current Reality Tree (CRT): This aims to document the current reality of the studied system based on the given symptoms;
- The Conflict Cloud: This forms the basis of the CRT. It represents the major conflict in which the system finds itself. It is worth noting that the method mentions that these conflicts can be grouped into a core conflict cloud;
- The Future Reality Tree (FRT): When the conflict diagram has been resolved, the user has a number of potential solutions. The purpose of this tree is to “inject” these solutions in order to verify that they will generate the expected effects;
- The Prerequisite Tree (PRT): Once the solution and the complementary actions have been identified, it is necessary to build the plan to move from situation A to situation B. This is the role of the PRT.

As Lisa Scheinkopf mentions in her book, “Thinking for a Change” (Scheinkopf, 1996), the sequence of work is as follows:

1. Establish and clarify the list of symptoms;
2. Connect the different symptoms together;
3. Identify source conflicts with the Conflict Cloud;
4. Build the core conflict;
5. Verify/review the consistency of the Current Reality Tree.

According to (Dettmer, 1995), the symptom corresponds to a very specific definition. This must be something from which the system suffers and which, if left unresolved, could call into question the overall purpose of the system. For example:

- “We don't have a schedule” is not a symptom. Indeed, it does not express a negative impact on the system and in addition, it induces a solution: to have a schedule;
- “We lose market share” is clearly a symptom. If this fact continues, the main objective of the company can be clearly called into question. Thus, we have something that hurts and we cannot longer continue in this way.

Generally, it takes between 7 and 10 symptoms (Goldratt, 1998) to begin the following sequence: linking the different symptoms together, which consists in constructing the Current Reality Tree (CRT).

The exercise here is different. It is a question of taking the list of symptoms and seeing if any links exist among them.

The question here is to determine, through a logical construction of cause and effect, whether the different symptoms can be linked together. If I have symptom [A], then I suffer from symptom [B] because [C]. Thus, by linking the different symptoms, we will end up with a tree of causes connecting all the symptoms:

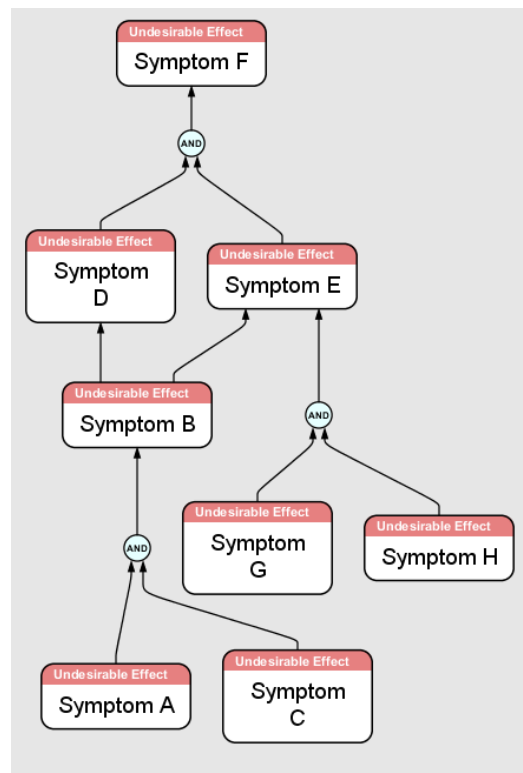


Figure 15. Schematic representation of a Current Reality Tree

For example, suppose we have the following list of symptoms:

- A. Our customers systematically receive late deliveries;
- B. Our company loses market share;
- C. Our manufacturing/delivery cycles are long compared to the needs of the market;
- D. Our finished products are out of stock;
- E. Our suppliers systematically deliver late;
- F. Our transportation costs increase.

It is easy to imagine a link between element C and element B. Indeed, if “our manufacturing/delivery cycles are long compared to the needs of the market” then “our company loses market share”. Another example could be: If “Our Suppliers systematically deliver late”, then “our transportation costs increase”.

The purpose of this step is to create what will be called the CRT, where these symptoms will be globally linked together.

Before proceeding to the next step of identifying source conflicts, there is a control mechanism unique to this method for verifying the veracity of the connections that have been created: the Categories of Legitimate Reservation (CLR). If we take our first example: If “our manufacturing/delivery cycles are long compared to the needs of the market” then “our company loses market share”, this is true under certain conditions:

- If the delivery cycle is an important criterion for the customer;
- If competitors are faster than us.

Indeed, if “our manufacturing/delivery cycles are long compared to the needs of the market”, if “the delivery cycle is an important criterion for the customer” and if “competitors are faster than us”, then “our company loses market share”.

It is these CLRs that allow us to complete the missing links among our different symptoms. There are several types (Dettmer, 2007):

- CLR #1: Clarity: The content of the symptom is not understandable.
- CLR #2: Entity Existence: The content is understandable but does not exist in the system. For example, when we say that we are losing market share, it might be appropriate to justify this position.
- CLR #3: Causality Existence: In this case, the existence between the two symptoms is questioned.
- CLR #4: Causality Insufficiency: There is a link between the two symptoms but one or more elements that reinforce these links are missing. This is exactly what is described in the previous example.
- CLR #5: Additional Cause: the link between the two symptoms exists but there is another symptom that generates the same effect independently of the other. For example, “We are more expensive than our competitors” does not need to be connected with “we have a manufacturing/delivery cycle that is long compared to the needs of market” to result in “we lose market share”.
- CLR #6: Cause/Effect Reversal: Here, we reverse the causes and consequences between two symptoms.
- CLR #7: Cause Sufficiency: We have created a link between two symptoms but the cause leads to another symptom previously unidentified by the team.

At this point, we have all the symptoms that are related to each other. The next step is to determine the root causes.

2. The Conflict Cloud

In this tree, the symptoms are all related but there are symptoms that have no antecedents. It is therefore from these specific symptoms that we will determine the potential root cause through the identification of a core conflict.

The core conflict is also called a Conflict Diagram or a Conflict Cloud. This represents a dilemma in which the organization finds itself, and is represented as follows:

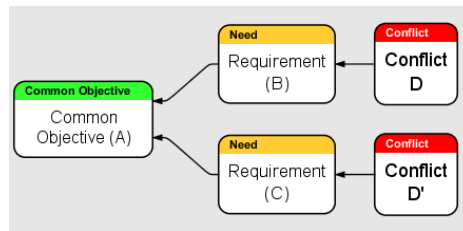


Figure 16. Schematic representation of a Conflict Cloud

- The letters D and D' represent the core conflict in which the company finds itself.
- The letters B and C represent the objectives inherent in the content of D and D'.
- The letter A describes the common purpose that connects B and C.

The manner in which this Conflict Cloud is constructed is shown below. It was documented in (Fedurko, 2015):

1. We take a symptom that has no antecedent in the previously written tree;
2. We look for the action that generated this symptom → This is written in box D;
3. We look for the opposite action to box D → This is written in box D';
4. The contents of box B and C are identified through two questions:
 - What is the purpose of the action contained in D? → Box B will then be completed.
 - What objective is at risk if only action D is taken? → Box C will then be completed.
5. We identify what the common objective is for the system to satisfy B and C.

Once these elements have been established, the conflict must be proofread to verify its overall consistency. To do this, we proceed as follows (Fedurko, 2015):

- In order to obtain [A], one must [B] and [C];
- In order to obtain [B], one must [D];
- In order to obtain [C], one must [D'].

Here is an example with the following symptom: “transportation costs increase.” Assuming it is a symptom without an antecedent, the steps mentioned above will be repeated:

1. We take a symptom that has no antecedent in the previously written tree: “Transportation costs increase”;
2. We look for the action that generated this symptom. → This is written in box D: “The company agrees to deliver partial orders to our customers”;
3. We look for the opposite action to box D. → This is written in box D': “The company delivers complete orders to its customers”;
4. The content of boxes B and C are identified through two questions:
 - What is the purpose of the action contained in D? → This will fill B: “The company immediately sells/delivers the products it has in stock”.
 - What objective is at risk if only action D is taken? → Box C will then be completed: “Satisfying the client's request”.
5. We identify the common goal for the system in satisfying B and C: “The company earns money, now and in the future”.

The way to interpret the Conflict Cloud described in figure 7 (Chapter II) is as follows: In order to make money, now and in the future, the company must immediately sell the products it has in stock and satisfy customer demand. Therefore, in order for the company to immediately sell

the products it has in stock, the company must deliver partial orders. But at the same time, in order to satisfy customer demand, it is necessary for the company to deliver complete orders.

These steps will be performed for each symptom without predecessors and then they will be connected to the tree created initially. Thus, the challenge of this step is to link the basic conflict with the symptoms identified in the first step.

If we take our example again, we have the following relationship: “If the company delivers partial orders” then “transportation costs increase”. However, we can also see that this conflict is related to other symptoms: If, on the one hand, “the company delivers partial orders”, and at the same time, “it delivers complete orders”, this may indicate:

- That some products are out of stock → Symptom D;
- That customers receive late deliveries → Symptom A.

By building these conflicts on symptoms without antecedents, we have a sum of conflicts, usually two or three, which explains all the symptoms identified in the system.

At this point, we have produced a complete CRT. We will now briefly describe the steps that follow the process of the *Thinking Processes*, even though this does not fall directly within the scope of this research (since it deals with the resolution of the problem and not its diagnosis):

- Resolve the Conflict Cloud;
- Construct the Future Reality Tree;
- Construct the Prerequisite Tree.

3. Resolving the Conflict Cloud

At this stage, we will look for the missing element that connects all the symptoms and will therefore validate the treatment of the problem (Fedurko, 2015). This is exactly the purpose of this resolution phase. Indeed, the approach is to reveal the underlying assumptions that caused the links to be linked together. The questions to ask are (Fedurko, 2015):

- What are the reasons that both B and D, and C and D' are connected?
- At what point do D and D' come into conflict?

Once these reasons are revealed, they are called the underlying assumptions. We will look for which assumptions are actually false in the studied system (Dettmer, 2007).

Then, from these false assumptions, we will be able to inject/propose solutions that invalidate the assumptions and help to solve the underlying problem.

We will look again at our example (Figure 7, Chapter II) and apply this to only one branch:

In order to immediately sell products in stock, it is necessary to make partial deliveries because:

- Even a partial delivery generates sales, and therefore turnover;
- The customer will partially use the product;
- When I sell a stored product, I make a sale while also reducing my inventory. Therefore, I make money.

What we call a partial delivery is this: When the customer places an order and their supplier cannot deliver everything, the latter will offer the customer a partial delivery that will contain

only a part of his order. The rest is delivered later, as soon as the missing products become available again.

Of the three points mentioned above, the last one seems to be true in all cases. However, the first two points are more debatable. For example, just because you generate partial sales doesn't mean the customer will pay you immediately. You can have a contract that triggers a full receipt payment. The other point is that the customer may need his entire order for a specific purpose and therefore the product cannot systematically be used partially.

With these erroneous assumptions, we can see that partial delivery is possible but that some assumptions justifying it are not. It is at this point that the team must look for a solution. In this specific case, an extremely simple solution could be: "When taking the order, the buyer confirms whether he wants a complete or partial delivery". With this solution, the company can deliver in part or in full while having asked its customer what he is willing to accept.

Generally, in this phase, several solutions will be proposed. These solutions are called "Injections". These injections must be confirmed. In other words, it must be verified that the proposed ideas:

- Will have a positive impact on the system;
- Will not generate serious side effects.

This control phase is carried out in the Future Reality Tree.

4. Constructing the Future Reality Tree

The Future Reality Tree verifies that the injections used for solving the problem will have the expected positive effect and not generate new negative effects. In order to achieve a Future Reality Tree, we need injections and the Current Reality Tree.

In the first step, the symptoms must be converted into something positive that we will call desirable effects (Dettmer, 2007). Once these symptoms are written positively, the group must link these elements together in the same way that was used to construct the Current Reality Tree. Then, we must link the selected injections with the desirable effects. In the same way as for the Current Reality Tree, we will use the Categories of Legitimate Reservations in order to consolidate the Future Reality Tree.

If we take our example again, we must convert the symptoms of the Current Reality Tree into something positive. For example:

- A. Customers systematically receive late deliveries → Customers receive deliveries on time;
- B. Our company loses market share → Our company gains market share;
- C. Our manufacturing/delivery cycles are long compared to market needs → Our manufacturing cycles are reduced/in line with the market;
- D. Our finished products are out of stock → The products are at the right level of stock;
- E. Suppliers systematically deliver late → The suppliers deliver on time;
- F. Transport costs rise → Transport costs fall.

These converted symptoms are called desirable effects (Dettmer, 2007).

In the same way as for the Current Reality Tree, we will see how these desirable effects are related to each other. Then, when all the desirable effects have been connected, we will take the injections and see how they are related to the different desirable effects established previously.

The Logical Thinking Processes Methodology in Depth

Thus, we get a tree that, at its base, contains the injections that are then connected to the generated desirable effects.

This first step will make it possible to verify that the injections generate positive effects for the studied system. However, some of them may be incomplete or cause other problems.

To detect this, it is necessary to divide up the Future Reality Tree and let oppositions be generated. This is called the “Yes, but...” phase. The aim here is to raise objections to the proposed injections.

Here is an example of the solution mentioned earlier: “When taking the order, the buyer confirms whether he wants a complete or partial delivery”, and now we will try to construct part of the Future Reality Tree.

If “at the time of taking the order, the buyer confirms whether he wants a complete or partial delivery”, then the supplier can inform us whether he will deliver the complete or the partial order. If the supplier is able to do this, we will be able to anticipate the transport that we are going to need. If we are able to anticipate the transport that we are going to need, then we can negotiate certain conditions of transport with the carrier. If we are able to negotiate, then our transport costs will be reduced.

Thus, from an injection, the expected positive effects can be verified. However, in reading this reasoning, you may have thought, “What is written is true unless something else happens.” This is exactly the “Yes, but...” phase. For example, we could equally challenge the last statement by saying that it is true, but that suppliers could warn us too late that they are going to deliver to us in part or in full. And if they warn us too late, we can no longer anticipate and negotiate effectively, and therefore the expected positive effect will disappear.

It is therefore necessary to consolidate the initial solution, which is necessary but not sufficient. For example, we could add: “The procurement team sets up a review 3 weeks before the delivery date to confirm the status of the order and the shipping conditions”.

Thus, we end up with the following sequence: If “at the time of taking the order, the buyer confirms whether he wants a complete or partial delivery” and if “the supply team sets up a review 3 weeks before the delivery date to confirm the status of the order and the shipping conditions”, then the supplier will be able to inform us whether he will deliver the complete order or the partial order. If the supplier is able to do this three weeks in advance, we will be able to anticipate the transport we are going to need. If we are able to anticipate the transport that we are going to need early enough, then we can negotiate with the carrier certain conditions of transport. If we are able to negotiate, then our transport costs will decrease.

Once this step has been fully completed, we will thus have a Future Reality Tree with a sum of injections that:

- Verifies that our ideas solve the problem;
- Does not generate any other problems.

The next step is to finally put the injections into an action plan that makes sense for the organization. This is the purpose of the Prerequisite Tree.

5. Constructing the Prerequisite Tree

The Prerequisite Tree is the last step in this process. It consists in focusing on the “how”, while the previous steps focused on the “what”. The deliverable of this phase is to obtain the sequence of the action plan of injections to be implemented. This process is also divided into two parts because it is intended to:

- Establish the action plan;
- Verify that the implementation of the action plan will not generate specific difficulties.

The procedure is as follows (Dettmer, 2007):

- Collect all the injections that were issued to resolve the problem;
- Put the injections in chronological order. To perform this step, we proceed as follows:
 - What do I need to start implementing the 1/2/3...x injection?
 - What did I concretely put into place when I finished my 1/2/3...x injection?
- At this point, we have all the deliverables and input data for each of the injections.
- The ultimate step is to link all these input/deliverable/injection data together with the same logic of “If...Then...If”.

If we take our example again, to make a Prerequisite Tree, we must:

- Clarify the expected deliverable for each injection. What will it mean when this injection has been implemented?
- Sequence the different injections to create an action plan. For example:
 - The buyer's deliverable that confirms whether his order will be partial or complete could be: “The delivery type field has been entered into the ERP”;
 - The procurement deliverable that sets up a review 3 weeks before the delivery date could be: “The report of the supplier meeting indicates the list of partial and complete orders”.

Thus, we realize that the second proposal precedes the first: if the report indicates the list of partial and complete orders, then the buyer will be able to confirm whether his order will be partial or not by entering the type of delivery field in the ERP. By creating this sequence, we write a sequence of rational action that is more logical for everyone.

6. Thinking Processes: a particular Bayesian network?

When the Thinking Processes method is analyzed, it is clear that the approach is strongly linked to that proposed by Bayesian networks. Indeed, according to Stephenson et al. (2000), “the Bayesian network is a system representing knowledge and making it possible to calculate conditional probabilities providing solutions to different kinds of problems.” It has the particularity of simultaneously considering expert knowledge with accumulated experience in the data to be extracted (Wang et al., 2003).

These two peculiarities make it possible to create a Bayesian network that is divided into two elements:

- The graph of the model;
- The statistical elements of the data to be linked.

A Bayesian network can be represented as follows:

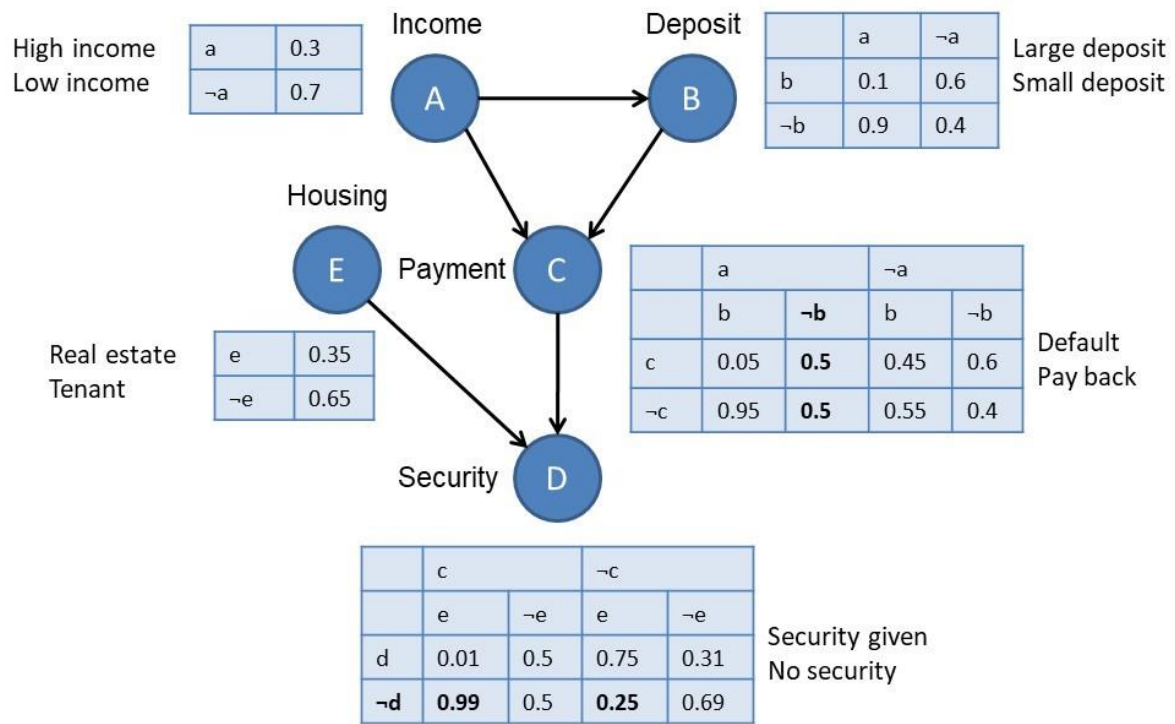


Figure 17. Examples of a Bayesian network (Stephenson, 2000)

In figure 17, we see different causal links between events as well as elements of statistics associated with the different choices. This combination of events and statistical links leads to node D and thus to an assessment of the security risks taken.

In this figure, we seek to model the links between people's incomes and how they save this income (A & B nodes), taking into account the risks taken concerning their real estate. Indeed, this income and savings are used to generate payments (C nodes). If we take the combination of income, savings and payment along with the share of the owners (node E), then we can identify the level of protection of the individual as regards his property.

Bayesian networks are often associated and/or compared with other representative models such as: decision trees, neural networks, failure trees and logic models (Chickering, 2002). This networked approach serves many use cases, including (Chen et al, 2012):

- Acquiring knowledge easily from heterogeneous data sources in order to synthesize it and provide a workable representation of a system's behavior;
- Representing knowledge in a formal and explicit way so as to facilitate updating and utilization.

As for the systems studied, Bayesian networks are applied in a number of sectors (chemistry, oil & gas, health, etc.) and on a number of application topics, including diagnostics (Marcot et al., 2019). However, the literature indicates that in the field of industrial diagnostics, Bayesian networks focus mainly on machine diagnostics, safety risks, quality, etc. (Stephenson, 2000). Finally, the implementation of “pure” Bayesian networks in the case of organizational manufacturing or supply chain diagnostics does not seem to have been seriously investigated.

Compared to the TP method, there is another element on which Bayesian networks stand out, and these are acyclic elements (Jaakkola et al., 2010). In these, there are no loops between the different elements of the network. For example, in the previous example (Figure 18), it is

impossible for D to be connected to B. This is not the case for TPs which mention the presence of its loops within the different trees. However, some articles mention uses of Bayesian networks adapted to partially cyclic environments (Acid et al., 2003).

In addition, there are some limitations noted in the literature regarding the use of Bayesian networks that may cast doubt on their relevance in the strict case of industrial diagnostics:

- Ability to generalize the model: This type of model is very useful for analyzing specific systems. However, it seems quite difficult to use a sum of Bayesian networks to arrive at a general representation of a complex system. Compared to our thinking on diagnoses, this is not a real problem in itself because the diagnosis is made on a defined scope. However, organizational diagnostics are often performed on complex systems (Chen and Pollino, 2010).
- Mathematical dimension not very intuitive: Although the graphic side allows a translation of mathematical elements, (Stephenson, 2000) and (Chen and Pollino, 2012) mention that the mathematical mechanics behind the representation are complex to grasp and may deter the use of the approach. (Naim et al., 2002)
- Limited legibility of the resulting graphs: Even if the previous figure seems readable, it is necessary to imagine oneself in a complex system with multiple parameters to integrate. In this type of configuration, graph readability can be particularly difficult to achieve (Naim et al., 2002.)

Finally, the analysis of the TP method vis-à-vis that of Bayesian networks demonstrates similarities in their respective characteristics and assets. Indeed, both approaches seek to use knowledge to describe a behavior and show the origin of certain events. However, Bayesian networks have significant limitations that reduce their relevance with regard to TP for the realization of industrial diagnoses. Thus, Bayesian networks:

- Do not have an accessible generalization model. This makes it mandatory to have a business expert in order to carry out the analyses;
- Have an underlying mechanics of trees that is not explicit, requiring the use of experts and limiting potential attachment to results;
- Propose trees generally perceived as difficult to read even when they are labelled.

7. Synthesis and perspectives

To summarize, the approach of the *Thinking Processes* is to:

- Agree on the problem by identifying the symptoms and conflicts in order to construct the Current Reality Tree;
- Agree on a solution by finding different solutions and testing them through the use of the Future Reality Tree;
- Agree on the sequence of actions to be carried out for implementing the different solutions that have been envisioned.

As mentioned in the previous chapter, this approach is certainly effective but it has a number of difficulties:

- A high level of skills required (Doggett et al., 2005);
- Significant time needed to complete the process (Doggett et al., 2004);
- Some difficulty in using the tools at first glance (Scheinkopf, 1999);
- A weak visual approach (Doggett et al., 2005);

- A lack of categorization of possible causes, such as in the 5M in the Ishikawa diagram. (Liliana, 2016).

In addition, the entire process is to be carried out for each subsystem studied. So, if you were to diagnose multiple market segments of the same company, you would need to duplicate this process for each of them. What we call a market segment is selling the same product or product family, but in a different way. For example, the Amazon company has at least two market segments, Amazon Prime and Non-Prime, where both provide access to the same product but with different delivery times.

Users of this method have often found (Smith, 2019), (Scheinkopf, 1999), (Dettmer, 2007), that within the same production system, even though there are different market segments, there is a certain homogeneity in the conflicts deduced from the symptoms (Smith, 2019). This communality of conflicts was modeled by (Smith, 2019) as follows:

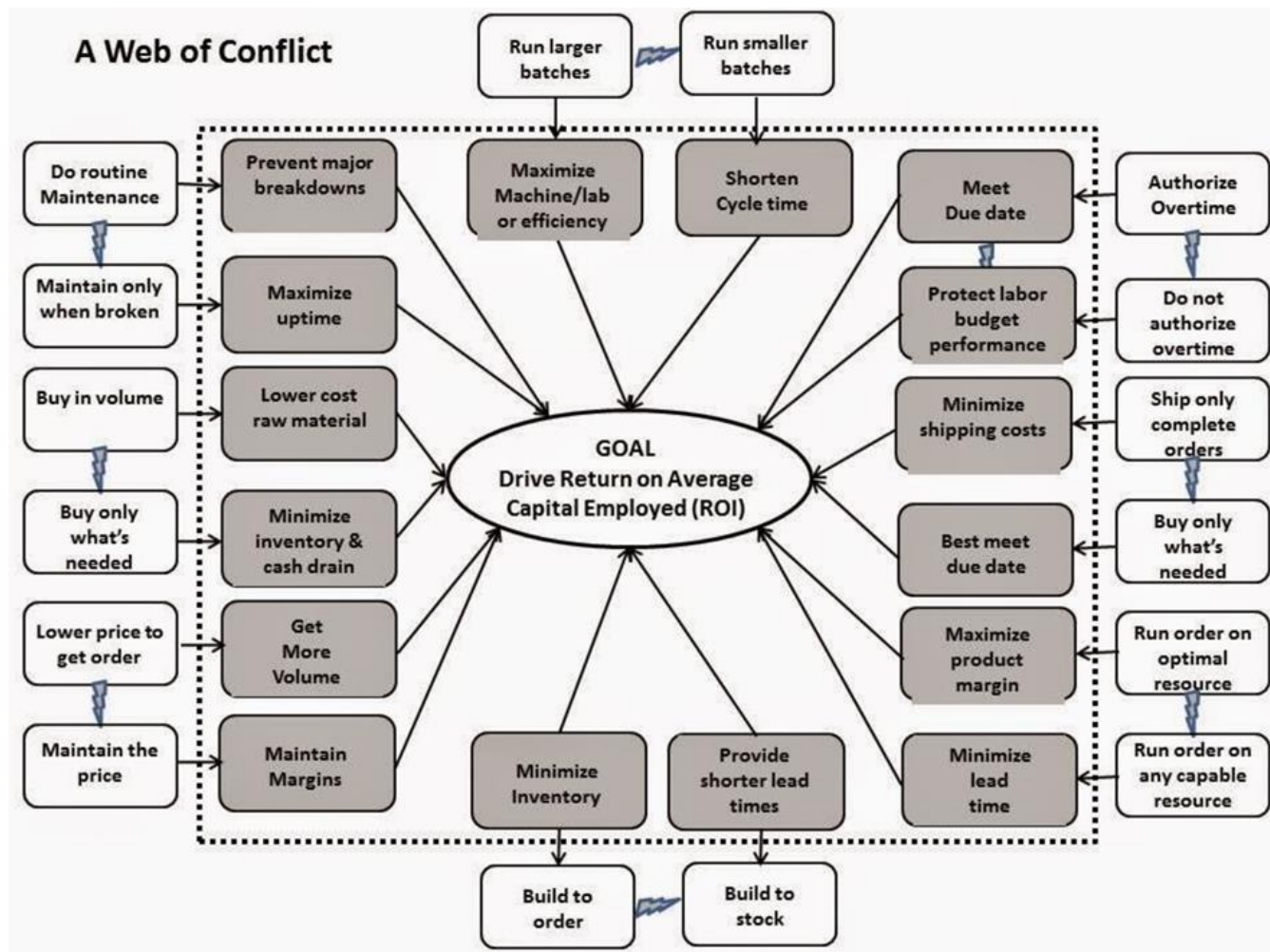


Figure 18. A Web of Conflict (Smith, 2019)

The author proposes 8 generic conflicts that would be inherent in all companies producing goods or services (MTO, MTS, ETO):

1. Increase batch sizes in order to increase resource efficiency on the one hand, or on the other hand do not, in order to reduce cycles;

2. Allow overtime to satisfy customer demand on the one hand, or on the other hand do not, in order to protect operating expenses;
3. Ship complete orders to minimize transport expenses on the one hand, or on the other hand do not, in order to make sales faster;
4. Work with the most efficient resource to maximize the product margin on the one hand, or on the other hand do not, in order to minimize the cycle;
5. Manufacture to stock or to order to offer shorter cycles on the one hand, or on the other hand do not, to minimize stocks;
6. Maintain sales prices in order to protect margins on the one hand, or on the other hand do not, in order to increase sales;
7. Buy in volume in order to reduce purchase costs on the one hand, or on the other hand do not, in order to minimize stocks and cash consumption;
8. Carry out preventive maintenance in order to prevent major breakdowns on the one hand, or on the other hand do not, in order to maximize the use of machines.

Here we have the beginning of a solution to one of the difficulties of the *Thinking Processes* approach, which is the lack of categorization of possible causes. However, the model suggested in the previous figure by (Smith, 2019) is a simple, isolated experimental observation. It has never before been scientifically proven or even documented. Our work focuses on, among other things, this ambition.

Thus, one of the objects of this doctoral thesis is to verify the proposition that these 8 conflicts are inherent in all production systems. In addition, we want to create a decision support tool that would allow any user to benefit from the method without having to acquire advanced expertise upstream on the one hand, and without having to devote too much time on implementation on the other hand. In the rest of this chapter, we propose a description of this contribution by developing (i) the overall functional architecture of the tool, (ii) the technical architecture and finally (iii) the associated implementation process.

In order to clarify the vocabulary and associated acronyms in the rest of the document, we will refer to the following terminology:

- CRT will stand for Current Reality Tree and will refer to the graphic representation of the cause-and-effect links between the different elements.
- Diagnosis will be defined as the fact of drawing up an inventory in terms of the content and links between the different symptoms in order to reach the origin of the conflict.
- The notion of conflict will refer to the inherent contradiction in the system. As in Figure 17, it is a question of highlighting the different conflicts that we will present in the rest of the document.

CHAPTER III. DECISION SUPPORT SYSTEM PROPOSAL

“Things are not where we want them to be just because we want them to be ... that doesn't mean they're where they should be ...”

Dr. House

In this chapter we will describe precisely the decision support system that we have created to answer our research problem. This chapter is divided into two parts.

First, we will describe the functional architecture of the original method we are proposing. In the second part, we will describe the technical architecture of the decision support tool we have designed, developed and implemented to address the problem described in Chapter I.

On the basis of the results presented in the previous chapter, we have chosen to base our contribution on the method of *Thinking Processes*, specifically on the part relating to the implementation of industrial diagnostics, namely the development of a Current Reality Tree. We will therefore begin by further developing this method in order to grasp all its particularities.

1. Decision Support System Proposal

1. Functional architecture

A decision-making system is based on the duality between the user and the system itself. So schematically, the functional architecture of the decision-making system we have created is as follows:

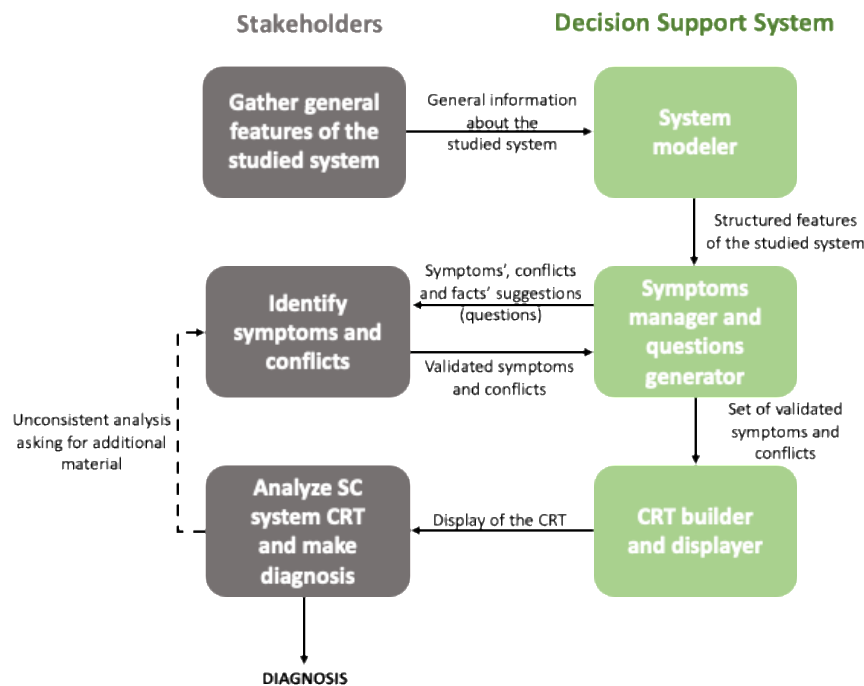


Figure 19. Representation of a decision support system

As demonstrated previously, one major issue with the CRT methodology is that the process takes a long time to execute, particularly regarding the time needed to construct the CRT itself. This is mainly explained by the fact that the combinations of potential symptoms, facts and conflicts are numerous and depend on many features and behaviors of the studied company.

Consequently, our proposal recommends speeding up the process by questioning the user in order to focus only on the symptoms, facts and conflicts which could occur in relation to the gathered knowledge about the studied system. In essence, the decision support system (DSS) will start by asking the user about some key features of the company. This information mainly regards the name of the company, the scope of the improvement project and material-flow strategies (MTS/MTO, ETO). Then, the DSS will ask the user questions in order to help identify symptoms, facts and potential conflicts. A first set of questions will be generated based on the key features indicated during the first step. Then, questions will be adapted on-the-fly, depending on the answers given by the user in order to avoid orienting the user in useless directions. This is done to optimize the time needed to gather the necessary information for constructing the CRT. Once the DSS has gathered enough information to set up the CRT of the studied system, it will then automatically construct and display it. The user will have the possibility of updating the result by directly modifying the CRT (e.g., adding/removing some elements) or by going back to the previous step in order to indicate additional symptoms, facts

Decision Support System Proposal

or conflicts. Finally, based on the resulting CRT, the user will have the opportunity to formulate his/her qualitative diagnosis to support his/her improvement step.

As mentioned in the following figure, the functional architecture is composed of 3 types of components: an interface, services and a database.

- The interface component relates to the necessary user interface functionalities as with any type of DSS. There is no specific innovation on this part.
- The database components are at the core of the system as they include not only the usual database for the storage of collected information, but also a specific database known as the “Generic Reality Tree”. This is another major contribution of the proposal. (SO1 and TO1)
- The service components include some important contributions from specific algorithms allowing useful knowledge to be gathered and utilized for the automatic generation of the CRT. This is one of the main contributions of the proposal (SO2 and TO2).

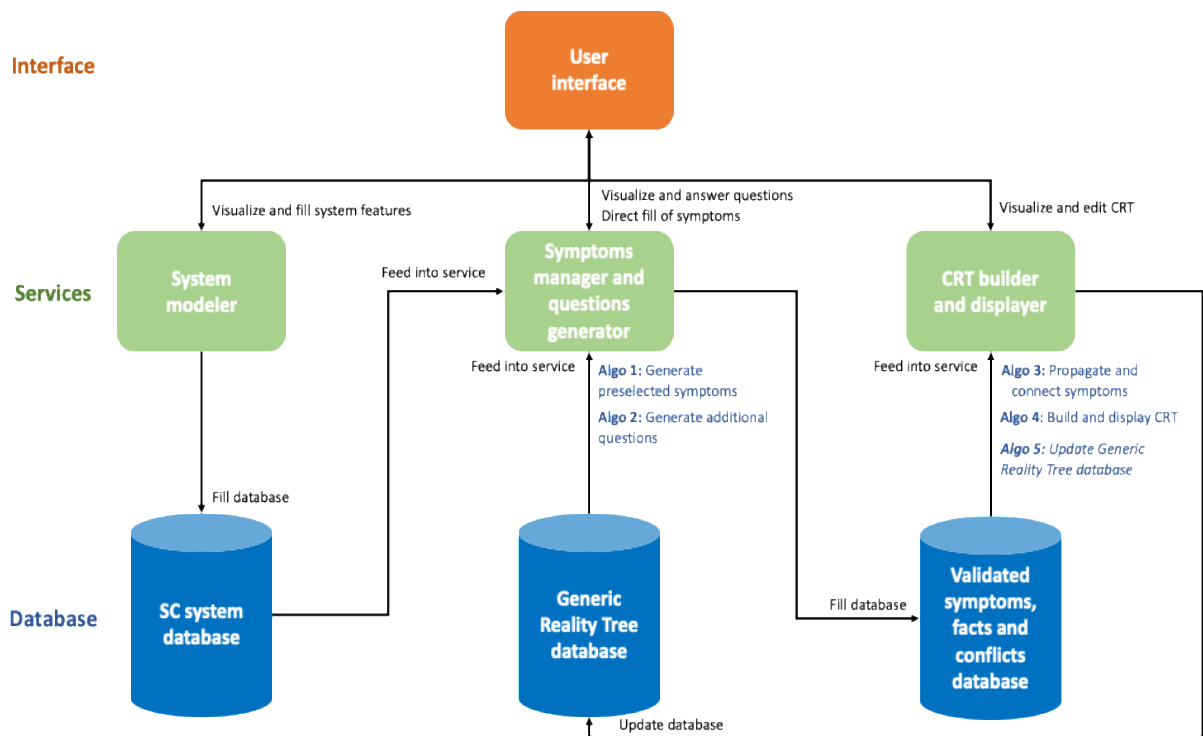


Figure 20. Representation of the building blocks for a decision support system

Now we will look in more detail at each of the functional components of the proposed system.

At the database level:

- SC System Database: Represents the informational elements of the studied system; the name of the company, the types of flow, etc.;
- Generic Reality Tree: Represents the knowledge bases that connect all the symptoms to the various suggested conflicts. This basis, a central element of our proposal, is the subject of a complete chapter (Chapter IV);
- Validated symptoms, facts and conflicts database: This will represent the knowledge accumulated by the tool, which will allow its questioning system to be refined and will therefore increase its speed.

At the service level:

- System modeler: This is the service that will capture the data. This is a type of form;
- Symptom manager and question generator: This is the heart of the tool. Indeed, this service aims to collect the different symptoms of the user. It is also the service that will allow the user to validate or invalidate the symptoms suggested by the knowledge base;
- CRT builder & displayer: This is the service that will display and, in particular, format the results of the symptoms and conflicts according to the answers given. To summarize, this is this service that will allow the user to see the final result of his diagnosis and to begin his analysis.

At the level of algorithms:

- Algorithm 1 - Generate preselected symptoms: Depending on the data entered in the modeler, this tool will preselect a list of potential symptoms. When the user starts entering their symptoms, they will access this information and can select symptoms that may or may not be part of the list;
- Algorithm 2 - Generate additional questions: When the user selects the symptoms, the tool will look for any potential conflicts they are connected to by identifying the associated logical sequence. Once this logical sequence has been identified, the tool will check with the user regarding the relevance of the identified sequence. The user will be able to answer “Yes/No/I don't know”. This response will be fed back into the same algorithm until the tree has been consolidated. However, we will see in Chapter V that we have put into place a mechanism to accelerate this step. Thus, this algorithm makes it possible to clearly identify the contents of the tree;
- Algorithm 3 - Propagate and connect symptoms: The tool will retrieve the information from the previous algorithm and create all the associated links;
- Algorithm 4 - Build and Display CRT: The tool will display the consolidated tree in its entirety by formatting it. For example, in terms of formatting, when the user selects a conflict at the base of their tree, the tool will highlight the associated symptom sequence;
- Algorithm 5 - Update generic tree database: the algorithm aims to allow the user to make changes to the proposed tree in terms of content and links. These changes are then saved as a complementary field in the generic database. This will thus:
 - Increase the richness of the vocabulary when searching for symptoms;
 - Refine the questioning mechanics of Algorithm 2.

2. Technical architecture

Given the ambitions for user accessibility targeted by the project, the databases, the services and the algorithms to be implemented, the following technical choices have been made to support the technical developments of the decision support system:

- JavaScript: This tool provides an integrated web for users on any type of web explorer. Thus, anyone with an internet browser will be able to connect and carry out their diagnosis;
- Oracle: Given that a knowledge base will be created that we want to be modular in the event that symptoms/conflicts are incomplete and/or erroneous, the Oracle solution provides the greatest capabilities for creating and modifying databases. In addition, this solution works in close connection with the JavaScript language. Oracle interfaces are lightweight and fast, so it is easy to have a large number of users in parallel. Oracle databases are also easier to modify because there is a very large community of practitioners who can help solve particularly complex problems;

- Orient DB: As we have seen earlier, one of the issues to be solved is the visualization of the tree as well as its modification. Thus, we have chosen to use Orient DB technology to meet these two objectives:
 - The tree can position itself in a computer window and thus avoid a cluster of mixed arrows;
 - The user can modify the contents of the tree and adjust the database if the changes are recurring and similar;
- PostgreSQL: SQL corresponds to the computer language used. As we have seen in the previous section, the tree is based on “If-Then” logic. The SQL language is based on this same logic. It therefore seemed rational to use this technology to program our tool. In addition, PostgreSQL will serve us in the management of the questions proposed by the tool. One of our objectives is for the tool to suggest precise questions to the user. Thus, we need this technology to link the conflict knowledge base, the symptoms and the associated user interface together.

The architecture can be summarized as follows:

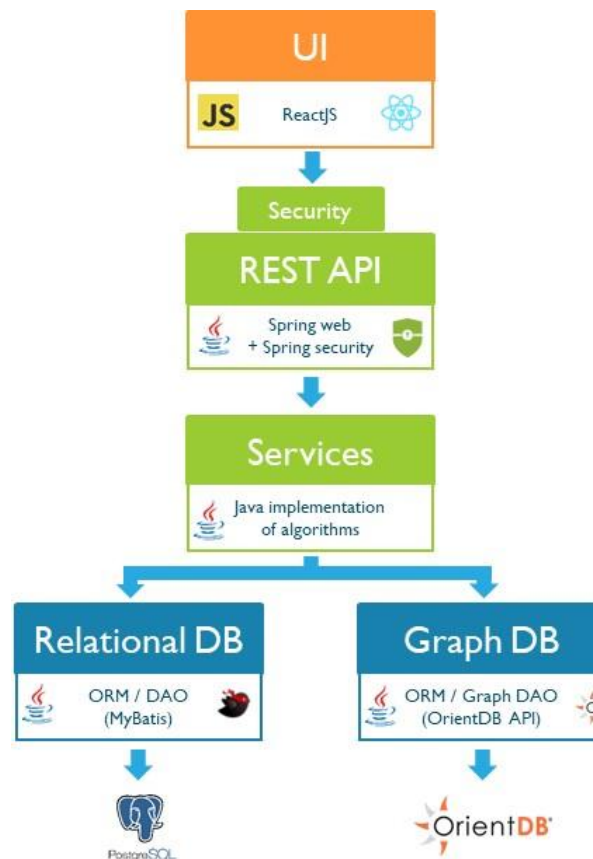


Figure 21. Representation of the IT architecture of the tool

3. Usage process

Now that we have seen the architecture of the proposed system, let's look at how a user can make use of it. In the principle of operation, we hypothesize that there will be two types of users:

- An expert in industrial organization (a consultant, for example);
- A manager of a company with extensive knowledge of the operation of the studied company.

The process is broadly the same for both actors because it differs only at the beginning of the process. Indeed, the general process of using the tool will be as follows:

1. Clarify the studied organization;
2. Collect the symptoms;
3. Check the coherency of conflicts;
4. Analyze the results;
5. Share the results.

This process can be represented by the following diagram:

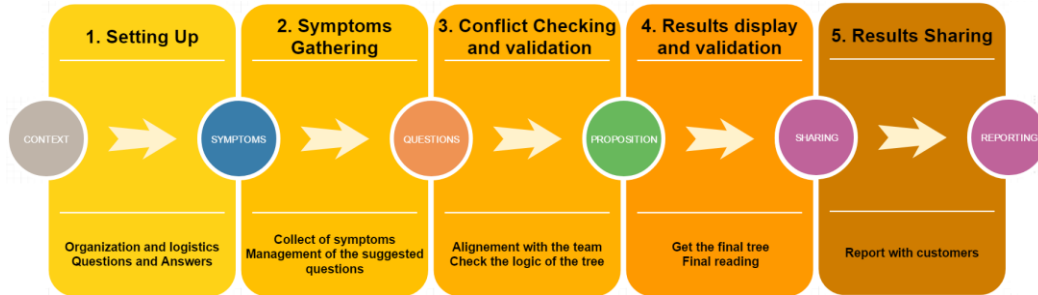


Figure 22. Description of the operating process

1. Setting up

This step consists in selecting the profile of the production system that the user wants to study. It is also a question of characterizing the product typology associated with the production system. The user will have to specify the type of generic tree the company will be based on. There will be a choice between an MTO/MTS-oriented or ETO-oriented tree (project oriented).

2. Symptom gathering

This step consists in identifying an initial list of symptoms among a set of potential symptoms from generic trees of knowledge (see Chapter IV) and/or past uses. In practice, the collection of symptoms can be done through two independent but complementary exercises:

- Interviews: The principle of the interview can consist in speaking with a panel of people on the different problems observed. With this information, the consultant can collect the most recurrent symptoms heard during the interviews. Thus, he will have a consolidated view to enter in the tool;
 - Visits to the concerned production site: Visits are a classic way for the consultant to go and observe other operational symptoms or to prepare interviews with the teams.
- ➔ It should be noted that an expert who is hired to carry out a diagnosis will probably have to conduct a site visit before the diagnosis, and he will probably have collected some symptoms during the discussions in the phases prior to the diagnosis.

As far as company managers are concerned, we believe that they know their production sites and are able to identify for themselves the symptoms of the system being studied. However, if this is not the case, interviews can similarly be conducted or meetings organized to collect information on different problems from the teams.

3. Conflict checking and validation

During this phase, the decision support system will propose the questions to which they wish to have answers in order to confirm or refute certain conflicts. The tool will thus generate the list of questions and will progressively update the list of questions as the answers are given.

At this stage, the answers to the questions should only be “Yes/No/I don't know” to confirm or not the suggested symptom. In practice, all actors will answer the list of questions on the basis of their intrinsic knowledge.

When the user answers “I don't know”, the tool will go digging into the knowledge base in order to observe past answers. Through these answers, the tool will question symptoms directly related to the answer “I don't know”.

If the user answers “Yes/No” to these suggested symptoms, the tool will consider their answers to validate or not the “I don't know” answer.

4. Result display and validation

When the previous tasks have been carried out, the decision support system is able to produce a Current Reality Tree of the studied production system. At this point, the tree is displayed as a graph on which the following actions are required:

- To arrange the different components of the tree for ease of reading;
- To read the logical sequence that makes up the tree and the symptoms;
- To possibly update some of the symptoms or links in the tree. In practice, this is a question of modifying the proposed vocabulary or creating additional links between different symptoms.

At this point, it is also possible to return to the previous step in order to remove a symptom. However, the tool allows you to make the modification directly in the tree. This feature is especially interesting when the user has answered “I don't know” and the decision support system has made the choices for him. This allows the user to see what the tool has retained or not. To make these choices, the tool will dig into the knowledge base (see next chapter) and observe the recurrence of symptoms associated with the “I don't know” response. If you selected “I don't know” for a symptom called D, but you validated the presence of symptoms A/B/C, then the tool will go to check the cases where A/B/C/D were associated together. If in 80% they were associated, the tool will validate the presence of D in the diagnosis.

5. Result sharing

This is the last step in the process. The tree has been established and checked, so it is now a matter of sharing it with the team. The reading sequence is the same as the one mentioned at the beginning of the chapter: If [Symptom 1] then [Symptom 2].

The reading is done from bottom to top, starting from the conflict positioned as low as possible on the tree. It should be noted that there is a feature that allows you to select a conflict and the tool will highlight the most recurrent sequence of symptoms associated with this conflict.

To conclude, this first section has made it possible to describe the first contribution of the research work, consisting in formalizing and structuring an industrial diagnostic approach inspired by the TP method. This proposal responds to the second scientific objective, SO2, defined in Chapter I, and takes the form of a decision support system comprising an original functional architecture and technical architecture, as well as a process of use directly inspired by the original method of TP. In the rest of this chapter, we will focus on the technical contribution of this work, which consists in concretizing the proposal for a decision support system in a usable software prototype. This second contribution, responding to the second technical objective, TO2, described in Chapter I, will address in particular the obstacles related to the automation of the reasoning of the decision support system, and in particular to the definition of the main underlying inference rules, in particular those which :

- Generate questions by studying the different possible branches;
- Offer to validate answers when the user does not know;
- Ask questions based on what has been documented in the knowledge base and other diagnoses.

2. Software Prototype

In this section, we will give form to the contributions presented earlier through a software prototype. This prototype, called DOSSARD (named after the joint project between AGILEA, IMT Mines Albi and the *Occitanie* region, which financed this doctoral work), makes it possible to encapsulate in a single software solution all the functional and technical elements developed previously.

To explain the basics of the different operating mechanics of the software prototype, we will take a simplified tree. This tree is represented by the following figure:

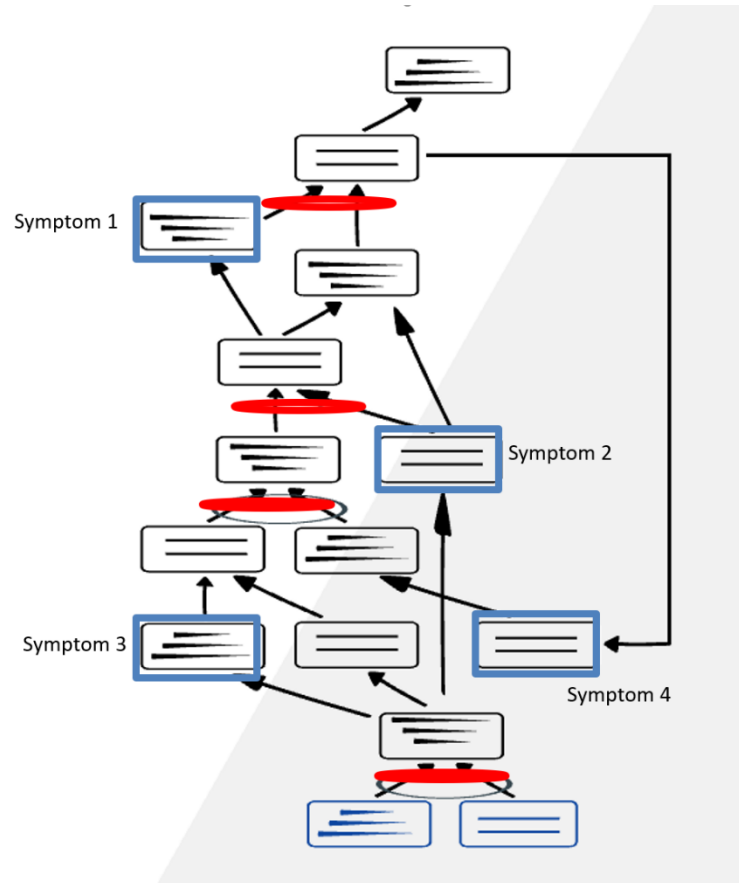


Figure 23. Simplified representation of a DOSSARD prototype tree

The different elements of the tree are as follows:

- The blue-framed rectangles represent symptoms the user has selected. It could be : The company has shortages, Suppliers are late, Sales budget are not achieved.
- The black boxes represent symptoms of our generic tree. For example, “Customers are complaining about our deliveries”, “The company has extra cost of express transportation”.
- The red bars represent the convergence points of the tree. These are the points where several symptoms converge on another common symptom. For example : If “the company has shortages and Customers are complaining” then “the company must spend extra cost of express transportation”. It is a “and” connection.
- The blue boxes represent conflict sources. For example a possible conflict could be : “Deliver complete customer order” vs “Deliver partial customer order”

1. Main functional capabilities of the prototype

Three key functional blocks are to be noted regarding the operation of the DOSSARD software tool:

- Generating questions;
- Displaying the tree;
- Links between the tree and the knowledge base.

1. Generating questions

The purpose of this paragraph is to explain how the DOSSARD tool will generate the question list for users. The user selects the symptoms by means of the interviews that have been carried out. These symptoms are represented by the blue boxes and are called symptoms 1/2/3/4.

The first task that the software tool will perform is to identify the links between the symptoms and then look at which conflict these symptoms are most related to. In our case, the algorithm will identify the following branches (in green):

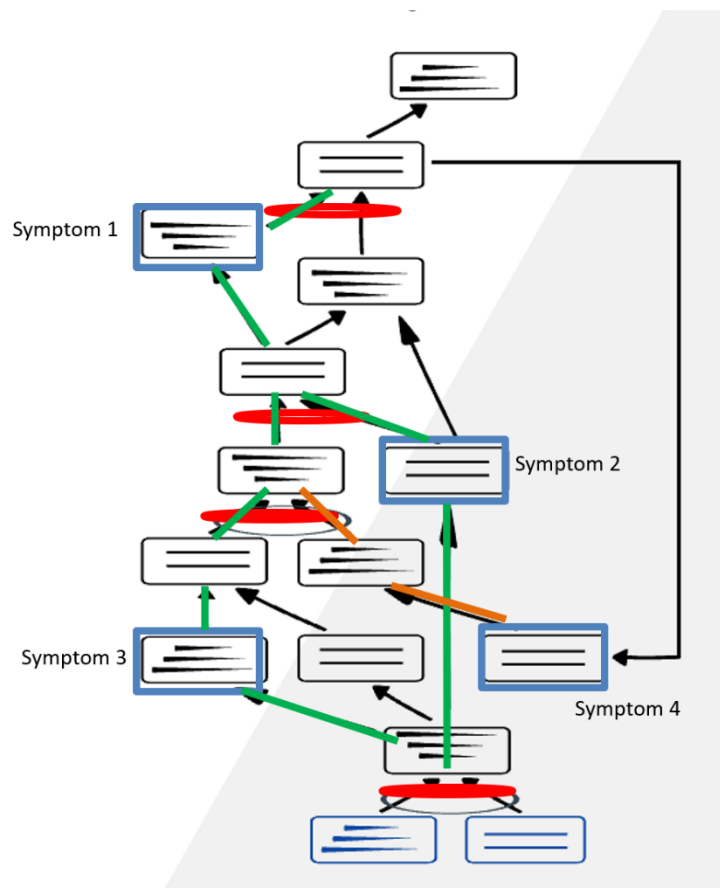


Figure 24. Simplified representation of the links between symptoms of a DOSSARD prototype tree

In these green branches, the tool will identify the number of symptoms present on the branch reported by the user.

Then, through a progressively decreasing quantity of groups of symptoms, the tool will ask the user to check the convergent symptom represented by the box located above the red bar. Once the user confirms the presence of the symptom, the tool continues to suggest symptoms with the previous approach; if the user invalidates the symptom, the branch is automatically cut off.

Software Prototype

However, if the convergence point is connected to two branches, the tool will ask the question twice.

For example, in the preceding figure, there are two green paths: the one on the left and the one in the middle. When analyzing the middle branch, if the user invalidates the convergence point at the bottom of the page, this branch will be cut off. However, as this same point of convergence is pointed toward the left branch, the tool will ask the question again to be sure that the branch needs to be cut. If the user answers “No” again, then the green branches will disappear.

From the moment the user answers “Yes” to a point of convergence, the tool will continue to identify the intermediate symptoms in order to question them and highlight them in the final result by counting them. Thus, the tool can record that symptom 1 appears in three valid branches, symptom 3 will appear in one valid branch, etc.

In the prototype, this mechanism is represented by the symbol surrounded in black as shown in the following figure. Each time the user answers a question with this symbol, the tool indicates that it is testing the convergence of symptoms.

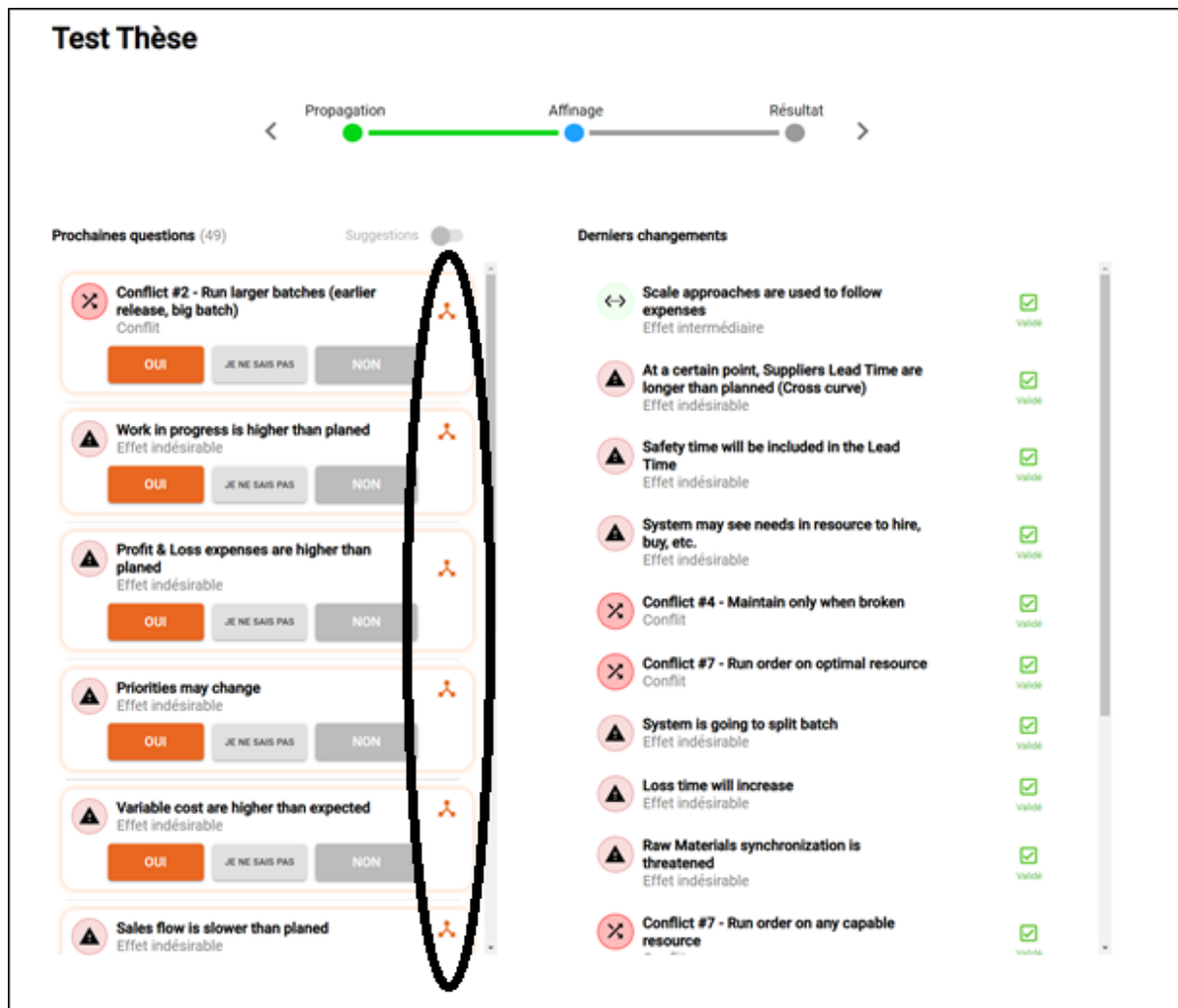


Figure 25. Screenshot of the DOSSARD prototype on question generation

When the user answers “I don't know”, the tool will initially consider the answer as positive. However, it will question the user about the symptoms directly above and below this question.

If the user answers “No”, the symptom and the branch will disappear. If the answer is “Yes”, it will create links between the boxes of the branch. This can be seen in the diagram of figure 23.

The point of convergence, in yellow, was declared an “I don't know” answer but the user initially declared the symptoms framed in blue. The tool will therefore question the two symptoms below and the one above; if the answer is “Yes”, the tool will create a link between the boxes going through the symptoms where the user has answered “Yes” by hiding the point of convergence. If the answer is “No”, the branch will disappear.

To enhance the acceleration of the diagnosis, we have added another feature called suggestions. As soon as the questions have been generated, the user can activate this feature at any time. It is surrounded by a black circle in the following figure:

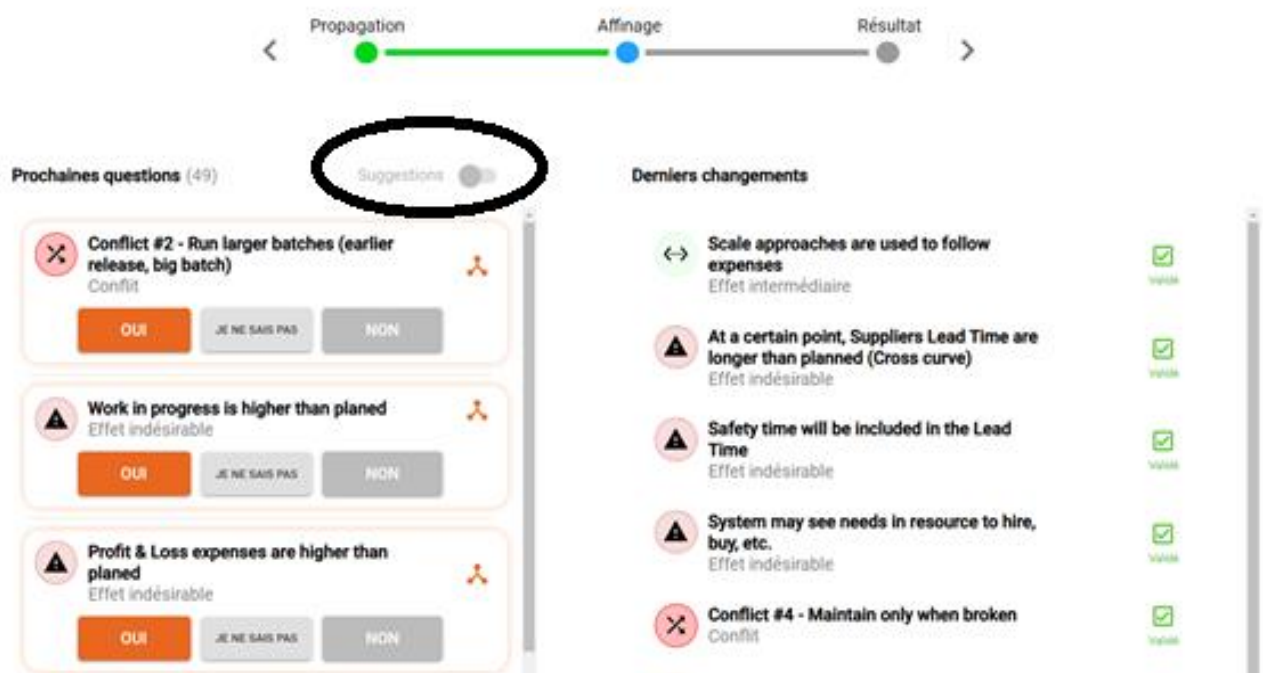


Figure 5. Screenshot of the DOSSARD prototype on the use of the question generator

When the user activates this feature, the tool will refine its questioning in the knowledge base.

As of the first answer to a question, if, for the generated question, the knowledge base has a positive answer in 80% of the cases or more for the typology of the studied system, then the answer is considered “Yes”. If “No”, the question will be asked of the user. The second aspect of this suggestion tool is when the user answers a question with “I don't know”. In this case, the tool will also look at the response rate to this question in the knowledge base of an equivalent system typology. If the response is present in 80% or more of the cases, then the response is recorded as positive. If the answer is “No”, the mechanics described in the previous paragraph will apply (we will question the symptoms above and below).

As we will see in the results of the final chapter, there must be a certain number of cases in the knowledge base for this option to be truly relevant. However, in the cases used, we observed that only one day of work was needed for carrying out the diagnosis, instead of the usual four days.

At this point, the tool has identified a sum of valid branches in which it has counted the number of times the symptoms have been identified. Now we will see how the tool will transcribe this information for the final result.

2. Tree display

Each symptom has a counter that validates the number of times a branch will go through this symptom.

The tool will offer two displays:

- The first will display the entire tree as a whole, where all the positive responses will be displayed;
- When the user selects a symptom, the tool will highlight the branch where the symptom counter was at its highest.

These two representations can be seen in the following images:

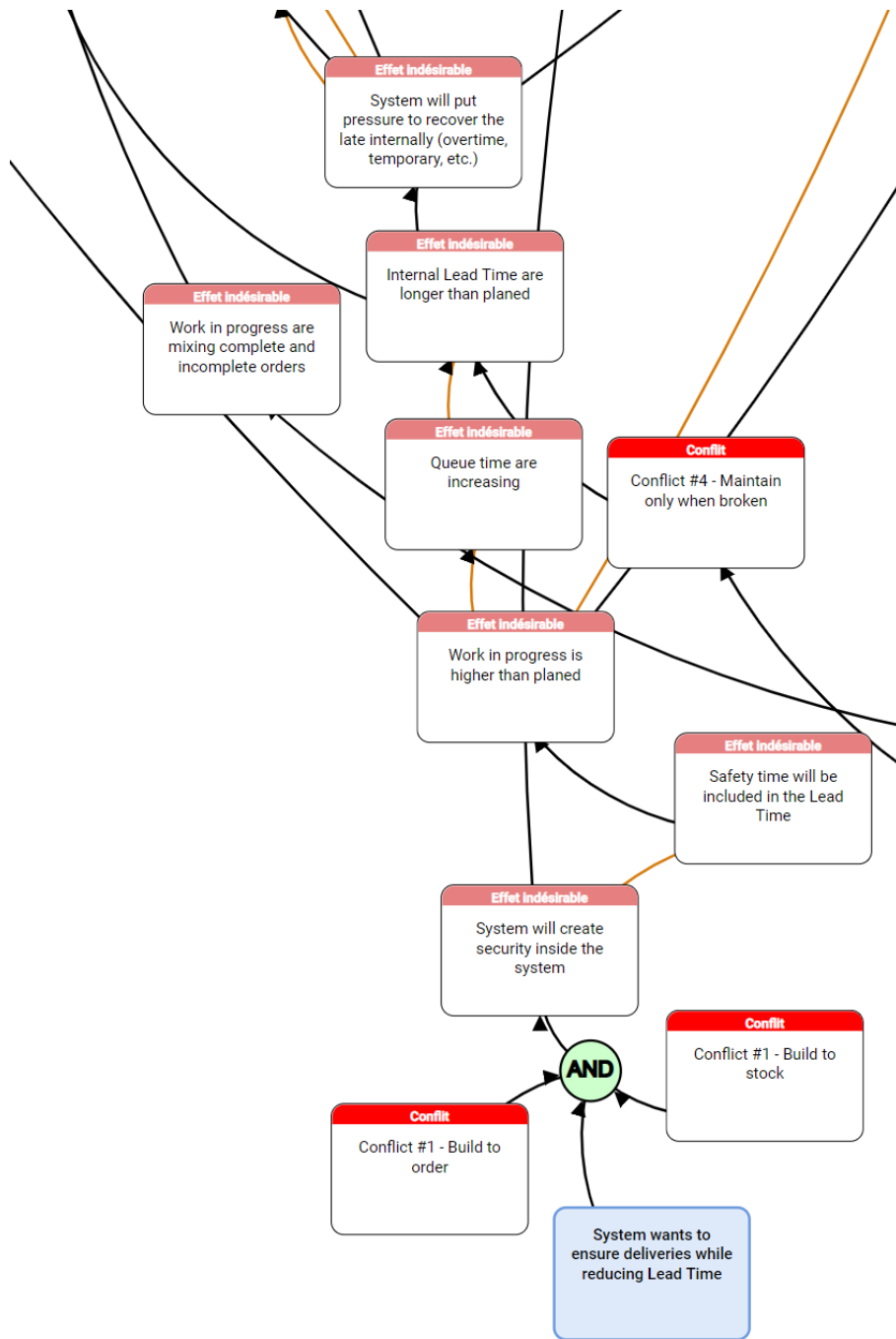


Figure 6. Screenshot of the DOSSARD - full results

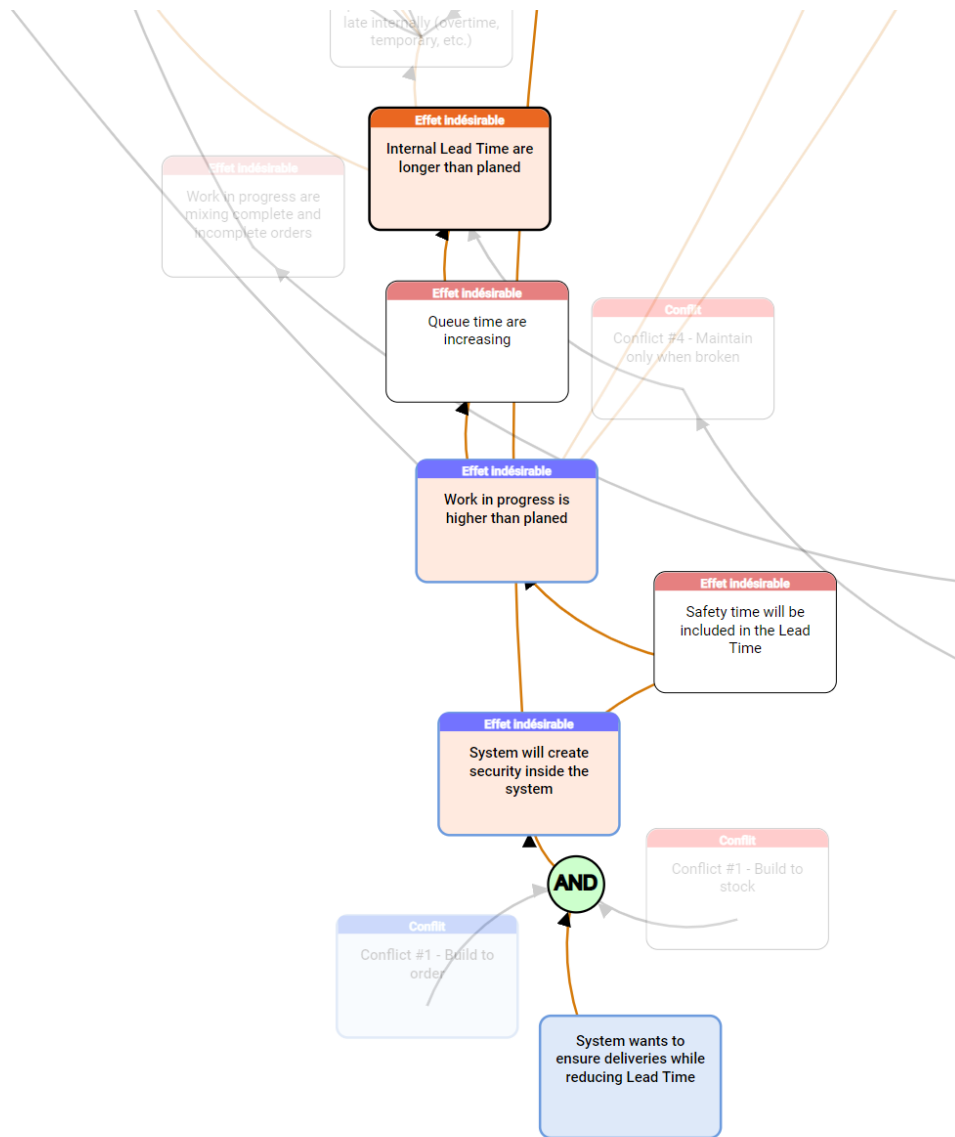


Figure 27. Screenshot of the DOSSARD - focused results

3. Links between the tree and the knowledge base

As we saw earlier, the tool is able to incorporate a change in the tree. Indeed, the user can make the following modifications:

- Change the vocabulary of a box;
- Create a link;
- Add/remove a box.

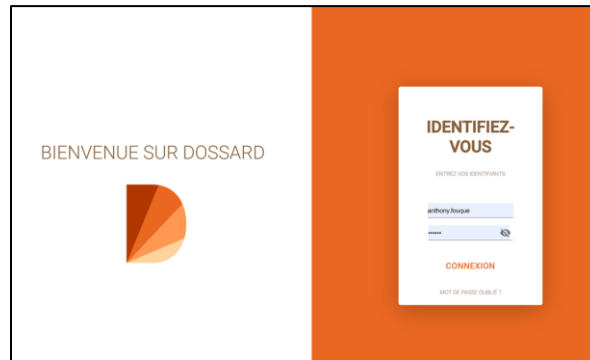
These changes are automatically integrated into the generic tree. However, they are only displayed in DOSSARD if, and only if, these changes are recurrent in up to 80% of the selected trees. As we will see in the case studies, this aspect has not yet been emphasized during use because the number of cases is still too limited for such a modification to be relevant. In addition, the changes that have been made are generally more clarifications than a questioning of the generic tree.

2. Utilization of the prototype

The purpose of this paragraph is to concretely describe what the user will see, based on the process described previously.

1. The administrative part of the prototype

As mentioned in the figure below, the user will have to log in. This connection will allow access the list of diagnoses in progress.



Nom du projet	Date début ↓	Langue	Volume	Variété	Type de flux	Type de projet	Consultant	Secteur d'activité	Statut	Actions
Excent ETO IE (2)	20/01/2021	FR	Fort	Fort	ETO	Project Management	francoise.castel		● En cours	⚙️ 🗑️
Excent ETO Local Tooling	16/01/2021	FR	Fort	Fort	ETO	Project Management	francoise.castel		● En cours	⚙️ 🗑️
Excent ETO Industrial Expertise	16/01/2021	FR	Moyen	Fort	ETO	Project Management	francoise.castel		● En cours	⚙️ 🗑️
Test_STS	14/12/2020	FR				Generic	anthony.fouque		● En cours	⚙️ 🗑️
Test STS	14/12/2020	FR				Project Management	Denis Saint-Joan		● En cours	⚙️ 🗑️
Michelin	11/12/2020	FR	Faible	Faible		Project Management	anthony.fouque		● En cours	⚙️ 🗑️
Company 2	24/11/2020	ENG				Project Management	anthony.fouque		● En cours	⚙️ 🗑️
Company 1	23/11/2020	ENG			ETO	Project Management	anthony.fouque		● En cours	⚙️ 🗑️
Company 87	23/11/2020	ENG				Project Management	anthony.fouque		● En cours	⚙️ 🗑️
PMA	23/09/2020	ENG				Project Management	anthony.fouque		● En cours	⚙️ 🗑️

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Figure 26. Screenshot of the DOSSARD prototype on the administrative part and connection

From this diagnostic list, the user can:

- Delete the diagnosis by clicking on the recycle bin;
- Edit/update the diagnosis by clicking on the gear icon. Indeed, when the diagnosis has been carried out, there is an option that allows it to be shared with the team as well as to modify it in case of additional information or new information requiring a review of the diagnosis.

When the users want to perform a diagnosis, they can click to create a new diagnosis. From there, the tool will request the entry of general information related to the project, as can be seen in the following figure:

Figure 27. Screenshot of the DOSSARD prototype on the part for creating a new diagnosis

As mentioned earlier, the user will enter basic information about the project name, language, etc.

Then the user will have to select whether to use the generic knowledge base dedicated to the MTS/MTO environment or the knowledge base dedicated to project environments.

Once this choice has been made, the user can enter additional information about the type of flow of the system being studied as well as about the volume and variability associated with this flow. The idea is to eventually collect the results with these parameters in order to refine the questioning of the tool in the following phases.

2. Entering symptoms

In this paragraph, the goal is to see how to enter the symptoms that the user has collected through customer exchanges or his observations. There are two ways to collect the symptoms:

- By use of a search engine;
- By selecting symptoms from the list.

These two options are represented in the following diagrams:

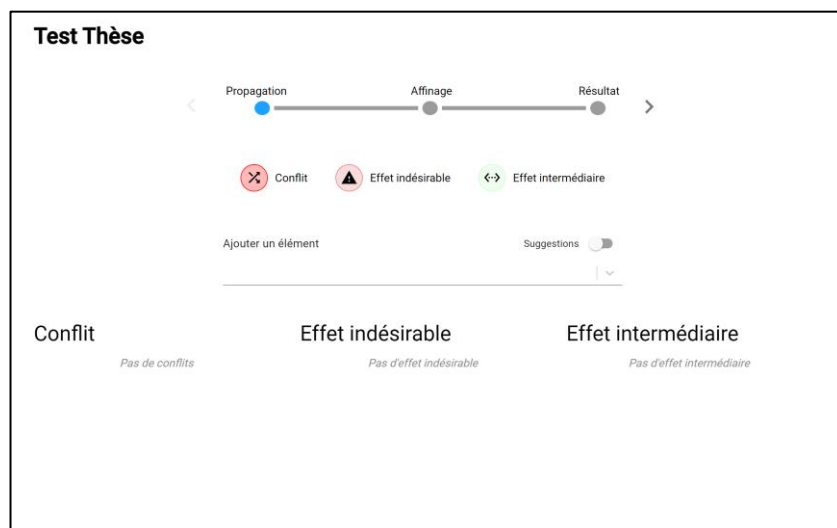


Figure 28. Screenshot of the DOSSARD prototype on the research motor

In the upper part of the screenshot, the user can enter text and the tool will offer a list of symptoms corresponding to this text. The search engine is able to do a contextual search and not just a literal translation.

In the following figure, we can see the other mode of symptom selection, where the user clicks on the drop-down menu and chooses the selected symptom.

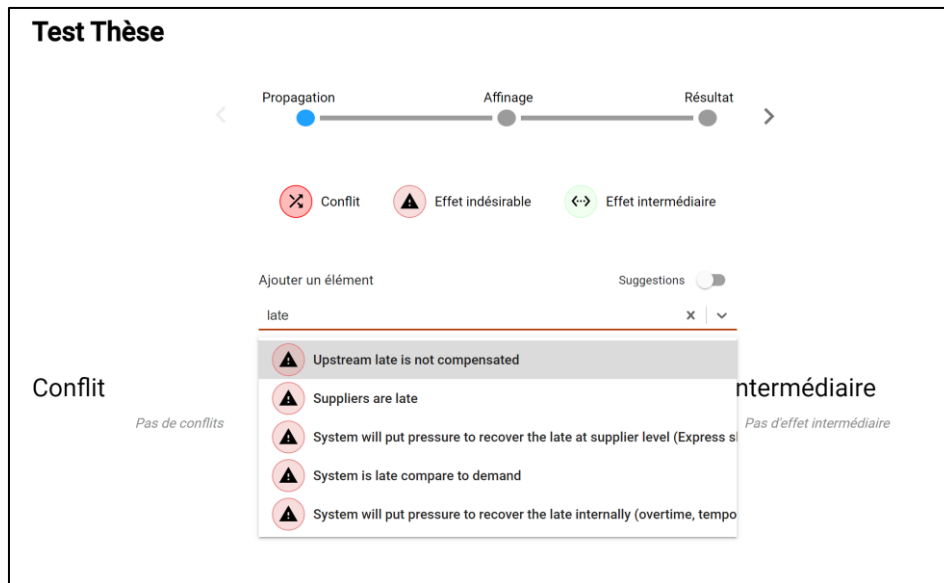


Figure 29. Screenshot of the DOSSARD prototype on the selection of symptoms

At this point, the user has entered the list of symptoms and has possibly already been able to identify conflicts in the system. At the end of this sequence, the user can view the elements as shown in the following diagram:

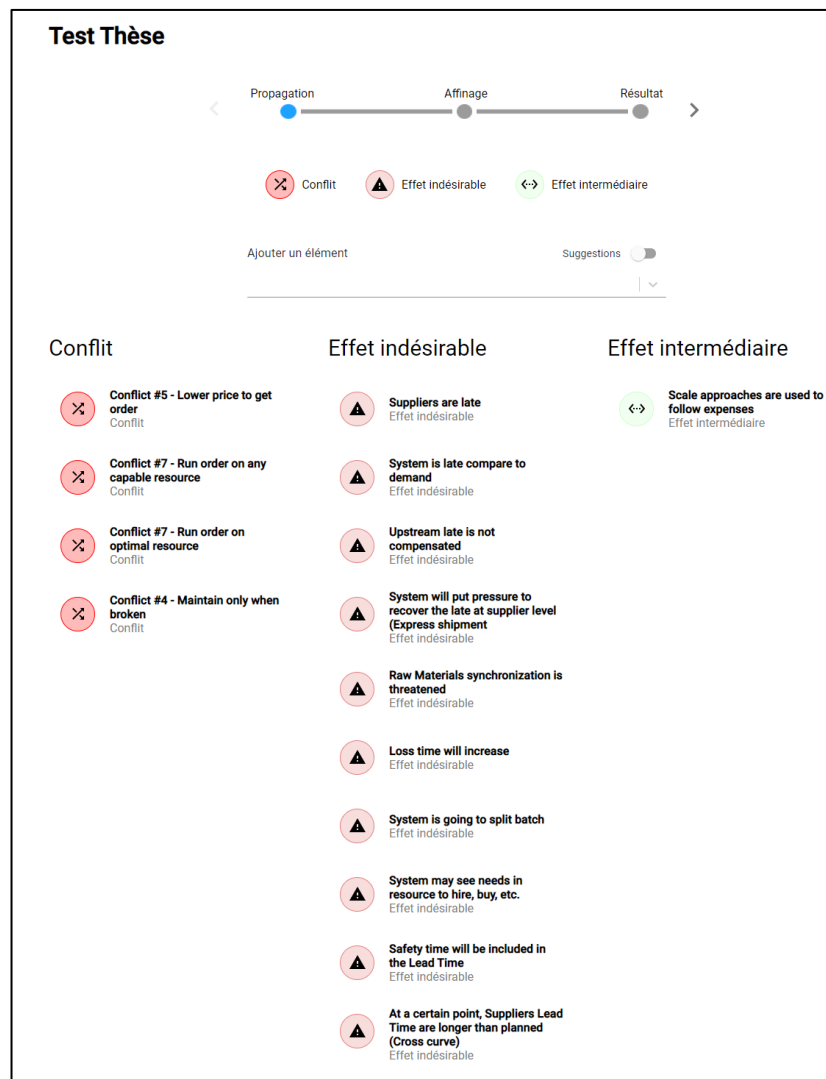


Figure 30. Screenshot of the DOSSARD prototype on the results of the selected symptoms

In the previous figure, the user has entered 10 symptoms, called Undesirable Effects, and has also been able to identify 4 conflicts as well as an intermediate effect. It is at this stage that the links with the knowledge base will be created. Indeed, the tool will identify the most relevant branches to question and thus check the validity of the symptoms mentioned. These relevant branches are fully described in Chapter IV.

3. The treatment of questions proposed by the prototype

In the next section, we will describe the results of the generation of questions as well as the way in which the answers are handled by the user. At this point, it is a matter of describing what the user will see and has to achieve at this stage.

The user will see the following figure:

1. Operating mechanics
 - a. Question choice
 - b. Sorting responses
 - c. Display of the tree based on the responses

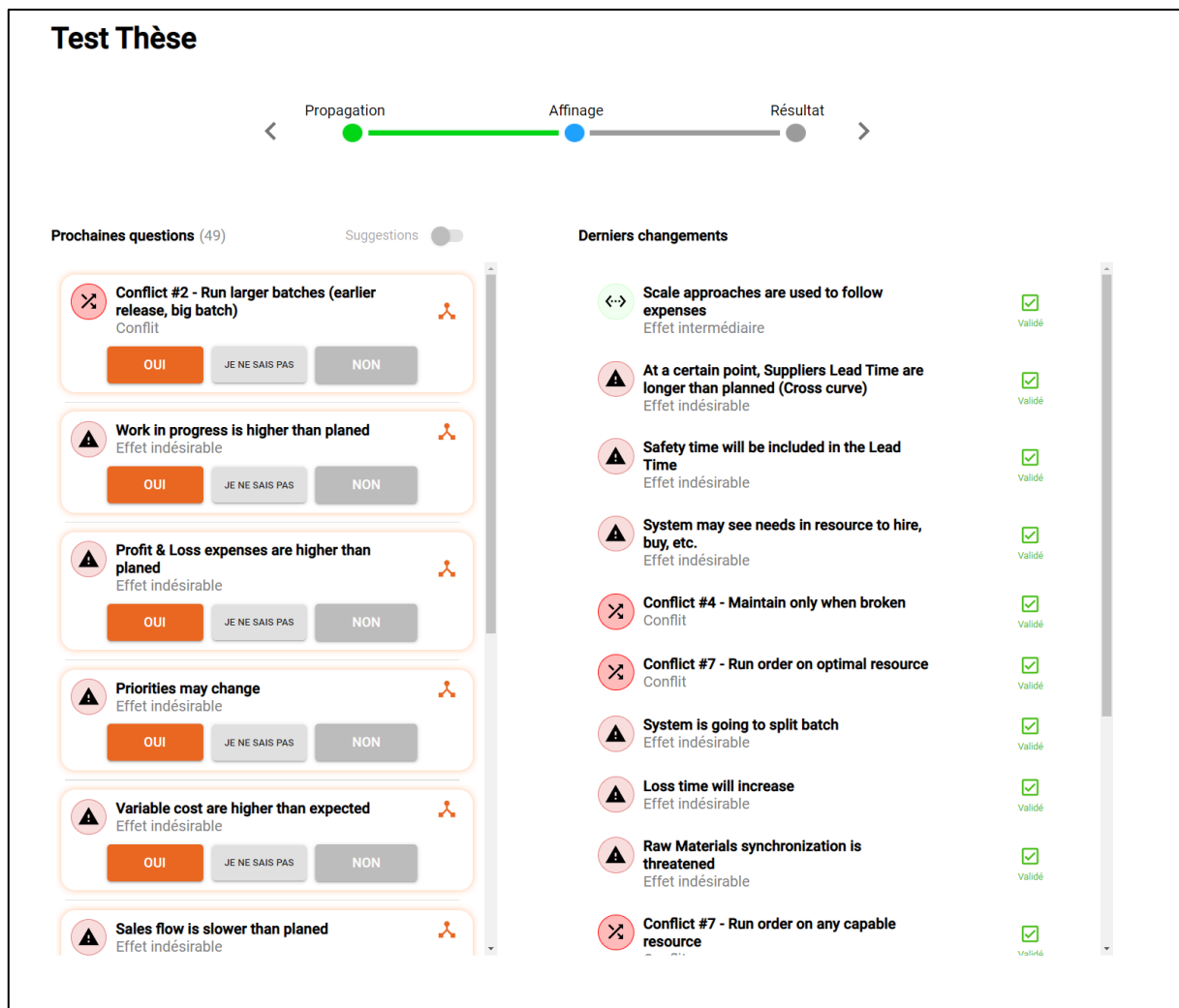


Figure 31. Screenshot of the DOSSARD prototype on the generation of questions

On the left side of the above figure, the user will see the list of questions and symptoms that he will have to confirm or not. He will have 3 options available to him:

- If the symptom exists, he will click on “Yes”;
- If the symptom does not exist, he will click on “No”;
- If he doesn't know the answer, he will click on “I don't know”.

During this phase, there are several choices available, depending on what utilization the user wishes to have. Indeed, the user can:

- Reply to and/or complete answers based on what has been learned during the interviews
- Take the list of questions and collect the answers from the teams.

The idea is that this can complete the diagnostic phase in as much detail as possible. On the right side of the above figure, the user can see the answers that have been provided, whether they are positive, negative or unknown. In addition, by clicking on the icon on the right, the user can also correct his response.

When this phase has been completed, the user will go to the last step, which is to view the tree.

4. Displaying and editing the tree

The tree will be displayed as soon as the user clicks on the arrow to go to the next step. The user will see the tree as displayed in figure 27.

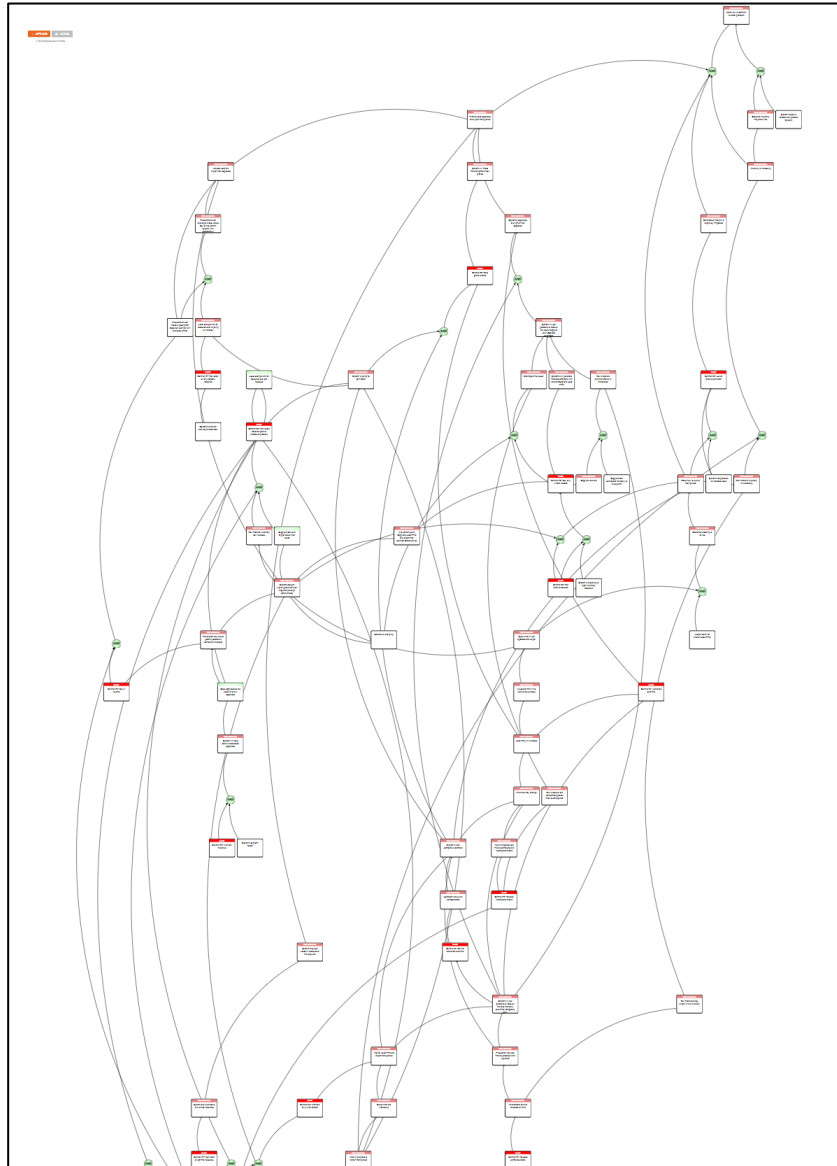


Figure 32. Screenshot of the DOSSARD prototype on the results of a tree of a diagnosed company

The role of the user consists in going down the tree to identify items that have no antecedent and that are considered basic conflicts. Given the responses, if the user is sufficiently aware of the initial conflicts, he will be able to validate a general consistency of the results.

However, it is by reading the tree from bottom to top that the user will be able to more accurately verify this logic. For this, the user will highlight the key branches of the tree. Indeed, when the user clicks on a conflict, the tool will highlight the most present symptom sequence and blur the least recurring branches. The tool achieves this separation based on the answers provided by the user as well as the history of the diagnoses carried out in the database. Thus, the rendering is displayed as in the following figure:

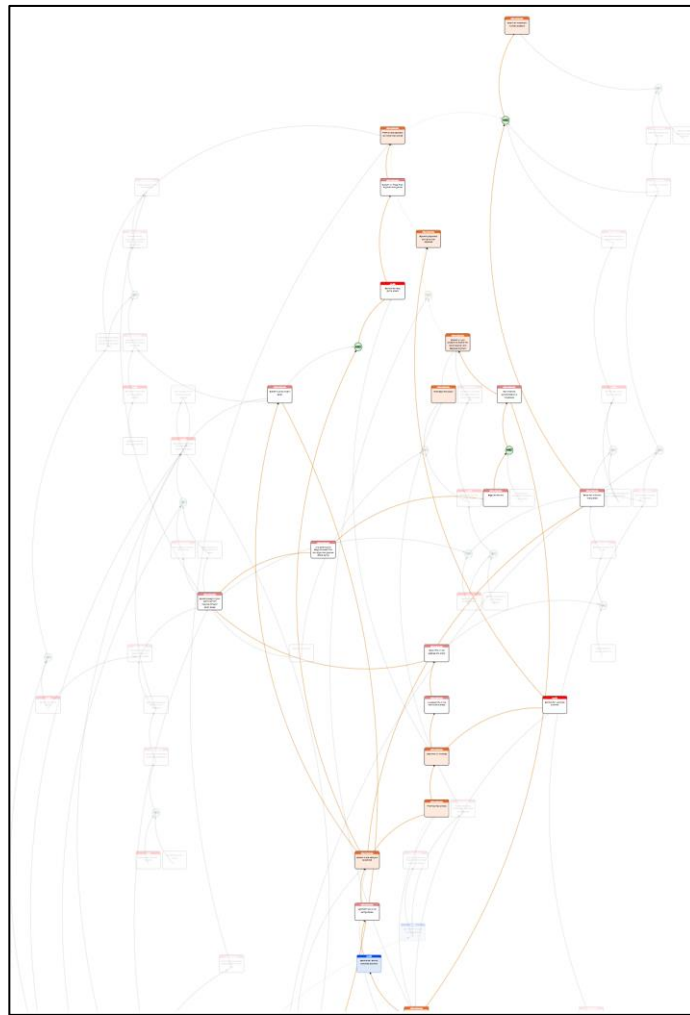


Figure 33. Screenshot of the DOSSARD prototype on the highlighted predominant branches of a conflict

Thus, the user can visualize the most critical sequence but above all, he can share it with the rest of the team to start rendering the diagnosis and completing certain information. In the event that the user wishes to make changes, he has two options available to him:

- To go back to the previous screen and by doing a right-click on the box, symptoms can either be removed or added;
- Or by clicking on one of the elements of the tree, the user can:
 - Modify the contents of a tree;
 - Create a new link;
 - Remove a symptom;
 - Add an additional item.

We can see this option in the figure below:

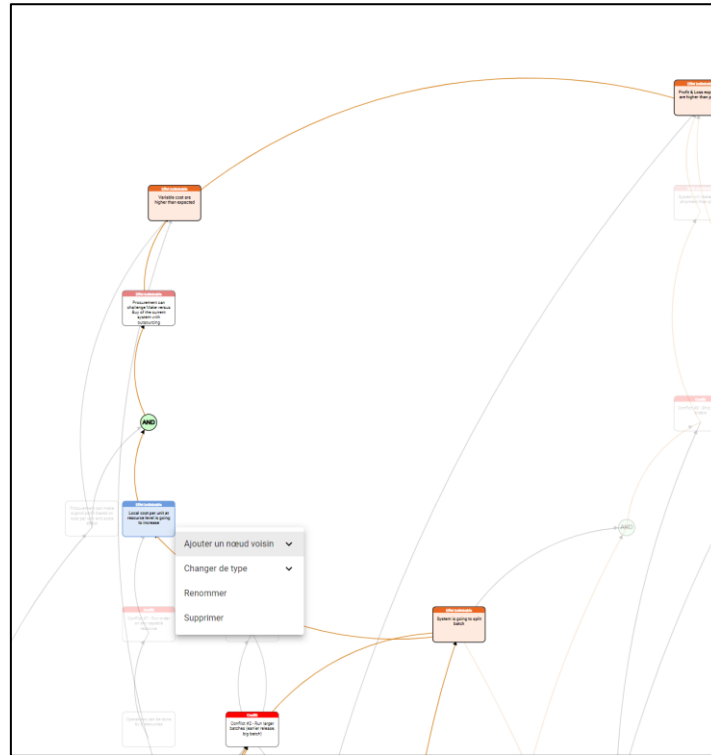


Figure 34. Screenshot of the DOSSARD prototype on the changes the user can make to the tree

In this chapter, we have been able to develop the first two contributions:

1/ The first scientific contribution concerns the definition of an original functional architecture and an original technical architecture to structure a decision support system capable of accompanying a semi-automated diagnostic approach inspired by the Thinking Processes method. This contribution responds to the scientific objective SO2 presented in Chapter I.

2/ The second contribution, this time of a technical nature, concerns the definition and development of a software prototype called DOSSARD to concretize the elements defined in the previous decision support system. In particular, this prototype makes it possible to collect symptoms, to create links with the generic tree (see Chapter IV) in order to propose a diagnosis in the form of graphs. This contribution meets the technical objective TO2 set out in Chapter I.

In the following chapter, complementary scientific and technical contributions will now be developed in connection with the SO1 and TO1 objectives.

CHAPTER IV. KNOWLEDGE BASES

- “What are you gonna do?”
- “I thought I’d get your theories, mock them, then embrace my own. The usual.”

Dr. House

The decision support system proposed in Chapter III requires, in order to function, a knowledge base of its own describing a generic Current Reality Tree of a system for the production of goods or services. In this doctoral thesis, in accordance with the work of (Smith, 1997; Smith, 2019) we have hypothesized that it was possible to create such a generic tree. Thus, in this chapter, we propose to formalize, justify and consolidate the elements proposed by (Smith, 1997; Smith 2019). We will verify that the resulting tree is relevant for MTS/MTO-like environments. We therefore propose in this chapter a second knowledge base, totally original this time, specific to ETO environments.

Thus, this chapter is divided into two parts:

- Structuring, validating and enriching the knowledge base of (Smith, 1997), adapted to MTS/MTO environments;
- A proposal for a new knowledge base for ETO environments.

1. Generic Current Reality Tree for MTS/MTO

In accordance with the work of (Smith, 1997; Smith, 2019), a Current Reality Tree is composed of Conflict Clouds that describe at least two possible, and *a priori* contradictory, ways to achieve the same goal. Thus, subsequently, we propose to explicitly formalize each of the conflicts suggested by (Smith, 1997; Smith, 2019) implicitly. In this way, we aim to make this knowledge usable in order to be able to support the reasoning associated with our proposal for a decision support system. Finally, we seek to validate the relevance of these conflicts by identifying the elements of ad hoc justification in the literature.

1. Build to Stock versus Build on Demand

1. Description of conflicts

One of the first conflicts suggested by Debra Smith is the following:

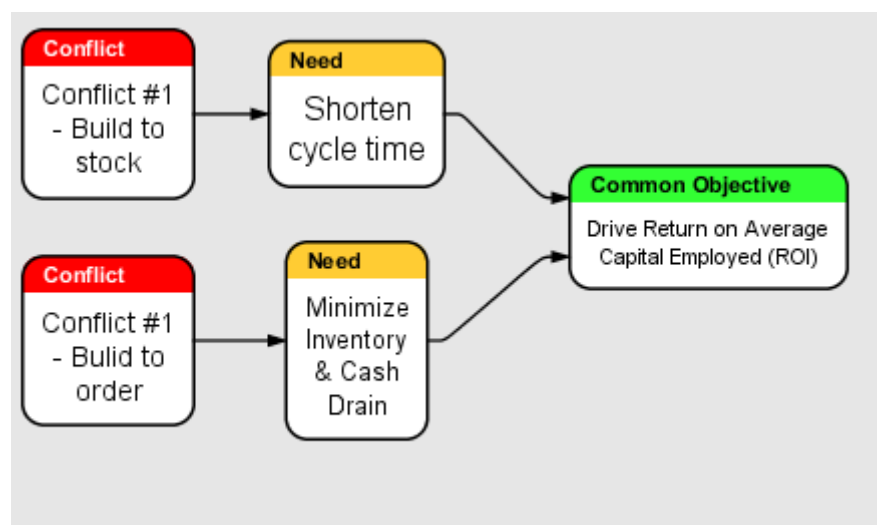


Figure 35. MTS/MTO Conflict Cloud

In order to improve the return on investment of the system, it is necessary to reduce manufacturing cycles and minimize the need for cash and stock.

To achieve significant cycle reduction, it is necessary to manufacture to stock. Thus, as soon as an order arrives, it can be filled using stock that the company has produced.

But at the same time, in order to minimize the need for cash, it is necessary to manufacture to order. Indeed, the principle of manufacturing to order consists in waiting to have a firm sales order before committing the resources of the company (purchasing expenses, human resources or machinery).

2. Description of the tree branch associated with the conflict

The branch associated with the previous conflict is shown in the following figure:

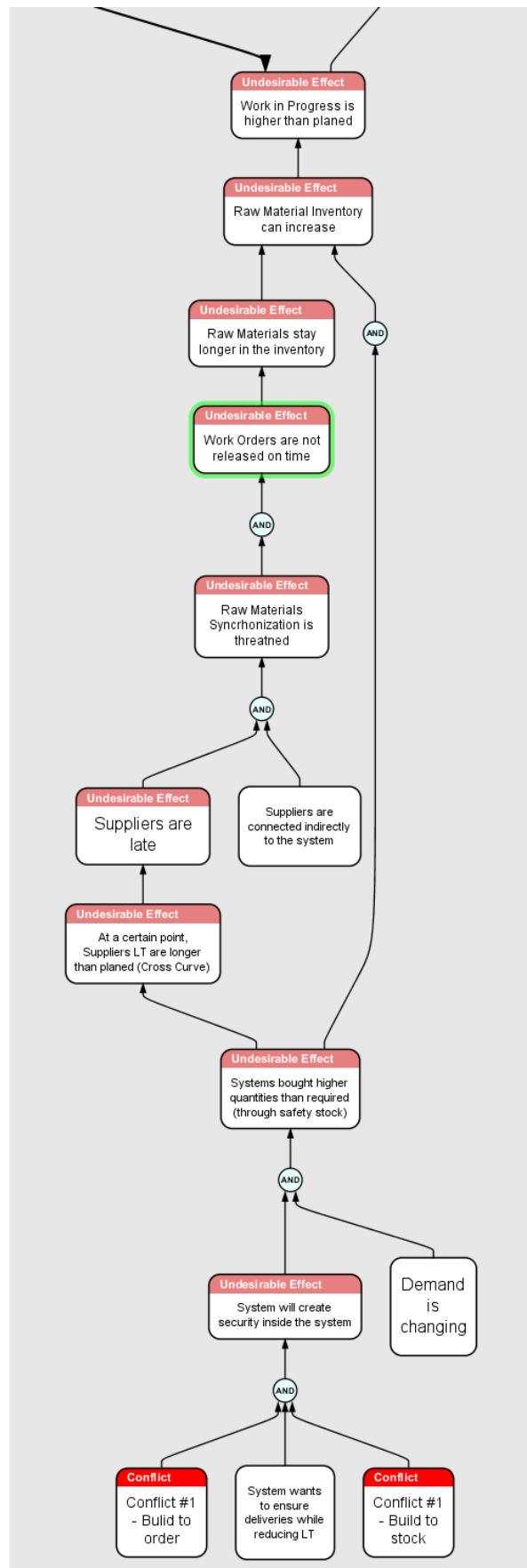


Figure 36. Representation of a Current Reality Tree associated with an MTO/MTS conflict (Part1)

The graph reads from bottom to top with connections of the “If-Then” type:

Generic Current Reality Tree for MTS/MTO

If I am looking to manufacture to order and to stock, then I'm looking to create security in my system. This statement is mentioned in particular in (Ashayeri et al., 2001).

Indeed, having stock is a means of security, but in an MTS /MTO environment, manufacturing takes up time margins within the stated deadlines. As described in (Chen et al., 2012), if the system generates security and demand changes, the systems will end up buying larger quantities than necessary or buying them earlier. When the system orders significantly more than necessary, this overloads the suppliers, which increases cycles and generates delay (Lee et al., 1997). If the supply chain is lagging behind and suppliers are directly linked to customer variations, then the timing of the raw material is threatened (Roodhooft et al., 1997). This desynchronization will result in a late release. If orders are issued late, then the components will remain in stock longer, which will lead to an increase in inventories (Leek et al., 2010).

The following figure shows the continuation of the previous sequence:

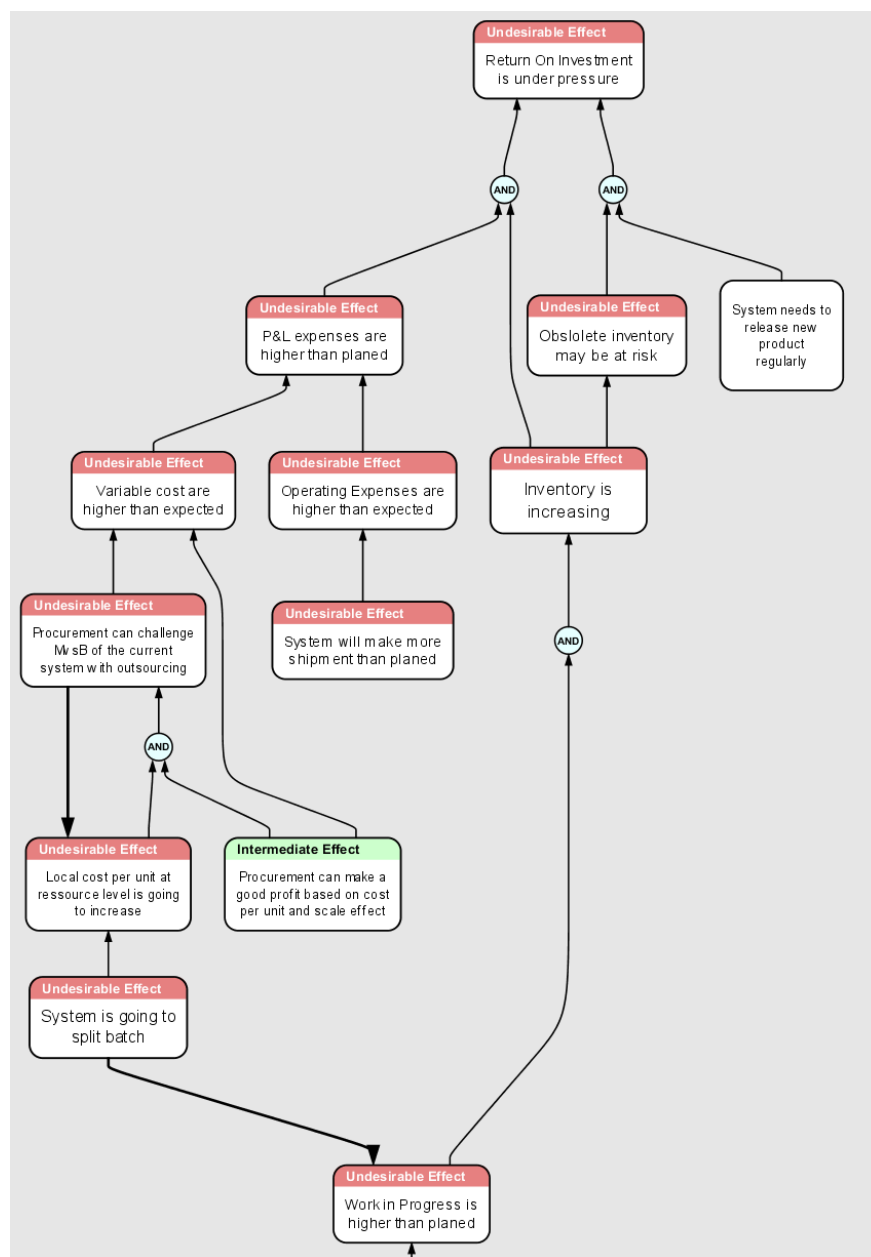


Figure 37. Representation of a Current Reality Tree associated with an MTO/MTS conflict (Part 2)

Here, the increase in work in progress generates other difficulties. An increase in work in progress tends to increase stocks, as mentioned in (Roodhooft et al., 1997). But since it is a question of supplying the system, the system may be tempted to reduce batch size to try to produce the quantity required (Gattiker et al., 2004). The division of lots will generate an increase in unit costs. This increase therefore generates a desire on the part of the purchasing teams to “outsource” components that have become too expensive (Maltz and Ellram, 1997). However, this phenomenon will lead to an increase in costs for the system (Mantel et al., 2006).

Furthermore, when stocks of raw materials increase over the long term, it should be noted that there is a risk of obsolescence of this stock (Teunter et al., 2011). Finally, rising costs and the risk of obsolescence pose a definite risk to the ROI of the system (Jacobson, 1987).

2. Preventive maintenance versus curative maintenance

1. Description of the conflict

The next conflict, mentioned by Debra Smith in “The Web of Conflict” (Smith, 1997), is as follows:

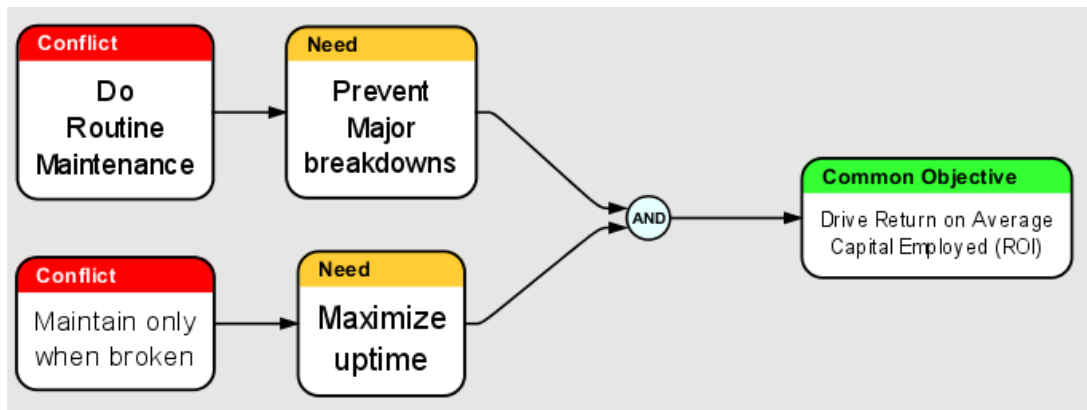


Figure 38. Preventive/curative maintenance Conflict Cloud

In order to improve the return on investment of the system, it is necessary to prevent major breakdowns for the teams and at the same time, it is necessary to maximize the time of the availability of resources.

Consequently, the prevention of major resource shutdowns will push the organization to set up routine maintenance, but the desire to maximize the availability of resources will push the organization to wait for a breakdown to start maintenance.

The principle of routine maintenance falls within the scope of so-called preventive maintenance operations. The aim is to check the state of the means of production before being used in order to guarantee the full utilization of the resource. In contrast, curative maintenance consists of repairing the resource at the moment when it fails to function.

The dilemma of the maintenance function is often summarized as follows: “Do I have to perform regular maintenance of my resources (even if it means reducing their efficiency)?” versus “Do I have to wait until my resource has failed in order to do the entire overhaul of the resource?”

2. Description of the tree branch associated with the conflict

The branch associated with the previous conflict is shown in the following figure:

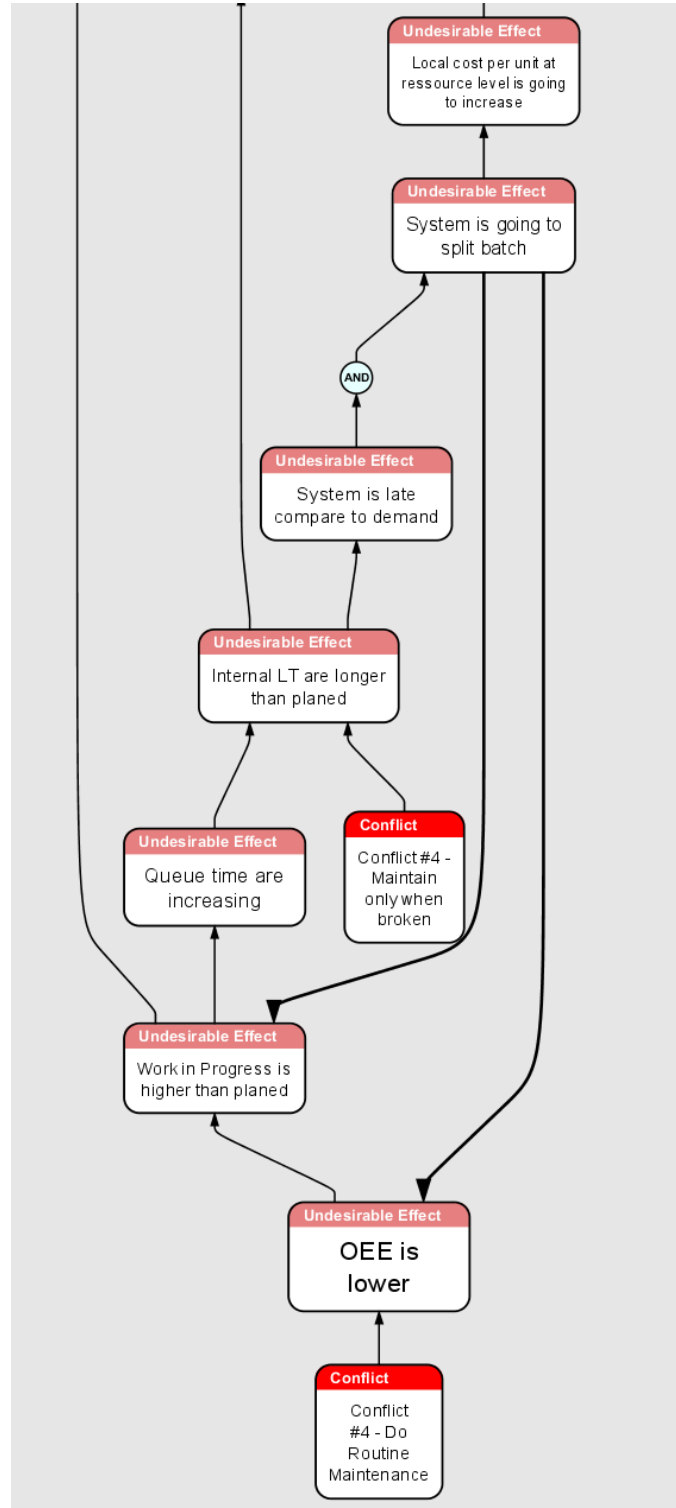


Figure 39. Representation of the Current Reality Tree associated with the preventive/curative maintenance conflict (Part 1)

As stated by (Malik, 2017), if I do routine maintenance, then I impact my Overall Equipment Effectiveness (OEE) negatively. If my OEE decreases, it means that my work in progress is higher than what is planned, as noted in (Sheyu, 2006).

As indicated by (Chhajed and Low, 2006), the increase in work in progress implies an increase in waiting times within the system. The increase in wait times will lead to delays in planning and therefore to delays in delivery, as indicated by (Disney et al., 2003).

To compensate for the delays in delivery, the organization can cut its batches to go faster, as mentioned in (Gattiker et al., 2004).

In addition, the division of the lot size will have the effect of increasing unit costs, as indicated by (Gattiker et al., 2004) as well. If the company chooses to perform maintenance only in the event of a breakdown, this will directly impact the cycles by increasing them (Malik, 2007)

The rest of the sequence is formalized in the following figure:

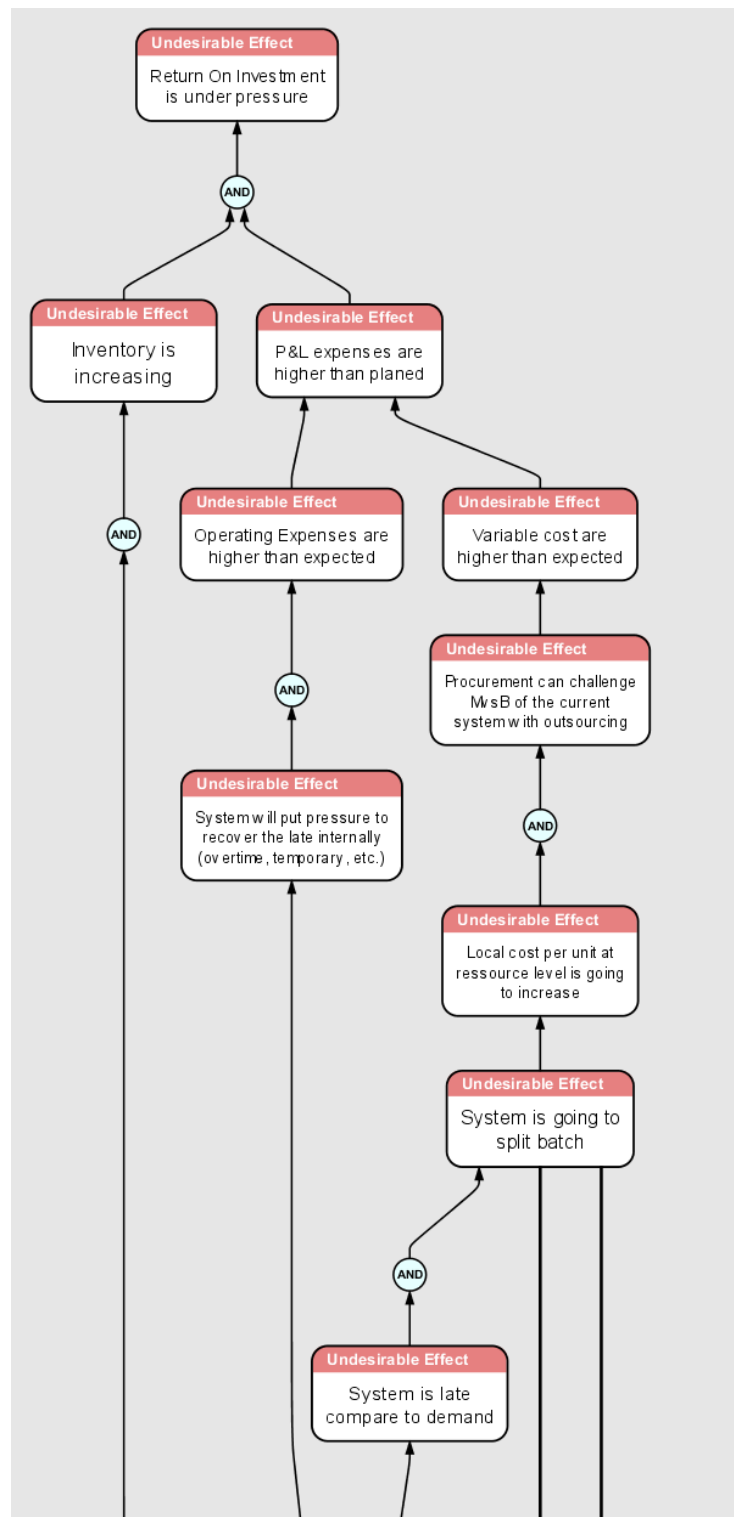


Figure 40. Representation of the Current Reality Tree associated with the preventive/curative maintenance conflict (Part 2)

This increase therefore generates a desire on the part of the purchasing teams to “outsource” components that have become too expensive (Maltz and Ellram, 1997). However, this phenomenon will also lead to an increase in costs for the system (Mantel et al., 2006). In addition, when the system is lagging behind, the organization will tend to put pressure on the system to catch up, as indicated by (Chen et al., 2010).

Thus, when operational expenditure increases, the return on investment becomes threatened (Jacobson, 1987).

3. Work with all resources or with the most optimal resource

1. Description of the conflict

The next conflict, referred to by (Smith, 1997), is as follows:

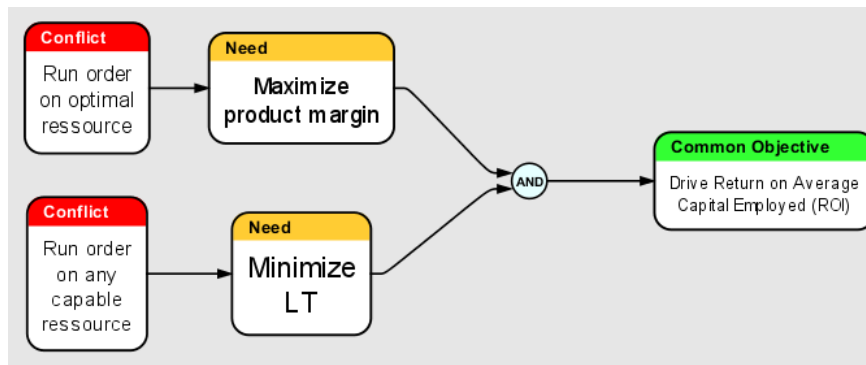


Figure 41. Optimum or generic resource Conflict Cloud

In order to improve the return on investment of the system, it is necessary to maximize the margin per product while minimizing the proposed cycle. The margin per product represents the difference between the sales price of the product and the purchases made that are associated with the sale.

The higher this value, the better the situation for the company. Thus, if the transformation of products goes through the most efficient resources, then the obtained margin is higher because only these resources were mobilized. However, to minimize the cycle, the company may be tempted to use any machine to advance its manufacturing from the moment it is able to carry out the transformation. Thus, by using less efficient resources, on the one hand the product margin will decrease, but at the same time, the company will be able to manufacture more components.

2. Description of the tree branch associated with the conflict

The branch associated with the previous conflict is shown in the following figure:

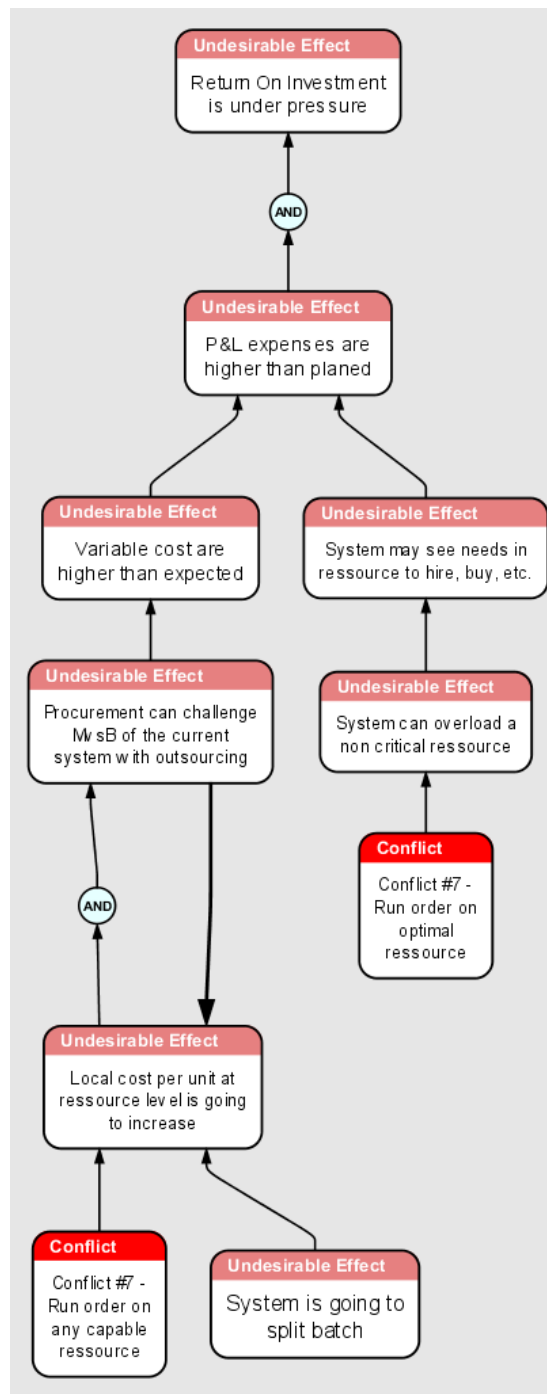


Figure 42 Schematic representation of the Current Reality Tree for resource usage

If I can place my production orders with any resource, then this will lead to an increase in my production costs, as mentioned in (Lucas, 1970). This increase in costs often leads to an awareness on the part of the purchasing team that products could be purchased rather than manufactured in-house (Maltz et al., 1997).

If the team decides to outsource its orders, then the variable costs will increase, as mentioned in the article by (Lucas, 1970). As noted by (Porteus, 1986), if, at the same time, the team is pushed to work only with the most optimal resources, there is a risk of clogging up these resources. This resulting bottleneck will give the impression that the system is overloaded and therefore push the company to want to hire, invest, etc. (Chen et al., 2010). Logically, as mentioned in (Porteus, 1986), this investment impacts the company's income statement.

4. Authorize overtime or not

1. Description of the conflict

The next conflict mentioned by (Smith, 1997) is as follows:

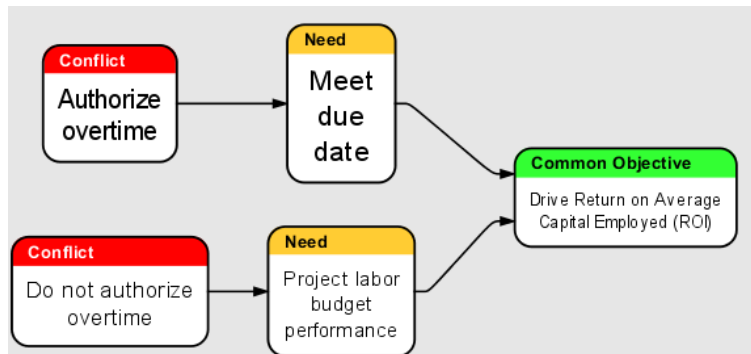


Figure 43. Authorize overtime or not Conflict Cloud

In order to improve the return on investment of the system, it must meet its delivery commitments while respecting the associated expenditure budget. To meet delivery dates, the system may agree to authorize overtime, although its desire to respect the budget causes the same organization not to allow overtime.

When the system is subjected to unexpected problems, this can generate variability in the system and in the manufacturing schedule. These productions can cause delays. Given that companies aim to satisfy their customers, the companies will seek to compensate for the delays generated by these unexpected problems.

One of the strategies for compensating for unexpected problems is to find additional capacity in the means of production of the company. This increase can be achieved through the acceptance of overtime. Since these overtime hours represent unbudgeted hours to be paid, this then leads to increases in expenses that can penalize the company.

Thus, the company finds itself in a dilemma between increasing its operating expenses to satisfy customers while also reducing its profit margin for their benefit.

2. Description of the tree branch associated with the conflict

The branch associated with the previous conflict is shown in the following figure:

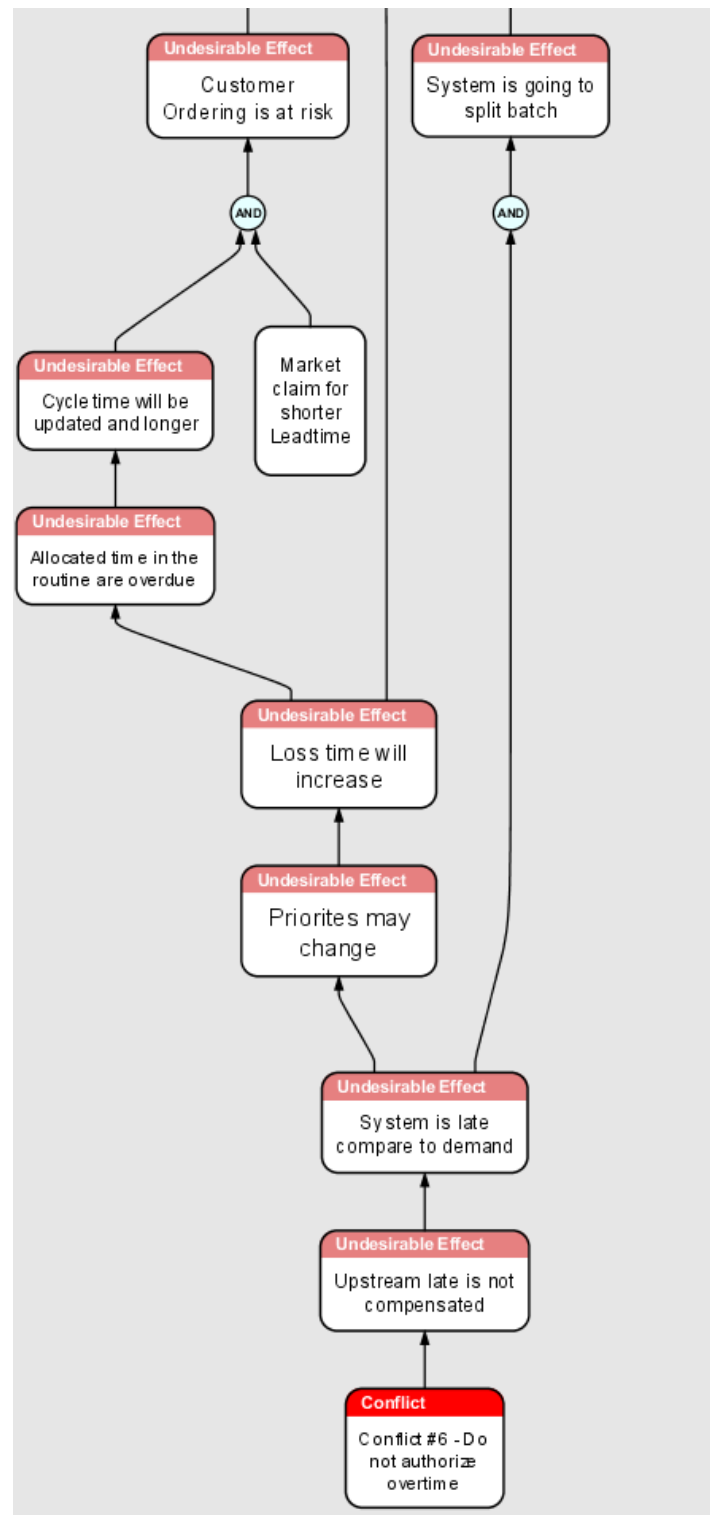


Figure 44. Schematic representation of the Current Reality Tree for overtime (Part 1)

If the company decides not to use overtime, then the delay will not be compensated as indicated (Lucas, 1970). In addition, this compensation will cause delays in the system.

As (Disney et al., 2003) indicates, the pressure of delay will lead to changes in priorities which, consequently, will increase the non-value added to the production cycle (Akkermans et al., 2003).

Thus, the allocated time for the ranges will be exceeded, as mentioned by (Abdulmalek et al., 2007), which will occasionally lead to the updating of cycles (Lucas, 1970). When cycles are updated towards an increase, this automatically puts the order book at risk (Treville et al., 2004).

We also know, as mentioned by (Gattiker et al., 2004), that the system will be tempted to reduce batch sizes to make up for the delay.

The rest of the tree is represented in the following sequence:

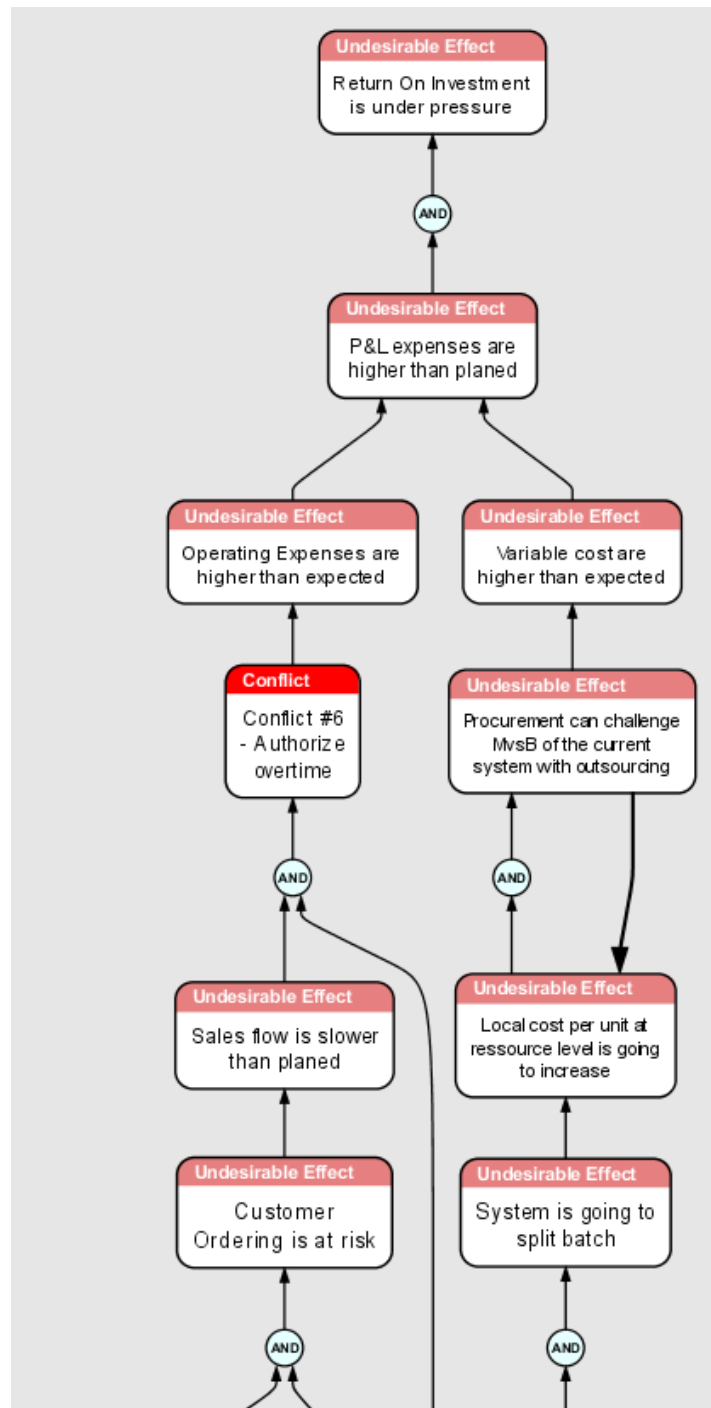


Figure 45. Schematic representation of the Current Reality Tree for overtime (Part 2)

As we have seen in the previous paragraphs, batch cutting will generate cost increases that will undoubtedly lead to a questioning of the “make versus buy” choice of the organization.

As we said before, the order book can become a risk. When this risk is confirmed, (Flynn et al., 2009) suggest that the sales flow will decrease.

If the impact of this decrease is very strong, it is possible that the company will finally decide to allow overtime, as mentioned by (Lee et al., 1997), which will lead to an increase in operating expenses and an adverse impact on the income statement.

5. Decrease or increase batch size

1. Description of the conflict

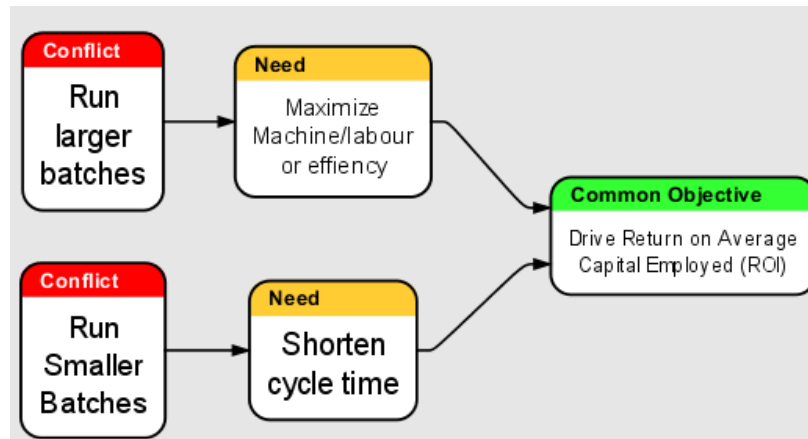


Figure 46. Increase or decrease batch size Conflict Cloud

In order to improve the return on investment of the system, it is necessary for the system to maximize the use of its resources while offering a shorter cycle.

To maximize the use of these resources, systems may tend to launch large quantities into manufacturing. The problem with this, however, is that in order to satisfy the short deadlines requested by customers, the system must launch smaller batches.

The principle of increasing batch sizes to maximize resources assumes that the machine and the resource (working on this machine) have a cost that must be amortized by production. To amortize this cost, it is therefore necessary to maximize production on this resource. When machine (or human) resources need specific adjustments (or tools), everything must be done to ensure that this adjustment allows production to be maximized. Thus, the company may tend to launch large quantities to produce in order to satisfy this production need.

Conversely, when the quantities produced are too large compared to the needs of the customers, then the company will have in its batches both the sales orders planned for a short-term horizon with quantities planned for customers on a more distant horizon.

Thus, short-term orders may become threatened because they have to wait until the manufacture of the entire batch is completed. In this context, the company finds itself in the opposite pattern: it will want to reduce its batch size to advance sales orders faster.

2. Description of the tree branch associated with the conflict

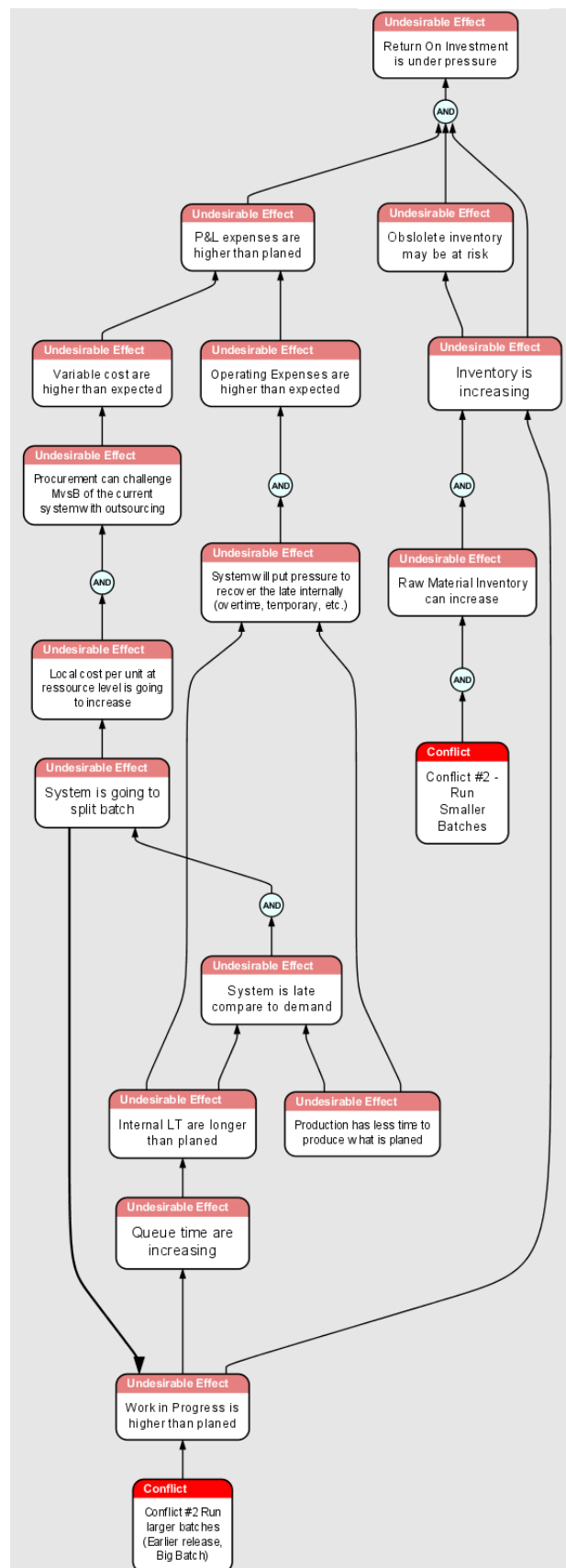


Figure 47. Schematic representation of the Current Reality Tree for batch sizing

If the organization launches the work in progress in greater quantities than expected, then the work in progress is going to be more substantial than what was planned. This is confirmed by (Leek et al., 2017).

The rest of the branch was described in the MTO/MTS conflict paragraph.

However, if the company seeks to launch the work in progress in smaller batch sizes, then the raw material cost and the production cost will increase, as mentioned by (Lee et al., 1997), and as we saw in the paragraph on MTO/MTS, this will result in an increase in the value of the stocks and the associated undesirable effects.

6. Buy only what is necessary versus buy in large quantity

1. Description of the conflict

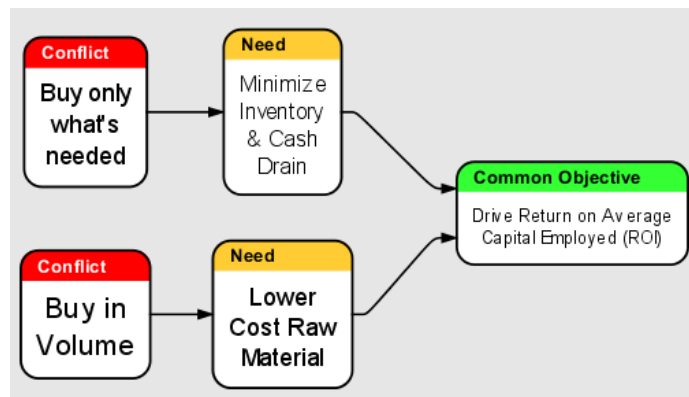


Figure 48. Buying only what is needed versus buying in large quantity Conflict Cloud

To improve the return on investment of the system, it is necessary to minimize the need for cash and to reduce the cost of raw material expenditures. To reduce the need for cash flow, teams need to supply only what is necessary. The problem here, though, is that to lower the unit cost of raw materials, the supply team has an incentive to buy in large volumes to take advantage of the scale effect.

This conflict works in the same way as for the previous one, except that instead of talking about an internal resource, the subject is now a supplier. Indeed, the supplier invoices a set of services to his customer (provision of resources, tools, transport, etc.). To reduce the cost, the customer has an interest in asking his supplier for large quantities in order to make full use of his means of production. In doing so, the cost of purchases for the customer will be lower.

In the same way, by requesting larger quantities than needed, the customer takes the risk that some quantities included in the requested batch size will be blocked if the manufacturing of the batch is not completed at the supplier level. The customer is therefore in the opposite situation, where he will want a smaller quantity to be delivered to satisfy internal needs at the expense of the supplier's costs.

2. Description of the tree branch associated with the conflict

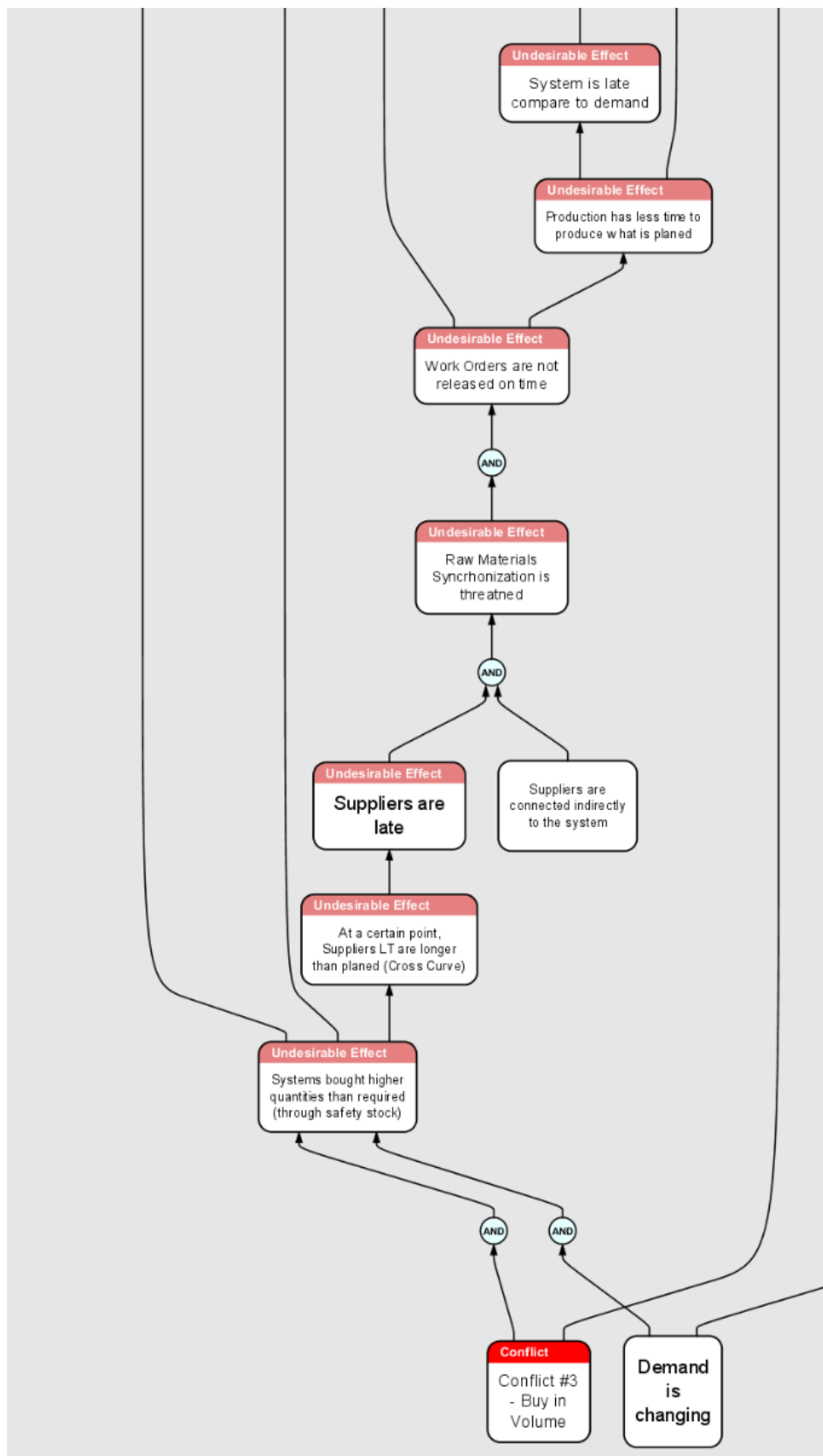


Figure 49. Schematic representation of the Current Reality Tree for scale purchasing (Part 1)

Generic Current Reality Tree for MTS/MTO

If I buy in volume and the demand changes, then the system will buy quantities in excess of needs, as mentioned in (Chen, 2012). When these quantities are much higher than needed, the initial cycles of suppliers are undermined, as suggested in (Hua et al., 2014).

This damage will lead to delays in the supplier's order book (Roodhooft et al., 1997).

When suppliers are late, this signals that the synchronization of materials among them is threatened, which will lead to the start of late manufacturing as indicated below.

Thus, production will have less time to produce what is needed, which will generate manufacturing delays (Ragatz, 1988; Lucas, 1970).

The rest of the tree is represented by the figure below:

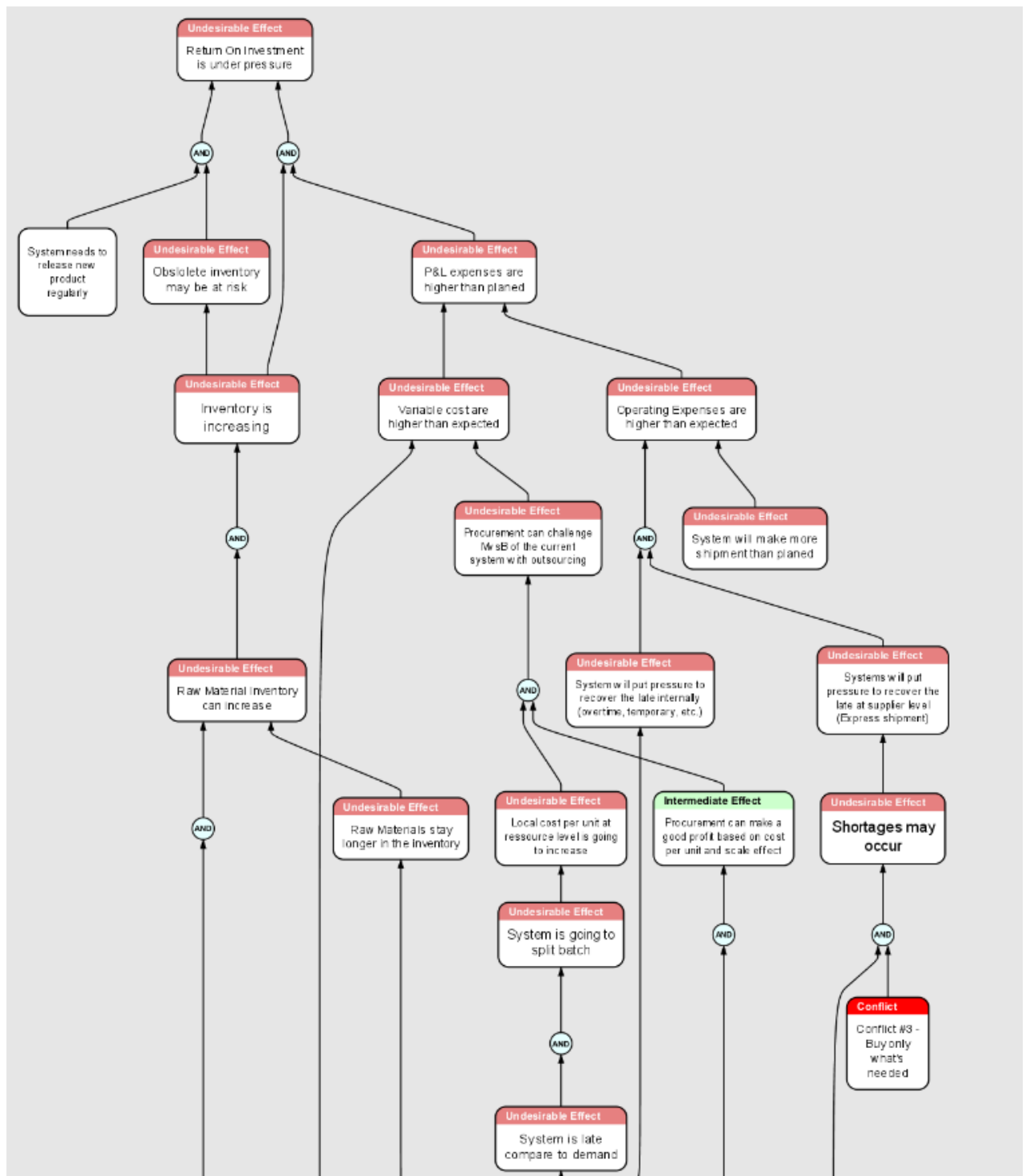


Figure 50. Schematic representation of the Current Reality Tree for scale purchasing (Part 2)

The branch leaving the system late in relation to demand has already been described in the MTO/MTS paragraphs.

However, if the system buys only what it needs and there are unforeseen problems, then disruptions may occur. These disruptions will cause an increase in the pressure in the system, as indicated by (Lee et al., 1997).

7. Maintain the price or lower the price to win the order

1. Description of the conflict

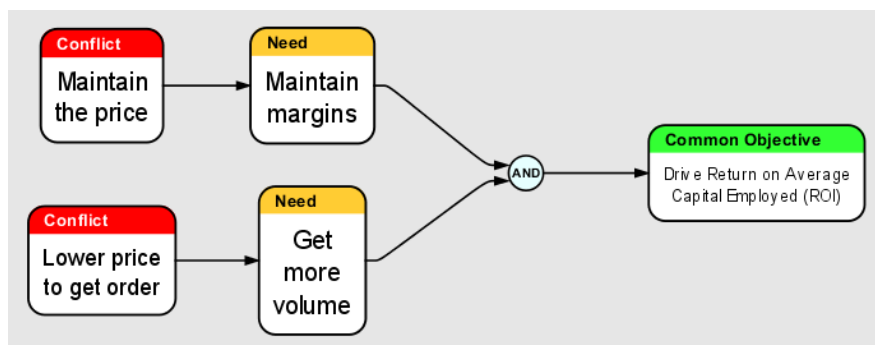


Figure 51. Maintaining the price or lowering the price to win the client's order Conflict Cloud

In order to optimize the ROI of the system, it is necessary for the system to maintain its margins while increasing its volumes. Maintaining margins often involves maintaining prices. The problem here is that in order to sell more volume, the system is pushed to make concessions on the price to win customer orders.

This is the dilemma of the sales function. Indeed, in a competitive market, winning new customers is an important issue. To win new customers, one of the options is to lower the price for the same level of service. Even though this reduces margins, it allows the company to obtain additional volumes that will improve its return on investment.

On the other hand, maintaining prices ensures that the margin is maintained in the short term and thus, the company's profitability.

2. Description of the tree branch associated with the conflict

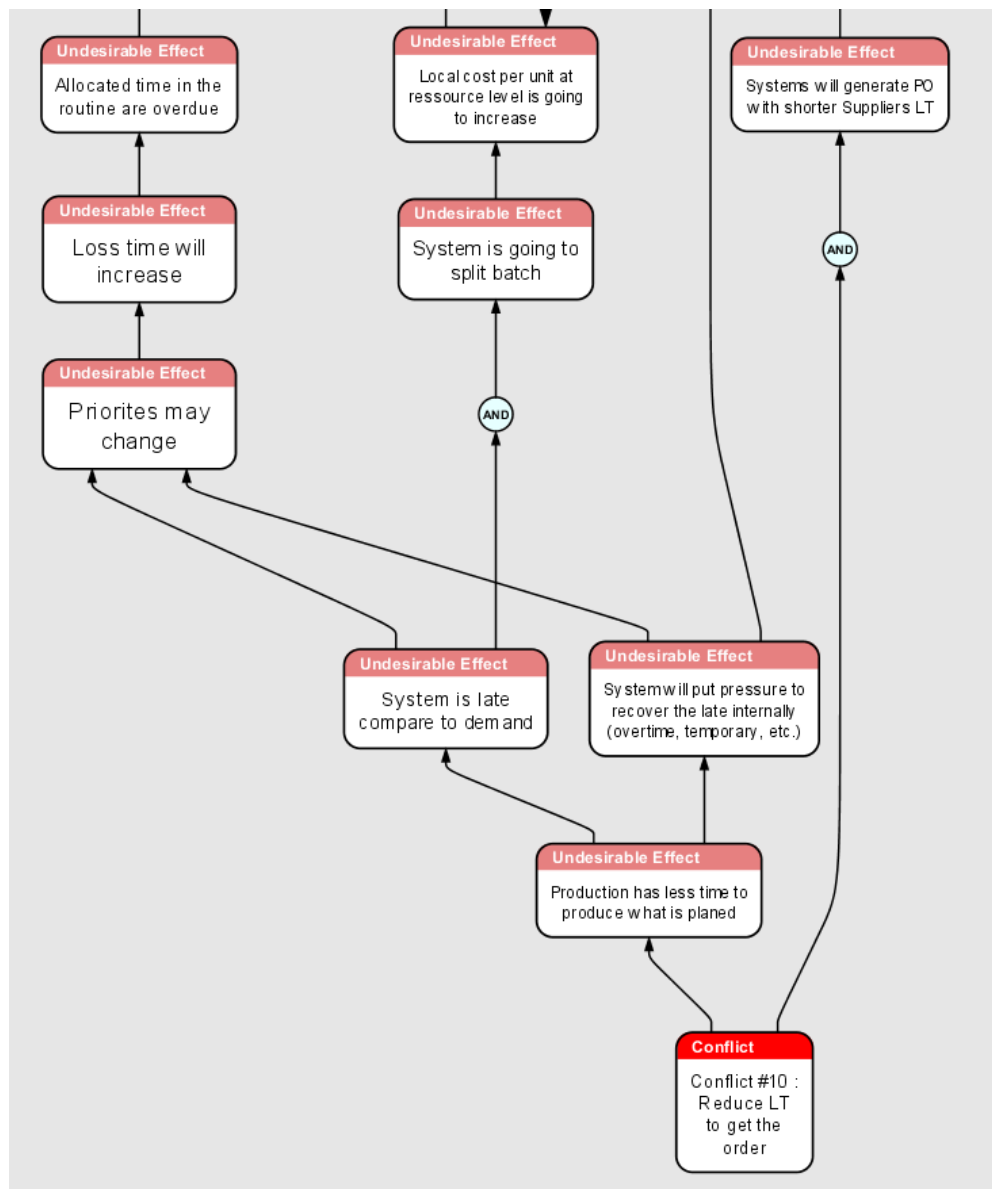


Figure 52. Schematic representation of the Current Reality Tree to reduce leadtime to get an order

If the sales team reduces the cycle to obtain the order, then production will have less time to manufacture the order, as indicated in (Mantel et al., 2006). The rest of the branches have been explained in section 1.3.2.

2. Generic Current Reality Tree for ETO

During the experimentation of the prototype (see Chapter VI), we found that our objectives were achieved in MTO/MTS environments. However, when we attempted to apply the previous generic tree in ETO environments, our results were inconclusive in terms of duration, quality and results.

This led us to the conclusion that the conflicts proposed by (Smith, 1997) were probably not adapted to this environment. Indeed, even though ETO is based on sales orders like MTO, it is nevertheless distinguished by upstream phases of industrialization as well as by orders in very small or even unique quantities.

Thus, it was important to make an inventory of industrial diagnostics in an ETO environment. The observation is that the literature is quite poor in this particular area. Only two articles in particular caught our attention:

(Gosling et al., 2017) suggests that the ETO environment needs to be made more flexible to resemble more closely an MTO environment. (Müller et al., 2018) suggests that the so-called Industry 4.0 technologies should be used to model complex ETO environments.

When we take the classical diagnostic models discussed in Chapter II, only the SCOR model evokes ETO, but only in a mapping process logic and not as an industrial evaluation tool (Huang et al., 2013).

However, the world of ETO is often compared to the world of project management (Sjörger et al., 2014; Morgan et al., 2017). When we refer to the world of projects and diagnostics, the literature of projects is abundant. However, the literature focuses on the diagnosis of a project and its state, rather than the diagnosis of a project organization such as an ETO system (Jaafari, 2007; Cronemyr et al., 2017). The other aspect of the concentration of project diagnoses is sectoral. These articles propose project evaluations by sector:

- Construction (Sarshar et al., 2000), (McCabe et al., 1998), (Al-Zwainy et al., 2017);
- Software (Kortum et al., 2017);
- Oil and gas (Ramos et al., 2018), (Gaisina et al., 2017).

In the same manner as the other articles, these focus on the criteria for the success of a project and do not address the diagnosis of project organization as such.

From the literature review conducted, we can draw two lessons:

- The diagnoses concentrate on a particular project;
- The diagnoses are sectorial.

Although literature on the subject is scarce, there are many piloting methods that aim to solve problems inherent in project management. Indeed, the project sector suffers structurally from a number of symptoms:

- Delays (Whittaker, 1999), (Olsson, 2006)
- Budget overruns (Blackstone et al., 2009)
- Quality below expectations (Serra et al., 2015)

Generic Current Reality Tree for ETO

And a number of articles proposing improvement solutions mention a number of problems in the execution of projects:

- Multitasking (Ben-Zvi et al., 2011), (Lechler et al., 2005)
- Change of priority (Lenfle et al., 2010), (Lewis et al., 2013)
- Lack of detail in the tasks to be performed (Kim et al., 2015), (Bahrami, 2005)

In conclusion, the literature agrees that there are problems in the execution of projects but that there is not a tool or a unified diagnostic method that would make it possible to diagnose a project organization accurately.

Also, in the following section we will propose such a tool based on the logic of the *Thinking Processes* developed for MTS/MTO environments. From a methodological point of view, we propose to assemble the symptoms inherent in the management of qualified projects in the literature into the form of a generic Current Reality Tree for the ETO/Project environment. However, the articles that mention these symptoms do not do so in a logic of diagnosis or evaluation. Instead, it is often done in order to promote a method of solving these problems (Agile, Lean Engineering, Theory of Constraints, etc.).

Thus, we propose the equivalent of the Web of Conflict of (Smith, 1997), applied to the ETO/Project environment. Then, as with the MTO/MTS Current Reality Tree, we will describe each of the branches associated with this ETO/Project environment.

1. Proposition of conflicts

Through the use of the *Thinking Processes* method and the symptoms mentioned above, the proposal of the Web of Conflict is as follows:

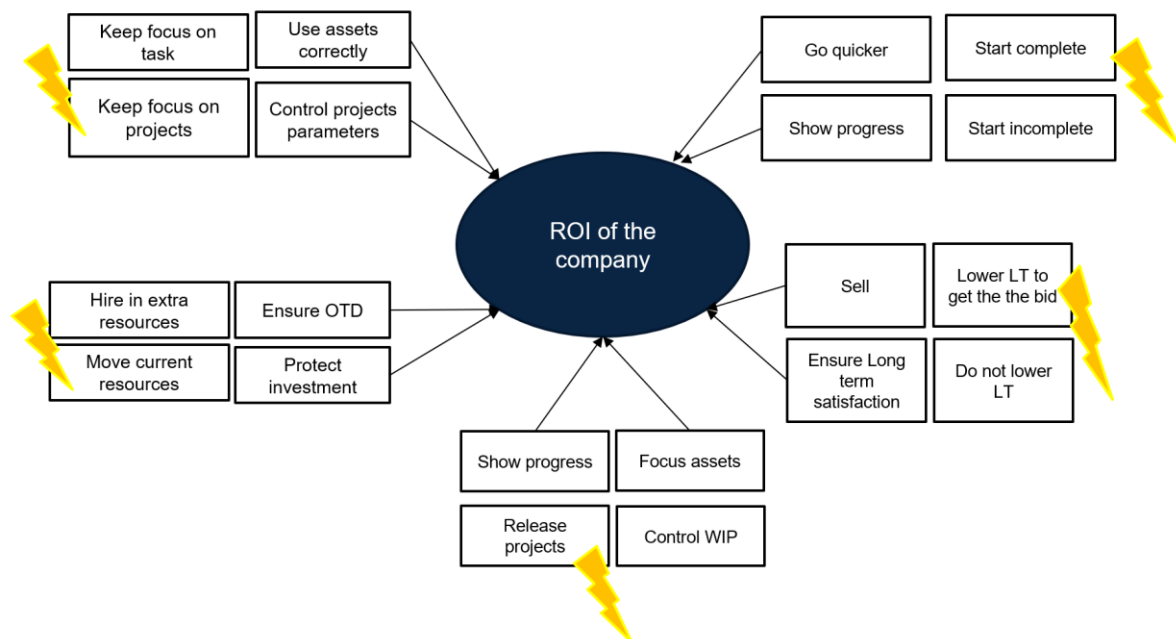


Figure 53. Proposition of generic conflicts in an ETO environment

Five conflicts have been identified:

- Add or not add additional resources;

- Stay focused on tasks or focus on the overall progress of the project;
- Start a task with all items or with missing items;
- Reduce the cycle to win the order or not reduce the cycle;
- Monitor the start of projects or start all projects at the same time.

2. Add additional resources to the project or not

1. Description of the conflict

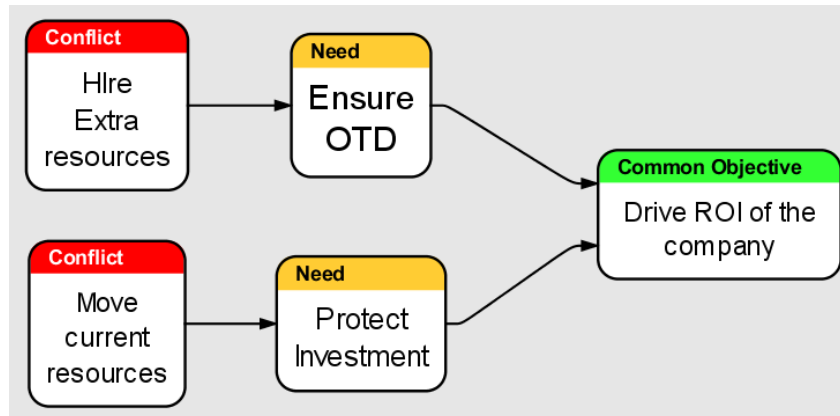


Figure 54. Hire extra resources or move resources Conflict Cloud

In order to guarantee the ROI of its project organization, the company is pushed to do everything possible to guarantee its commitment while protecting the time investment of its teams (Kendal and Rollins, 2003). The situation will become conflicted as follows: to ensure good quality of service (OTD) despite problems, the project team is pushed to demand more resources but to protect its investment, the company seeks instead to reallocate/move resources among the different projects (Kendal and Rollins, 2003).

When the project is subject to problems and the company is subject to firm customer requests, the company must find a way to compensate for the loss of time associated with these problems (Carvalho and al. 2015, 2017). The way to compensate for this loss is to move resources from one project to another (Mirabella, 2018). By doing this, the one-off increase in capacity will certainly help the project in difficulty but it will put the project from which the team was moved at risk. Thus, the company often finds itself sacrificing one project to save another.

2. Description of the tree branch associated with the conflict

The representation of the tree associated with this conflict is shown in the following figure:

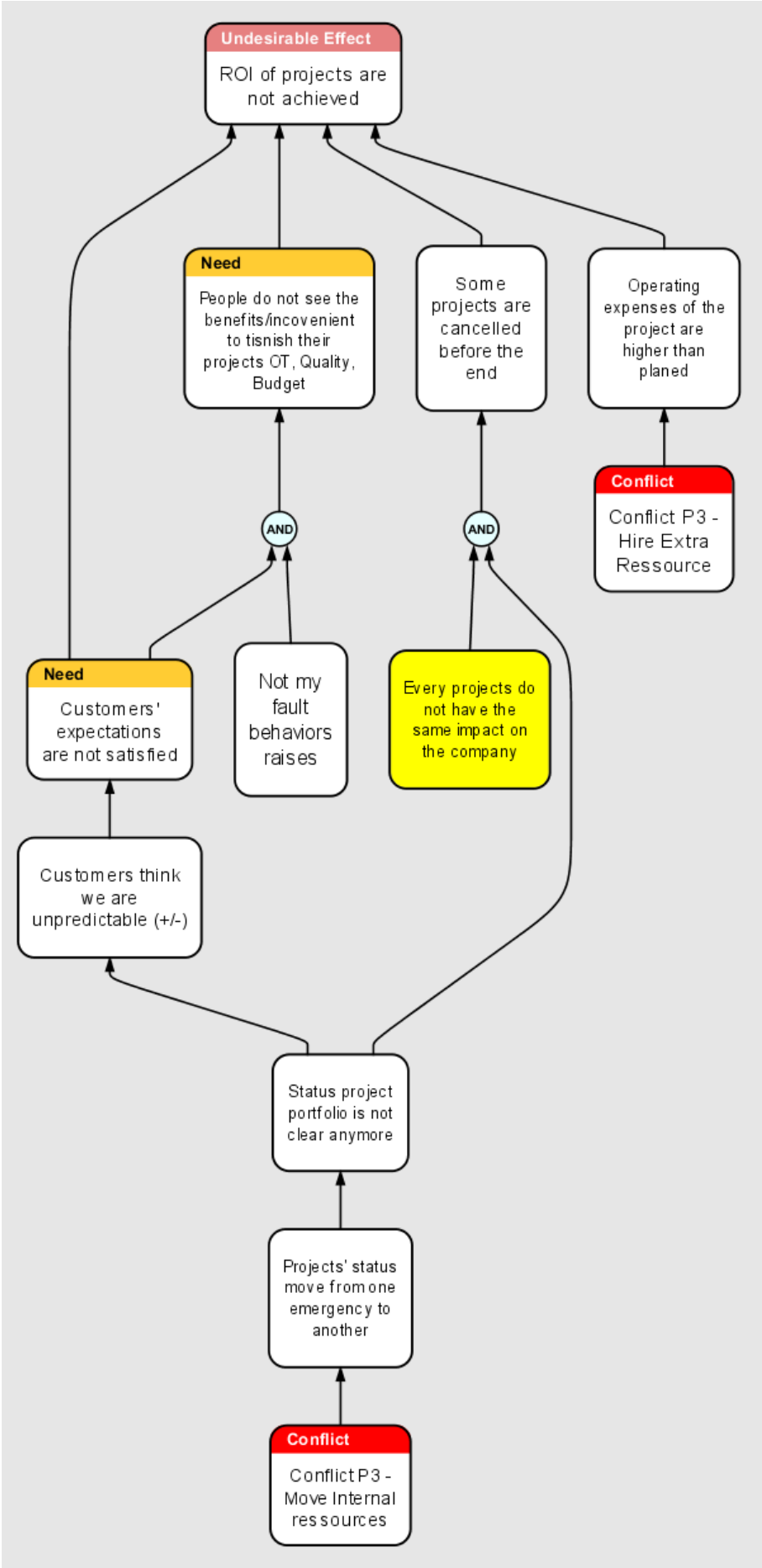


Figure 55. Schematic representation of the Current Reality Tree for resource allocation

If the company is forced to move resources from one project to another then it is likely that the status of its projects will go from one emergency to another (Mota et al., 2008).

When this is the case, the status of the project portfolio is no longer visible to the organization and its customers. The latter then think that the company is unpredictable. This leads to dissatisfaction with needs and thus a threat to ROI in the long run (Mota et al., 2008).

At the same time, if the status of projects is not clear, and not all the projects have the same impact on the organization, then some projects will be cancelled before the end, which will be a total loss in terms of ROI (Kendal and Rollins, 2003).

Finally, if the company chooses to hire additional resources, this will increase the operational expenses of the project and therefore negatively impact the ROI of its organization (Ghiyasinab and al. 2020).

3. Start with all inputs or start without all inputs

1. Description of the conflict

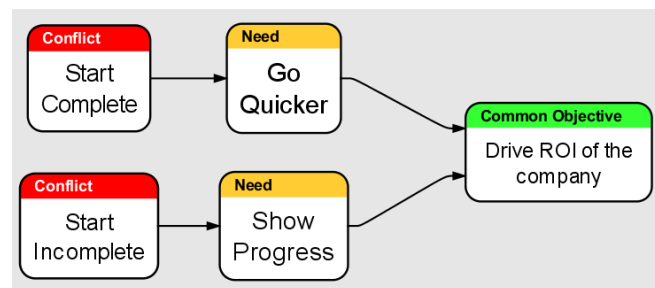


Figure 56. Start tasks with all inputs or without all inputs Conflict Cloud

In order to improve the ROI of its project portfolio, the organization must execute its projects as quickly as possible while showing progress to its customers. The way to go faster is to have all the input data to start the execution of a task; however, in order to show progress to its customers, the business may have a tendency to start without all the elements (Too and Weaver, 2014).

As we have seen previously, one of the challenges of the project team is to show its customers that the project is progressing at the desired speed (Browning, 2009). The most commonly used indicator is the percentage of project progress. This is measured by the time spent working on the task in relation to the total time allocated to complete the task (Cooke-Davies and Arzymanow, 2003).

For the team to show progress on their project, they have to show that they are working on the tasks. If one or more tasks are subject to problems, and the team wants to show that the project is moving forward, it may tend to start another task to show that work has been done on the project (Too and Weaver, 2014). Thus, the progress of piecemeal tasks is shown, as well as general progress.

On the other hand, the effectiveness of a project is measured by the time it takes to complete the task. This time is measured between the start date of the task and its end date. The comparison with the initial duration makes it possible to see whether the project team has fulfilled its commitments or not. When moving from one task to another because missing

elements have prevented a task from being completed, given that the task was started, the measurement of time continues (Browning, 2009). Thus, the surest way for a project team to keep its time commitments is to start by having all the elements needed for finishing a task, because this allows the team to be efficient in the execution of the task.

2. Description of the tree branch associated with the conflict

The following figure shows the Current Reality Tree associated with the conflict:

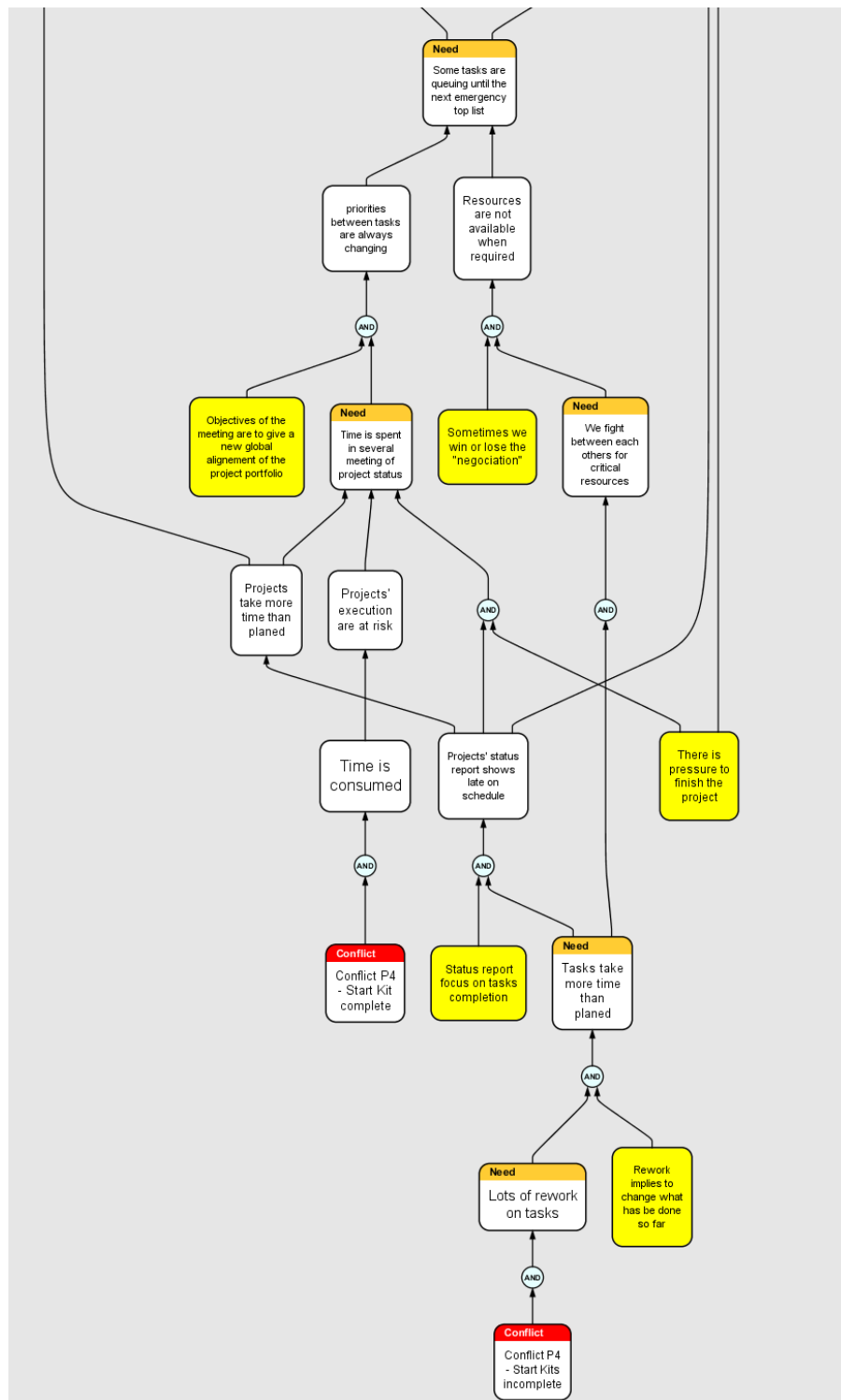


Figure 57. Schematic representation of the Current Reality Tree for starting with kits complete or not
(Part 1)

If the project team starts tasks without having all the elements, this may result in significant reworking of the tasks. If reworking involves modifying things already done, then the duration of the tasks will increase (Love et al., 2002).

If the duration of the tasks increases and the monitoring reports focus on what has been achieved, then the report will show some delay to the schedule. If the schedule shows delay and the organization is under pressure to finish on time, then the project team will spend a lot of time in meetings making progress reports. If the company and the project team spend a lot of time on progress reports, then the priorities between the tasks and the projects will change often.

If the tasks take longer than expected, we will tend to find the best capable resources and therefore commit ourselves to obtaining them (Tereso et al., 2008). When negotiating for resources, the chances of success are uncertain. In any case, this will mean that resources will no longer be available when they are needed. Finally, if the resources are no longer available when they are needed, then the tasks will wait in the queue.

The rest of the tree is shown below:

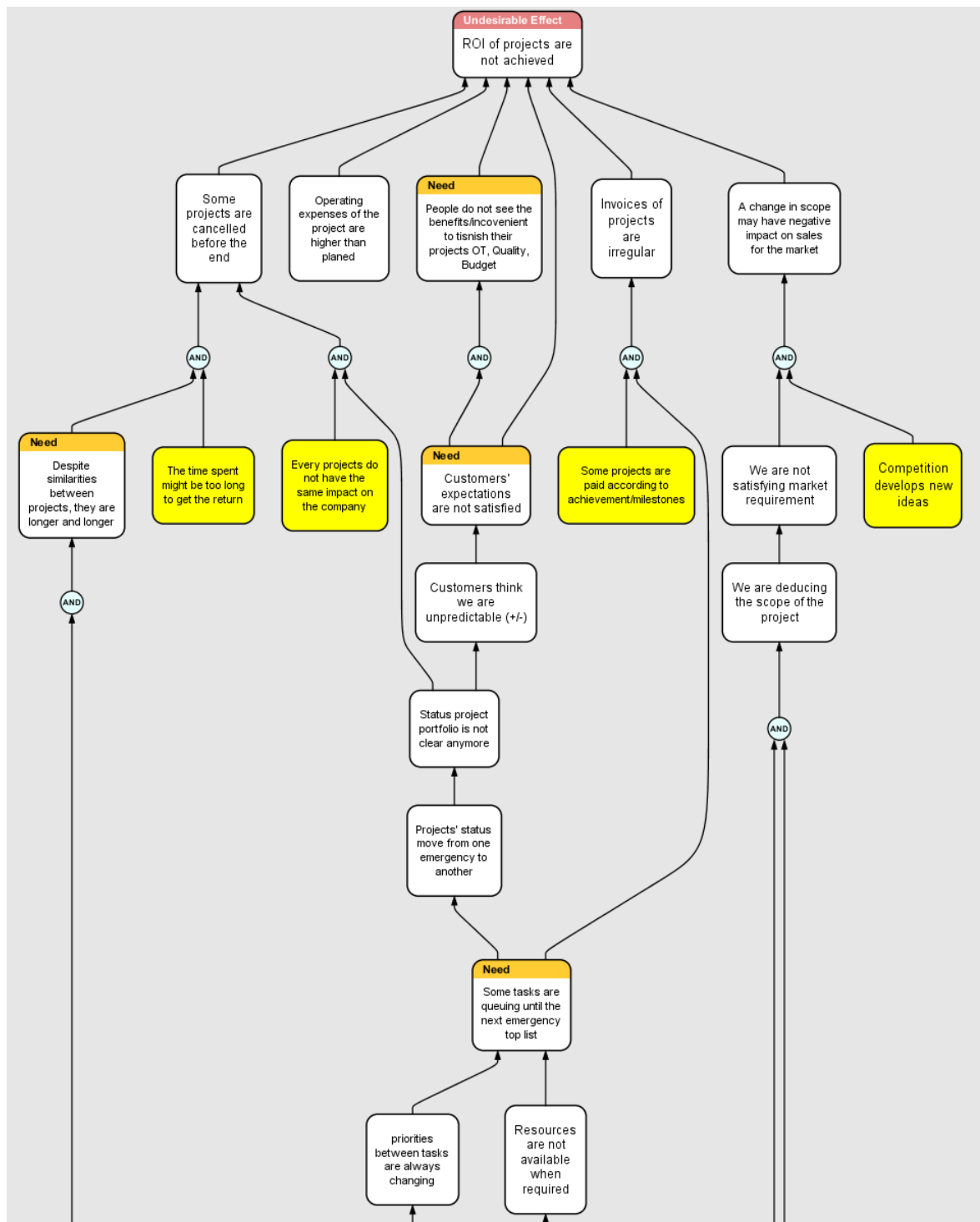


Figure 58. Schematic representation of the Current Reality Tree for starting with kits complete or not (Part 2)

As we have previously seen, when tasks wait in the queue, projects may move from one emergency to another, resulting in a lack of visibility across the portfolio and therefore client dissatisfaction (Anavi-Isakow and Golany, 2003).

Moreover, if the projects take longer than expected, we will observe time differences among the projects despite the fact that they are of the same type. In some cases, if these times are too long, the return on investment will be difficult to achieve and therefore the company may

choose to cancel its project before the end, which will result in a total loss for the ROI of the company (Anavi-Isakow and Golany, 2003).

Finally, when projects have been delayed and the company is under pressure to finish on time, the company or the project team can try to revise downwards the requirements of the initial specifications. By doing this, the company no longer meets market demand. If demand is no longer met and the market has several players competing among themselves, then the impact on sales can be significant (Shafiee and all, 2017).

If the impact on sales is significant, and projects are frozen before completion and project billing is irregular, then the ROI of the company's projects is threatened (Kendal and Rollins, 2003).

4. Focus on the task or on the project

1. Description of the conflict

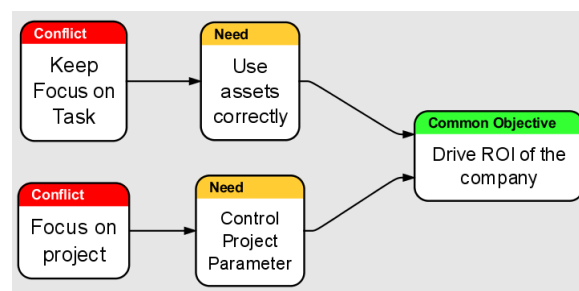


Figure 59. Focus on the task or focus on the project Conflict Cloud

In order to achieve the ROI of the company working on the projects, it is necessary to make proper use of the resources made available while ensuring that the project is properly executed (Bryde, 2005).

On the one hand, the project team must focus on the tasks one by one, because this ensures that all the resources are working and that these resources are fully used. At the same time, this detailed focus on the task does not allow the project team to see the overall status of the project (Newbold, 1998).

Thus, in order to have control over the project as a whole, the project team must focus on the generic parameters of the project (end date, critical path) to ensure customer satisfaction.

2. Description of the tree branch associated with the conflict

The Current Reality Tree associated with this conflict can be seen in the following figure:

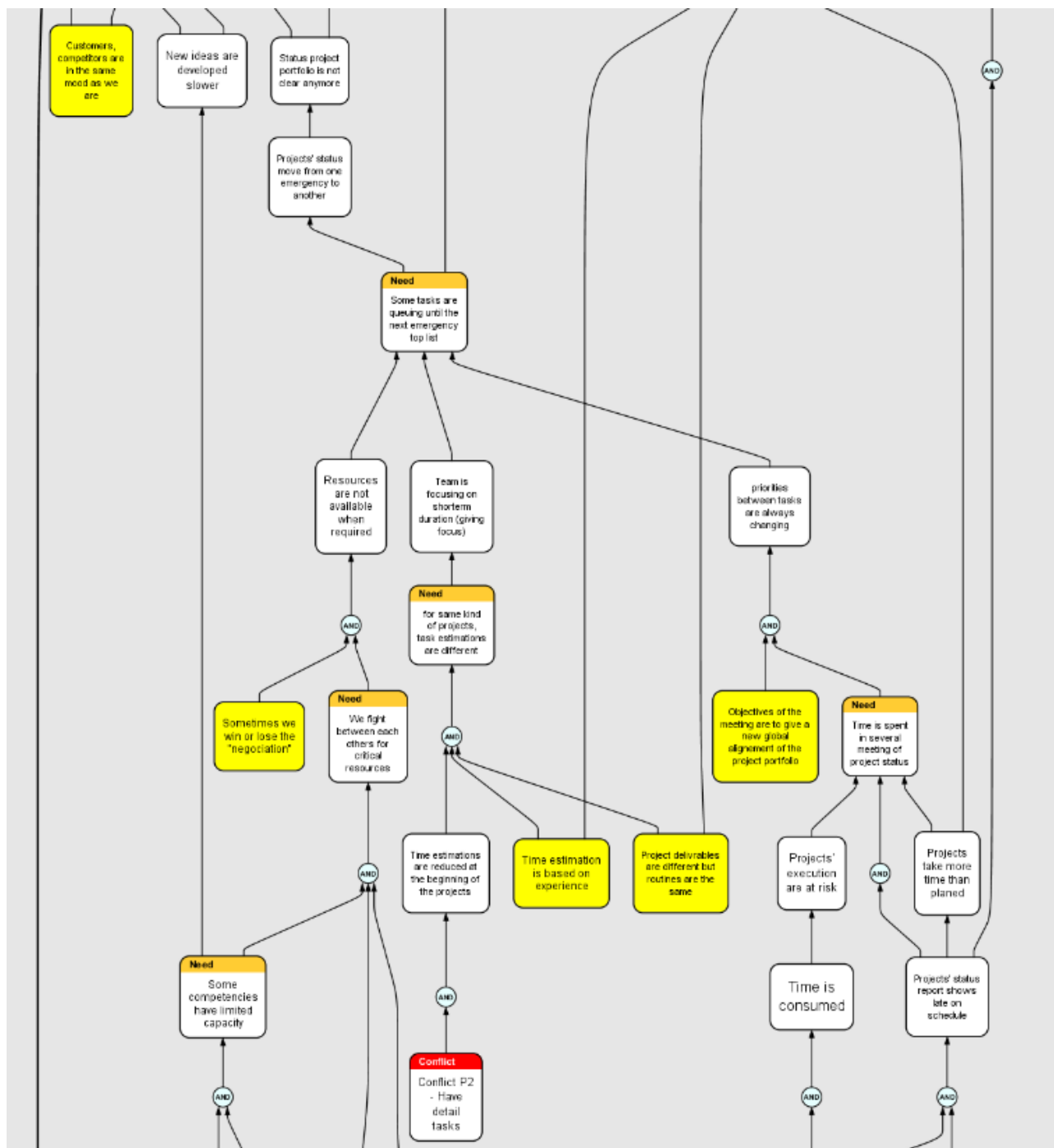


Figure 60. Schematic representation of the Current Reality Tree for granularity of task (Part 1)

If the resources have limited capabilities and they work on several projects in parallel, then the teams will fight to get the resources. Thus, not all resources will be available when they are needed (Newbold, 1998).

If the company has detailed its tasks in a significant way and the organization wants to go faster in the execution of its projects, then the organization will decide to compress the duration of certain tasks from the beginning of the project (Goldratt, 1997).

If the task estimates are reduced from the beginning of the project but the estimates are usually based on experience or on projects in the same portfolio that are similar in execution, then for the same type of project, the task estimates will be different. If, for the same project, the task

estimates are different, then the project team can focus only on tasks with a short-term horizon to execute its projects (Goldratt, 1997).

If teams spend time in meetings reporting, and if the purpose of these meetings is to align teams with what needs to be achieved, then the priorities within the project portfolio may change (Mota et al., 2008).

If that same team has to fight for the resources it needs and the organization sometimes gives or doesn't give the team these resources, then the resources are not always available when they are needed (Schwindt, 2006).

Therefore, if the resources are not available at the time of need and if the priorities among projects change and if teams focus only on the short term, then the tasks of some projects will wait until they become urgent for the organization. (Newbold, 1998).

At the same time, if there are tasks missing on the projects, then we will waste time doing them and put the execution of the project at risk. If the project is at risk, the company will put into place mechanisms to compensate for the delay (status report meetings) which will lead to changes in priorities (Leach, 2006).

The rest of the tree is represented as follows:

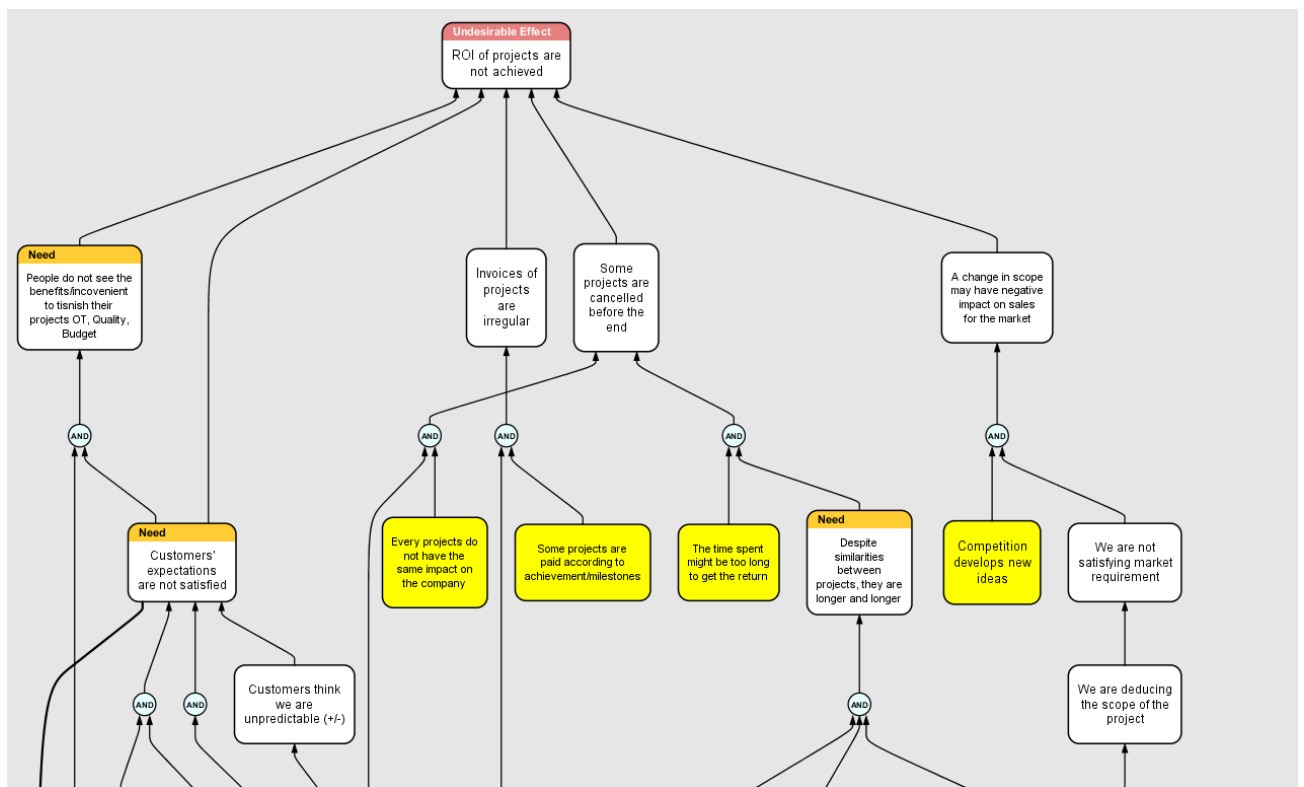


Figure 61. Schematic representation of the Current Reality Tree for granularity of task (Part 2)

As we have seen earlier in the paragraphs, the same causes produce the same effects with regard to customer dissatisfaction, delays and risks vis-à-vis the competition.

5. Propose a shorter cycle to win the order or maintain the cycles

1. Description of the conflict

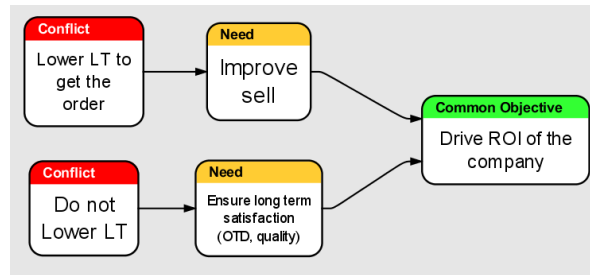


Figure 62. Reduce the cycle to win the order or maintain the cycle Conflict Cloud

In order to improve the company's ROI, it must increase sales while guaranteeing long-term customer satisfaction. To improve its sales, particularly in project management, the organization must offer shorter cycles to win orders, but at the same time, the organization must maintain its cycles to ensure it remains respected (Huang and Han, 2008).

In an ETO environment, price is an important asset but the cycle offered for delivering the ETO order is paramount. This generates strong competition on the cycles offered by companies on the market. Losing an order due to a small cycle gap has a very negative impact on the company. Given that most project schedules contain safety margins, it is possible to sacrifice this margin to offer a shorter cycle and therefore hope to win the order (Zarghami et al., 2019).

This margin is intended to protect the project from problems that may arise (Zarghami et al., 2019). By removing this margin, the project team puts its resilience to the problems of the project at risk. If there is no longer any resilience in the project and the team suffers problems, the stakes of the project are threatened. Thus, having to sacrifice the cycle to win the order will endanger the project and threaten its performance.

2. Description of the tree branch associated with the conflict

The Current Reality Tree associated with the conflict can thus be described in the following way:

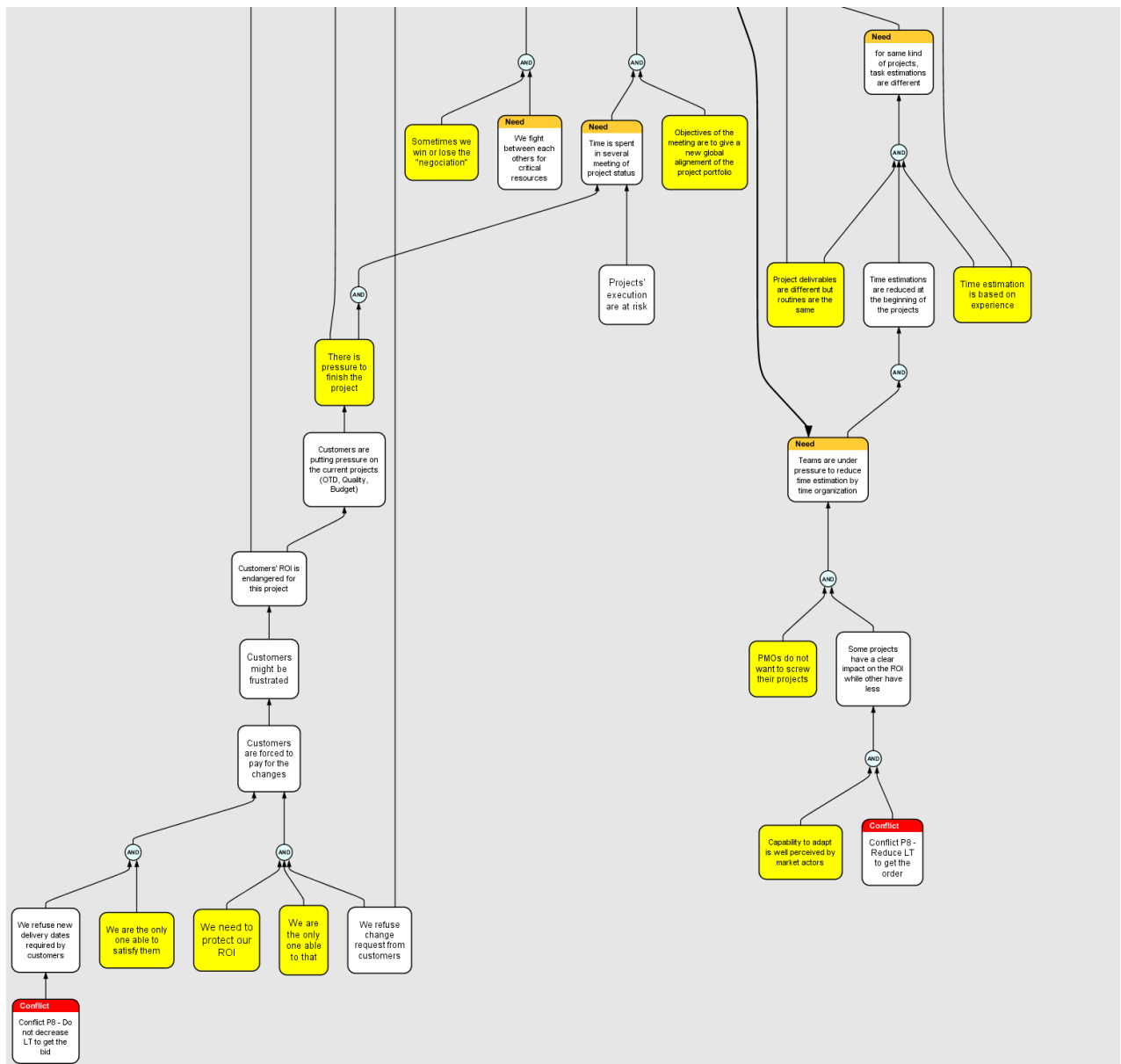


Figure 63. Schematic representation of the Current Reality Tree to manage Leadtime to get orders (Part 1)

If we refuse to reduce production cycles to win an order then we will refuse to satisfy the customer's needs. But if we are the only company that is technologically capable of satisfying the customer, then the customer will be forced to endure our actions or not (Kendal and Rollins, 2003).

This point will then potentially disappoint the customer who in addition will see his ROI threatened. When the client's ROI is threatened, the client may strongly insist on completing the project, and one of the means of using pressure is to organize regular follow-up reviews (Kendal and Rollins, 2003).

Or, if the company reduces the cycle to win the order and doing this is well perceived by the market, then the reduced project can have a very strong impact on the ROI of the organization. If the ROI is significant and the company wants to succeed, then the team will find itself having difficulty satisfying the durations that have been reduced (Kendal and Rollins, 2003).

Generic Current Reality Tree for ETO

When the durations have been reduced but the project remains similar to other projects carried out in the past, then the organization will end up with similar projects but with different execution times (Kendal and Rollins, 2003).

The rest of the tree is described below:

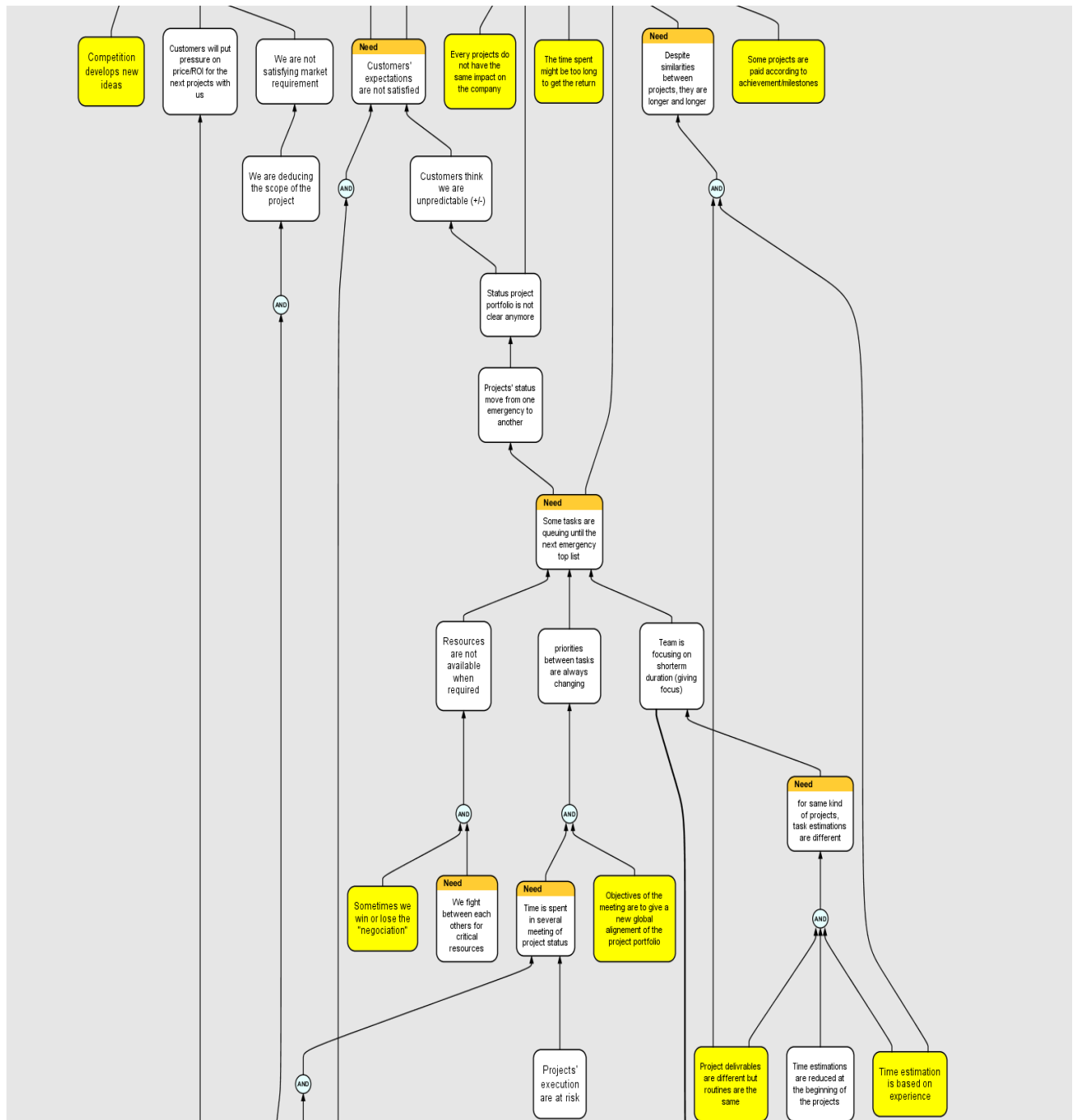


Figure 64. Schematic representation of the Current Reality Tree to manage Leadtime to get orders (Part 2)

When, for the same project family, the time estimates are different, this then causes teams to focus only on short-term tasks. Indeed, under pressure, teams tend to focus on the tasks they can complete. Generally, these tasks are known and mastered because they are within the short-term horizon of the person responsible for this task (Leach, 2014).

If, in parallel with this element, clients are frustrated and hold follow-up meetings, then priorities may have to change between the projects that do not meet the client's requirements and projects whose duration has been reduced in order to win a contract. Thus, the tasks will end up in the queue with regular priority changes. (Leach, 2014)

6. Start all projects or not

1. Description of the conflict

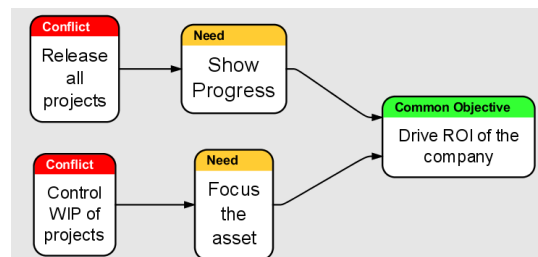


Figure 65. Control the start of projects or not Conflict Cloud

In order to improve the ROI of its project portfolio, the company must show that the teams are working on all the projects while at the same time showing that they are using the resources made available to them correctly.

To show progress on its entire project portfolio, the company must start and advance all its projects. But to demonstrate good use of its resources, it is necessary to monitor the ongoing projects so as not to disperse the teams (Nwokeji et al., 2018).

The parallel with the monitoring of the work in progress in the workshop is quite similar to ETO environments. Indeed, in an ETO environment, the company must show that the tasks in its project are executed correctly on all the projects for which it is in charge. Thus, to meet this objective, the company will start all projects in order to satisfy customers (Leach, 2014). By starting all projects, the company takes the risk of clogging up its portfolio and slowing down the execution of tasks. This will lead to the following phenomenon: all the tasks will show progress but none will be closed (Newbold, 1998).

By controlling the ongoing projects, which is to say, by limiting the number of projects in the system, the company takes the risk of having unoccupied resources. This vacancy may lead to loss of productivity and therefore gains for the company (Nwokeji et al., 2018). However, the advantage of this vacancy is that the resources that have tasks to perform will not be bottlenecked and will be able to execute their tasks more quickly. This faster execution will speed up the ROI of the company.

2. Description of the tree branch associated with the conflict

The description of the tree is represented as follows:

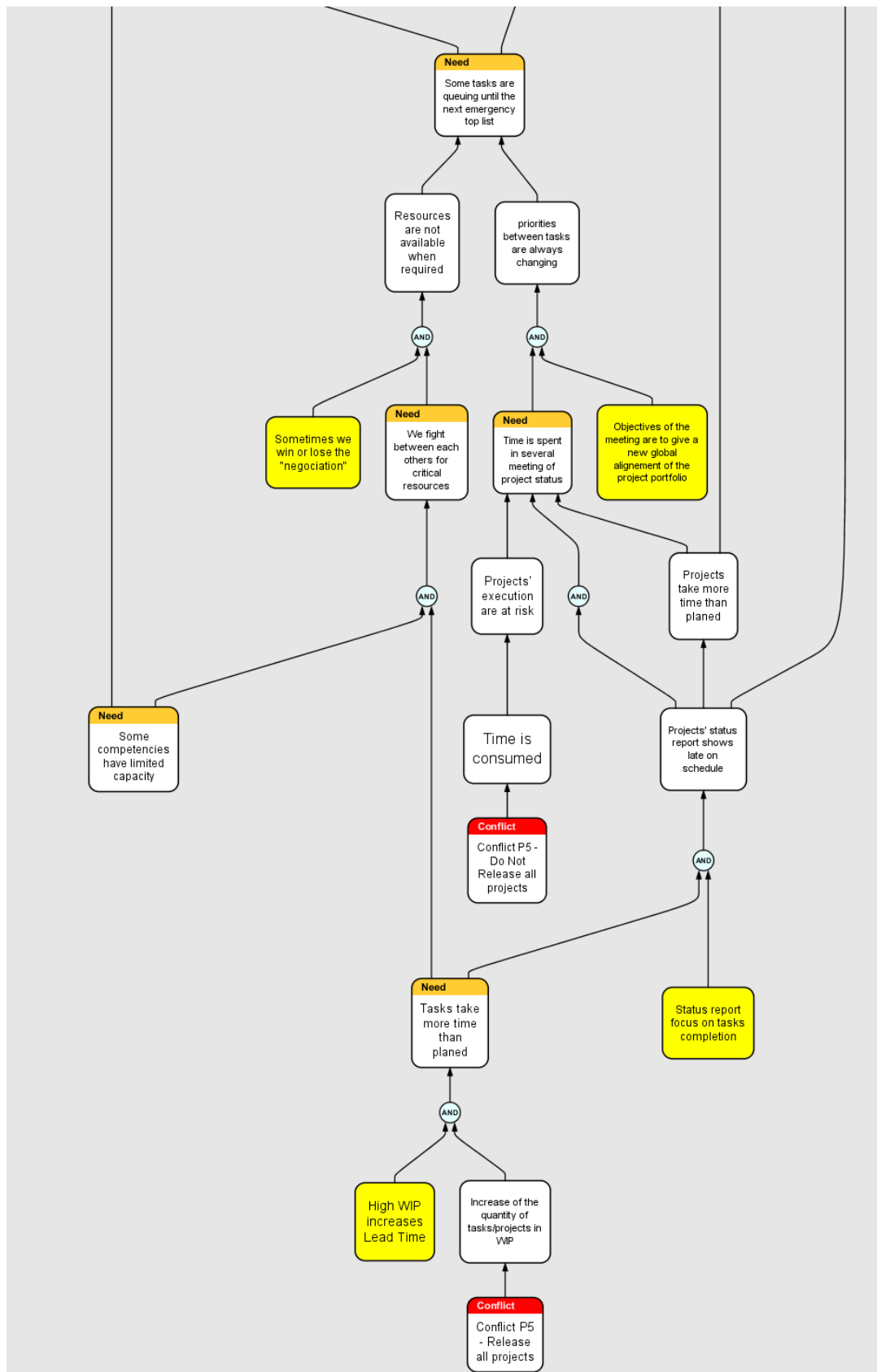


Figure 66. Schematic representation of the Current Reality Tree for releasing new projects

If all the projects are launched at the same time, then there will be a significant number of ongoing projects and important tasks. If the cycles increase when the work in progress is substantial, then the tasks will take longer than expected (Leach, 2014).

If tasks take longer than expected and resources are at a finite capacity, then project teams may fight among themselves for the resources they need (Nwokeji et al., 2018).

If the tasks take longer than expected and the task tracking of the teams focuses on the completion of the tasks, then the task tracking will show a delay on the schedule. If the projects fall behind schedule and the main challenge of the projects is to finish them on time, then the organization will generate a significant number of meetings to advance the projects.

If the projects are not all started at the same time, the project managers will feel that they are wasting time and putting the execution of the projects at risk because no one is working on the project and time is running out. As soon as project implementation may be at risk, project leaders will begin to establish organizational structures to track the start of the project (Goldratt, 1997).

By following the progress of a project and/or the beginning of the project at the same meeting, the project team will change the priorities in the projects. These changes combined with the unavailability of resources will increase the queue of tasks and projects in the work in progress (Newbold, 1998).

Now that we have seen the different elements contained in the knowledge bases, it is time to see how this knowledge base interacts with the information collected during the diagnostic phase. Once this element is described, we will show how we used it through case studies and then the overall results we obtained.

In this chapter, three new contributions have been developed:

- 1/ The first contribution, of a scientific nature, concerns the formalization of the validation and enrichment of a generic Current Reality Tree, in the form of a graph-oriented knowledge base, adapted to the characterization of MTS-type production systems. This contribution provides a first element of response with reference to the scientific objective SO1 presented in Chapter I of the manuscript.*
 - 2/ The second scientific contribution consists in the development of a generic Current Reality Tree adapted to ETO-type production systems. This second knowledge base is completely new and undertakes to complete the answer to the SO1 scientific objective of this research work.*
 - 3/ The third contribution, of a technical nature this time, consists in the implementation of a technical solution to instantiate the two previous knowledge bases within the framework of the decision support system described in the previous chapter. This contribution is in response to the technical objective TO1 described at the beginning of this manuscript.*
-

CHAPTER V. EXPERIMENTS AND VALIDATION

“Even a broken clock is right twice a day...”

Dr. House

In order to show the usability and relevance of the proposal, we will in this chapter develop two industrial case studies. The first will be dedicated to an MTO environment while the second will focus on an ETO environment. Next, we will discuss the validity of the proposal and its limitations, analyzing the results obtained on all the industrial cases carried out during this research work.

1. Field Experiments

1. Utilization of DOSSARD in an MTO/MTS environment

1. Presentation of the case

The studied company is an SME in the industrial sector. It manufactures springs for different markets:

- Aeronautics;
- Railways;
- Nuclear, oil & gas.



Figure 67. Example of the springs and customer applications

This company employs 55 employees distributed as follows:

- 40 workers in manufacturing;
- A 10-person support team which carries out procurement, planning, storage, and shipping;
- 5 people working on quality control operations & documentation.



Figure 68. Assets of the company

The production flow is divided into two segments:

- Short springs;
- Long springs.

Field Experiments

The reason the two flows are separated is solely related to the associated hardware constraints. The equipment needed for making long springs is larger than that used for the short ones.

From a quantitative point of view, one flow is not more voluminous than the other. It should be noted, however, that some markets are more volatile than others. The process of manufacturing a spring is as follows:

- Transfer of the material is the operation that consists in taking the raw material present in the storage area to make it available in the manufacturing workshop. The raw material is in the form of bars, as seen in the photo below:



Figure 69. Photograph of the raw material

- Cutting is the operation that consists in cutting the raw material to have the right length for the spring;
- Forming is the operation that consists in giving the final shape to the spring;
- Heating is the operation that consists in treating the spring so that it has the tensile strength requested by the customer;
- Traction is a quality control operation that consists in checking the resistance of the spring;
- Painting is the operation that consists in customizing the finished product to the color requested by the customer;
- Quality control & documentation is the penultimate step in the process. It consists in bringing together all the regulatory and technical documents and verifying that everything complies with customer requirements;
- Packaging & shipping is the last step in the process. It consists of packaging the finished product to make it available to the carrier for shipment to the final customer.

This process can be summarized in the following figure:



Figure 70. Process diagram

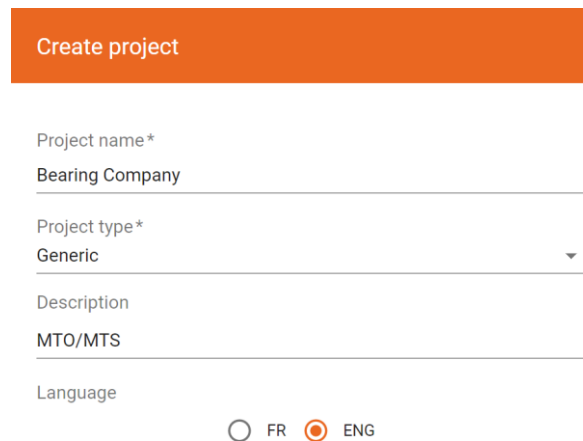
2. Utilization of DOSSARD

The way we in which we used DOSSARD is the same as for the process described in figure 21 (Chapter II).

In a practical way, we first started with two interviews during which we were able to collect the main symptoms. Then, a visit to the plant was carried out and we were able to complete the list of symptoms with other observations.

We used the DOSSARD prototype to enter the symptoms and rank the questions generated by the tool to accompany the information gathering process. This step took us about 10 minutes. With the help of the company's stakeholders, we were able to answer all the questions suggested by the tool. The publication of the tree was then carried out and it was shared with the team in order to carry out the last step of update and discussion.

Let us dwell for a moment on the details of the implemented process. At first, we had to grasp the category of the company. It was through the interviews and the factory visit that we were able to confirm that the company was indeed an MTO/MTS activity. Thus, we were able to configure our tool as seen in the following figure:



The image shows a web form titled "Create project" with an orange header. Below the header, there are four input fields: "Project name*" with the value "Bearing Company", "Project type*" with a dropdown menu showing "Generic", "Description" with the value "MTO/MTS", and "Language" with two radio buttons, "FR" and "ENG", where "ENG" is selected.

Figure 71. Generic characteristics of the company

The company's MTO activity translates as follows: in the oil & gas market, the company waits to receive orders to start manufacturing. Thus, the company makes forecasts based on the past. These forecasts allow it to determine the raw materials it will need. However, it is only when the order is received that the company will confirm its raw material needs with its supplier.

The MTS activity concerns the other sectors of activity of the company and is translated in a different way. The company determines its sales forecasts based on the past. It decides to produce the finished products without having the associated firm orders. Thus, it will store these products ready for shipment. When the customer expresses a firm need through his order, the company needs only to carry out the last two operations: quality control and packaging/shipment.

We conducted 5 interviews covering the different functions:

- Production manager who is in charge of the organization of the workshop to transform the raw materials into a finished product;
- Supply chain manager who is in charge of organizing the raw material supply activity as well as the planning of the workshop;
- Quality manager who is in charge of verifying the product from the technical and documentary point of view;

Field Experiments

- A scheduler who is in charge of planning and scheduling sales orders in the workshop;
- The supplier who is in charge of supplying the raw materials according to the needs expressed by the company.

These preliminary interviews had no particular framework. It was a question of letting the teams express themselves on the different issues of the company as well as the problems encountered by the company in responding to its challenges.

In the context of these exchanges, we were able to note the following symptoms:

- Suppliers are often late;
- The production system is obliged to incur additional expenses to deliver on time (overtime, temporary workers, subcontracting);
- The sales order book is decreasing;
- The company buys quantities of raw materials in excess of its needs;
- The stock (raw material, in-progress, finished product) is increasing;
- Team productivity (OEE) is decreasing;
- Priorities in the workshop change regularly.

The list of symptoms was integrated into the tool as outlined in Appendix A. At this stage, the DOSSARD tool can generate a set of additional questions to refine and consolidate the diagnosis.

The tool then automatically generated 57 questions as shown in the figure below. The full list of issues is presented in Appendix B.

Bearing Company

Progress bar: Propagation (green), Refining (blue), Results (grey)

Next questions (57)

Suggestions: ☐

- System will create security inside the system**
Undesirable effect
- The system buy higher quantity based on demand or forecast**
Undesirable effect
- Sales flow is slower than planed**
Undesirable effect
- Raw Materials synchronization is threatened**
Undesirable effect
- Internal Lead Time are longer than planed**
Undesirable effect
- Production has less time to produce what is planed**
Undesirable effect

Last changes

- Priorities may change**
Undesirable effect
☒ Validated
- OEE is lower**
Undesirable effect
☒ Validated
- Inventory is increasing**
Undesirable effect
☒ Validated
- Systems bought higher quantities than required (through safety stock)**
Undesirable effect
☒ Validated
- Customer ordering is at risk**
Undesirable effect
☒ Validated
- System will put pressure to recover the late internally (overtime, temporary, etc.)**
Undesirable effect
☒ Validated
- Suppliers are late**
Undesirable effect
☒ Validated

Figure 72. List of questions generated for the company

To answer these questions, we brought together the 5 people initially interviewed to collectively answer each of the proposed questions. The following figure shows the DOSSARD interface used to support this step of the process. All responses are provided in Appendix C.

Bearing Company

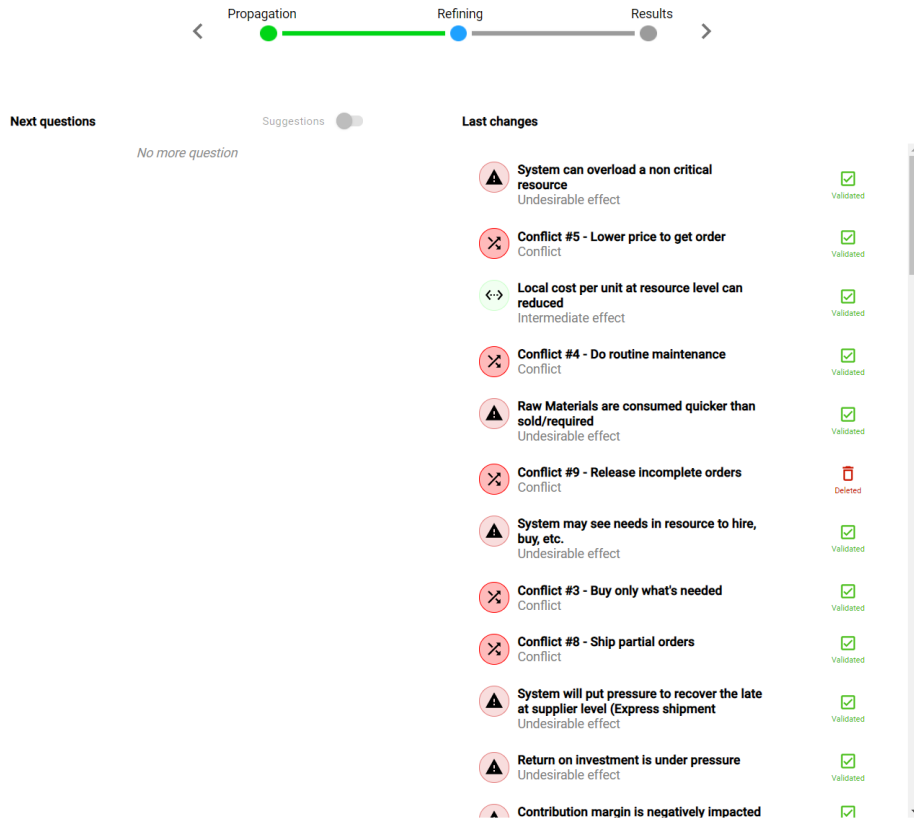


Figure 73. Screenshot of all responses

Once all the questions had been dealt with, and therefore all the symptoms had been validated, we were able to display the complete tree, which is presented in Appendix D. Given the richness of this tree (difficult to read in the format of this document), we propose to discuss several specific extracts.

During this step, the tool highlighted 3 major conflicts from which the company suffered:

- The conflict between making to order or making to stock;
- The conflict between buying the necessary quantities or buying more than needed;
- The conflict between producing large or small batch sizes.

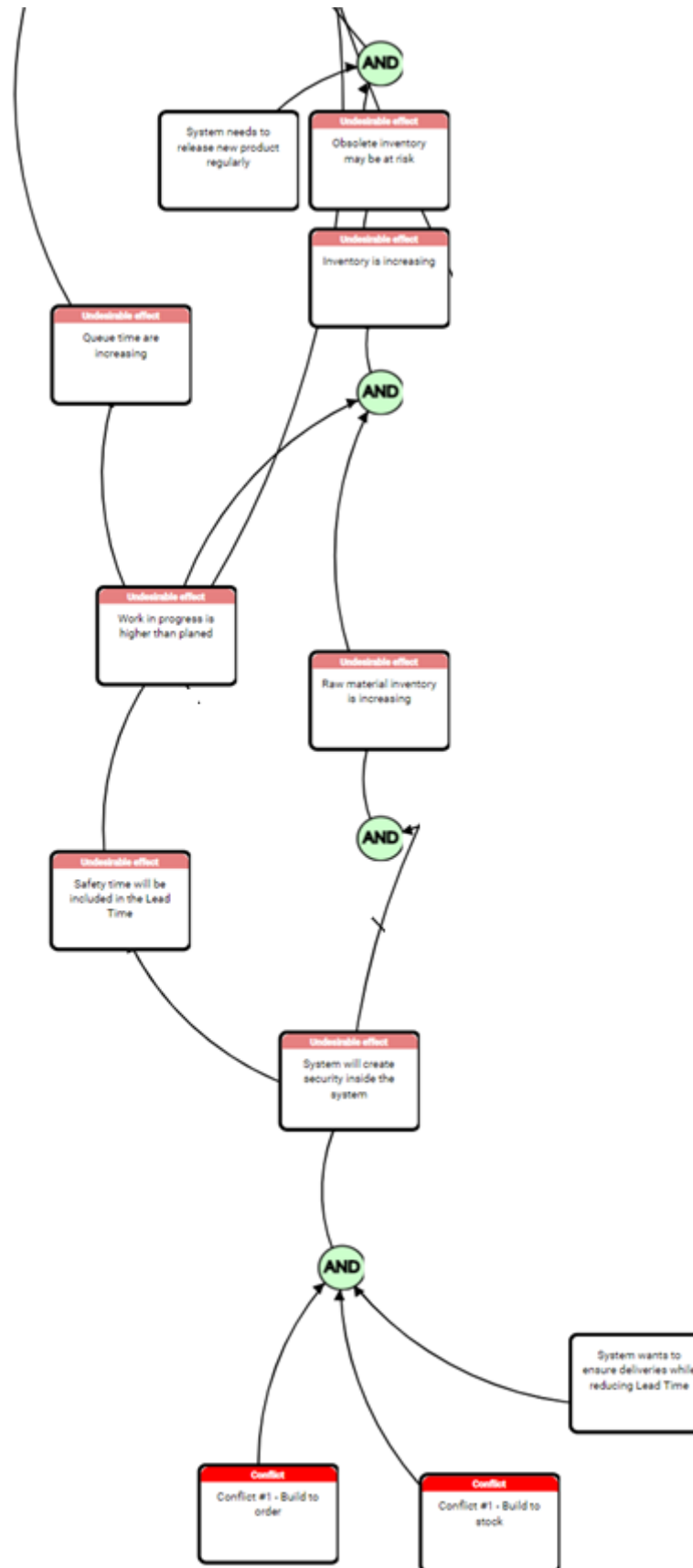


Figure 74. Manufacture to order or manufacture to stock Conflict Cloud.

In order to make these conflicts and their ramifications visible, we used the highlighting function of the tree. Below, we can see one of the logical sequences proposed by the tool concerning the

conflict of manufacturing to stock or to order. If this conflict exists, then the system will seek to protect itself through stock or time. These protections will generate more stock of raw materials and work in progress. This stock will slow down the flow and therefore increase manufacturing cycles when, at the same time, it generates a greater risk of obsolescence.

The other conflict mentioned is that of the purchase of the necessary quantity or the purchase of a larger quantity. The branch is shown in the figure below:

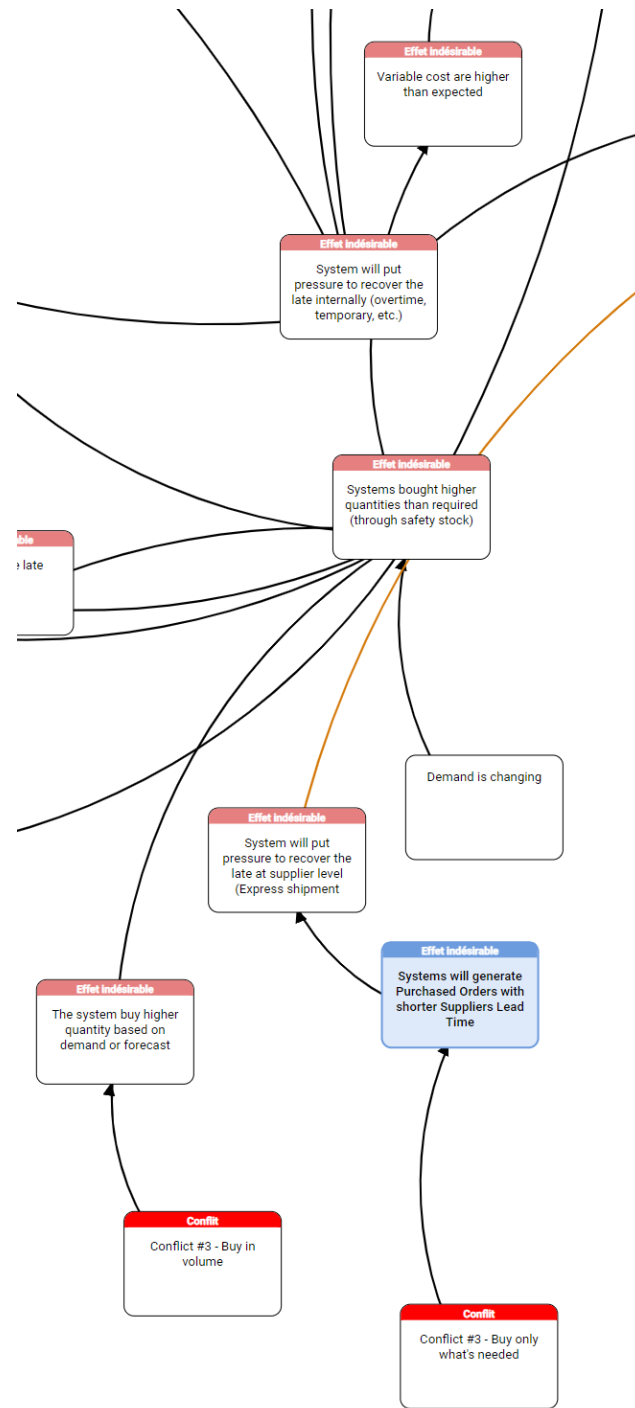


Figure 75. Buy in volume or by unit Conflict Cloud

In this branch, buying larger quantities generates stock. And as we saw in Chapter IV, this stock generation will lead to an increase in cycles and thus impact the entry of cash flow significantly.

The last conflict is shown in the following figure:

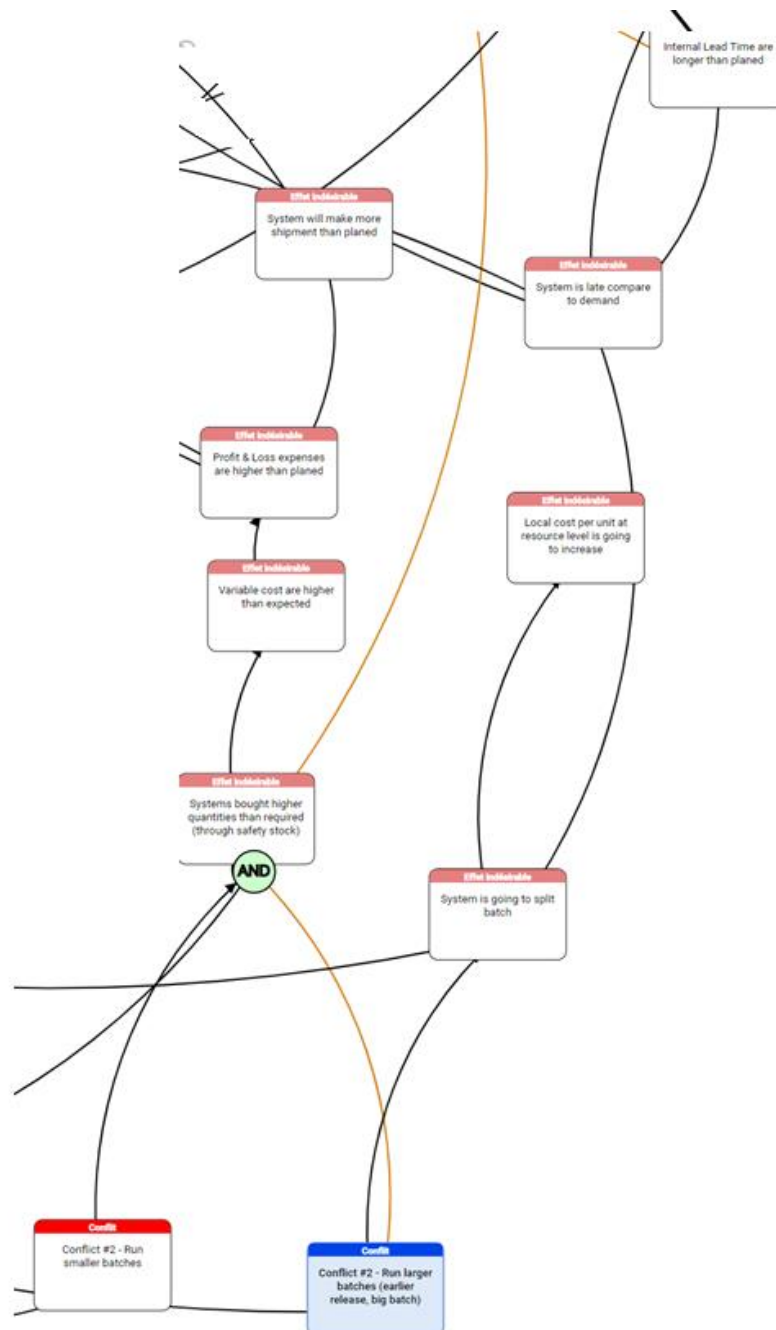


Figure 76. Manufacture in large batches or small batch sizes Conflict Cloud

Through this conflict, the tree suggests that the increase in batch sizes generates an increase in the stock of raw materials and therefore purchases in higher quantities. These purchases in higher quantities increase variable costs and invariably impact the company's income statement.

3. Summary of the implementation

In terms of implementation, it took half a day to conduct the interviews and visit the company. Entering the information into the tool took 23 minutes (the symptoms and answers to suggested questions). Reading, interpreting and sharing the diagnosis (the resulting tree) took 1 hour.

The analysis of the relevance of the results will be developed in section 2. However, we can already indicate that the audited team was able to confirm that the three conflicts identified by the DOSSARD system were indeed the main source of their problems.

2. Utilization of DOSSARD in an ETO environment

1. Presentation of the case

The company is an international group that is represented by a number of companies based in France, Europe and Asia. This company manufactures pumps for the nuclear and oil-related industries. Below you will find some photos of the products manufactured by the group.



Figure 77. Photographs of the company's products

As can be seen in the previous photographs, each product is different from the other despite the fact that all these products belong to the same pump family. A pump family corresponds to its pumping rate. This disparity is characteristic of an ETO environment because each pump is different despite similar technical characteristics.

The environment in which we made the diagnosis corresponds to an entity of 93 employees distributed as follows:

- 37 operators in production;
- 14 engineers in the design office who are in charge of translating customer specifications and designing the finished product;
- 5 people in the sales teams who are in charge of responding to customer specifications;
- 6 project managers who are in charge of the daily management of the projects;
- 12 suppliers who are in charge of placing and monitoring supplier orders;
- 4 planners who are in charge of planning the activity in the workshops;
- 3 quality controllers who are in charge of guaranteeing the compliance of the products;
- 6 people in sales administration who are in charge of the company's billing process;
- 8 members of the management team.

The process of fulfilling a sales order is carried out as follows:

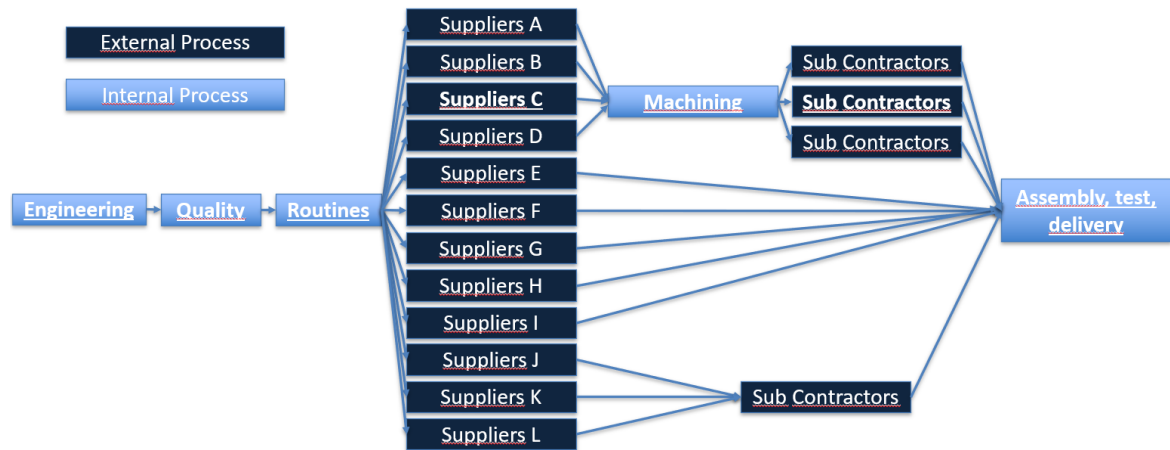


Figure 78. Schematic representation of the ETO business operation at the pump manufacturer

After the order is received, the engineers will translate the customer's specifications into a concrete language for the company. The team will then clarify the technical issues, design the product and specify all the information for the production of the project. Once this step has been carried out, the quality department will ensure the compliance of the engineering work with regulations as well as with the specific requirements of the customer. Then the quality team will validate these elements before the planning team enters all of its information into the company's management software in order to plan and also to set up the tracking of the product and its components. The team will also enter the manufacturing and assembly ranges of the finished product. Subsequently, the procurement team will place orders with suppliers, who include:

- Suppliers who deliver a component that will be directly assembled into the finished product;
- Suppliers who deliver raw material that will be machined by the company and then sent to subcontracting (surface or thermal processing);
- Suppliers who deliver material which will be transformed via external subcontracting operations.

Once all the components have been delivered, they are assembled, tested and delivered to customers.

2. Utilization of DOSSARD

As in the previous case, we had to characterize the categories of the company in the DOSSARD tool.

The collection of symptoms was done in a different way than in the previous case. Indeed, in the previous case, we had conducted individual interviews that allowed us to collect the symptoms as we went along. Here, we were able to conduct an interview directly with the entire team concerned. Thus, during the same sequence, we were able to speak with:

- A project manager;
- The manager of planning and the procurement teams;
- A supplier;

- A planner;
- 2 members of the design office.

Although the group was large, we proceeded in the same way to collect the symptoms and issues of their organization. Thus, at this meeting, we were able to collect the following symptoms (in citation mode):

- The projects are late with respect to the requirements of our customers;
- Resources are not available when we need them;
- We do not meet the technical requirements of the market;
- The teams are not motivated to carry out the projects;
- The status of the projects is not visible and clear;
- Our customers consider us unpredictable;
- We need to constantly update our schedules;
- Our customers force us to freeze the schedule.

The last two symptoms are quite significant because as can be seen in Figure 83, these symptoms are also in conflict. Thus, the group already seemed able to point out one of the root causes through the discussion. The complete entries of the collected symptoms are visible in Appendix E.

With this base, the DOSSARD tool automatically generated 54 questions according to the format shown in the following figure. The full list of issues is presented in Appendix F.

Pump Factory

Propagation Affinage Résultat

Prochaines questions (54) Suggestions Derniers changements

<p>Customers expectations are not satisfied Effet indésirable</p> <p>OUI JE NE SAIS PAS NON</p>	<p>Customers think we are unpredictable(+/-) Effet indésirable</p> <p>Valide</p>
<p>Project's status move from one emergency to another Effet indésirable</p> <p>OUI JE NE SAIS PAS NON</p>	<p>Status project portfolio is not clear anymore Effet indésirable</p> <p>Valide</p>
<p>Conflict P1 - Focus On Tasks Conflit</p> <p>OUI JE NE SAIS PAS NON</p>	<p>Hard to keep motivated the team Effet indésirable</p> <p>Valide</p>
<p>Priorities between tasks are always changing Effet indésirable</p> <p>OUI JE NE SAIS PAS NON</p>	<p>Conflict P6 - Freeze Schedule Conflit</p> <p>Valide</p>
<p>Return On Investment of projects are not achieved Effet indésirable</p> <p>OUI JE NE SAIS PAS NON</p>	<p>Conflict P6 - Update Schedule Conflit</p> <p>Valide</p>
<p>We fight between each others for critical</p>	<p>We are not satisfying market requirement Effet indésirable</p> <p>Valide</p>
	<p>Resources are not available when required Effet indésirable</p> <p>Valide</p>
	<p>Project's status report shows late on schedule Effet indésirable</p> <p>Valide</p>

Figure 79. List of questions proposed by DOSSARD

Field Experiments

Given that the team was assembled, we were able to quickly proceed to the answers of all the additional questions suggested by the tool. Thus, it can be seen that all the issues were dealt with in the following figure. All responses are presented in Appendix G.

Pump Factory

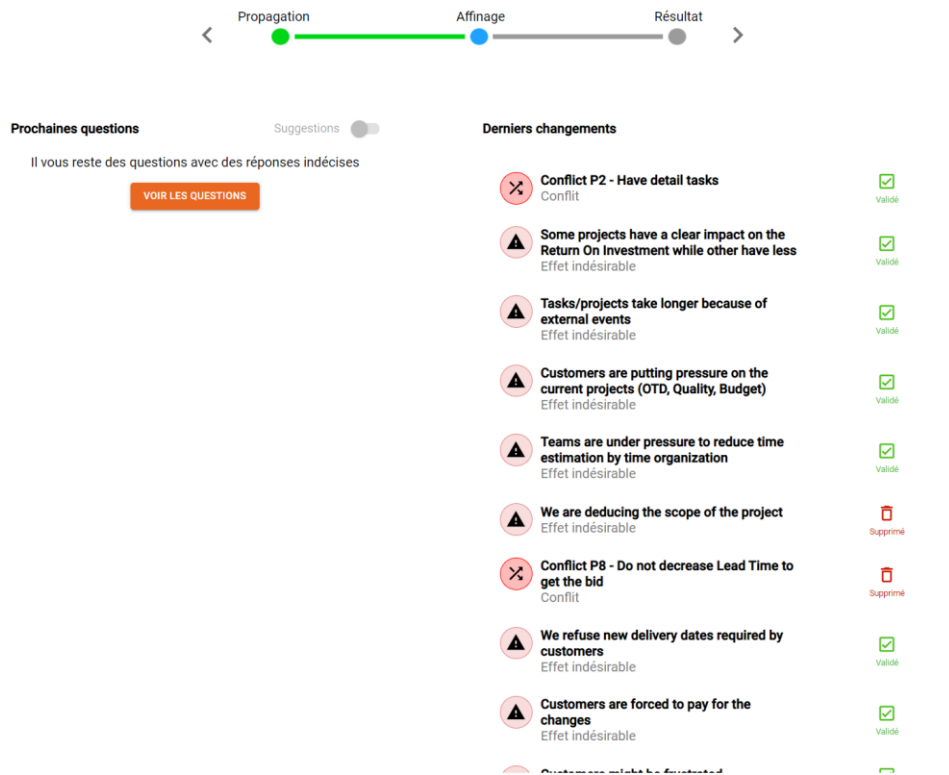


Figure 80. Answers provided by the company to the questions proposed by DOSSARD

Once all the symptoms had been validated, and all the suggested questions had been addressed, we were able to proceed with the display of the complete tree, which is presented in Appendix H. For the same reasons as before, we will not attempt an exhaustive description of the tree here, but will note that the process revealed three major conflicts from which the company suffered:

- Follow the project globally or follow the tasks one by one;
- Update the schedule or freeze it;
- Start all projects at the same time. It is worth noting that on the final tree, the opposite of launching all projects at the same time is not present. Indeed, controlling the launch of projects was simply inconceivable for the company. This option has therefore not been mentioned explicitly.

The branch of the first conflict is shown in the following figure.

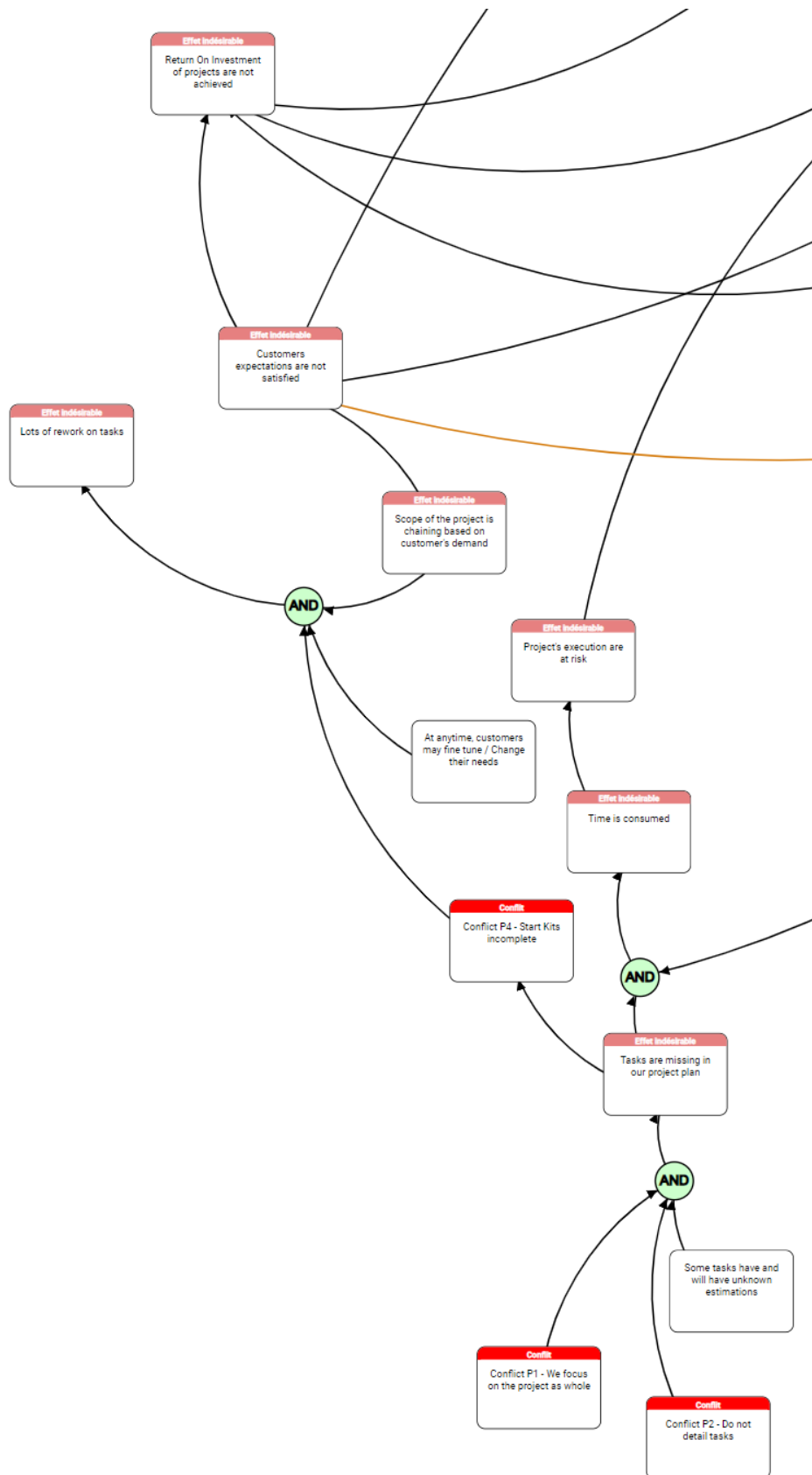


Figure 81. ETO conflict branch: Detail the tasks or not

When this conflict arises, the company takes the risk that some tasks will be missing from the project plan. Missing tasks generate two main negative effects:

- The risk of starting some projects with missing input data;

- To waste time when it becomes necessary to do the missing tasks.

Starting tasks without having all the elements generates both a risk of a resurgence of work (lots of reworking on tasks) and also unsatisfied customers because there are needs that have not been met.

At the same time, when time is lost on tasks, it means that the execution of the project is at risk. This risk creates, as we have seen in Chapter IV, significant difficulties in the implementation of the project.

The second conflict is the systematic updating of the project compared to freezing the schedule. The branch is represented by the following figure:

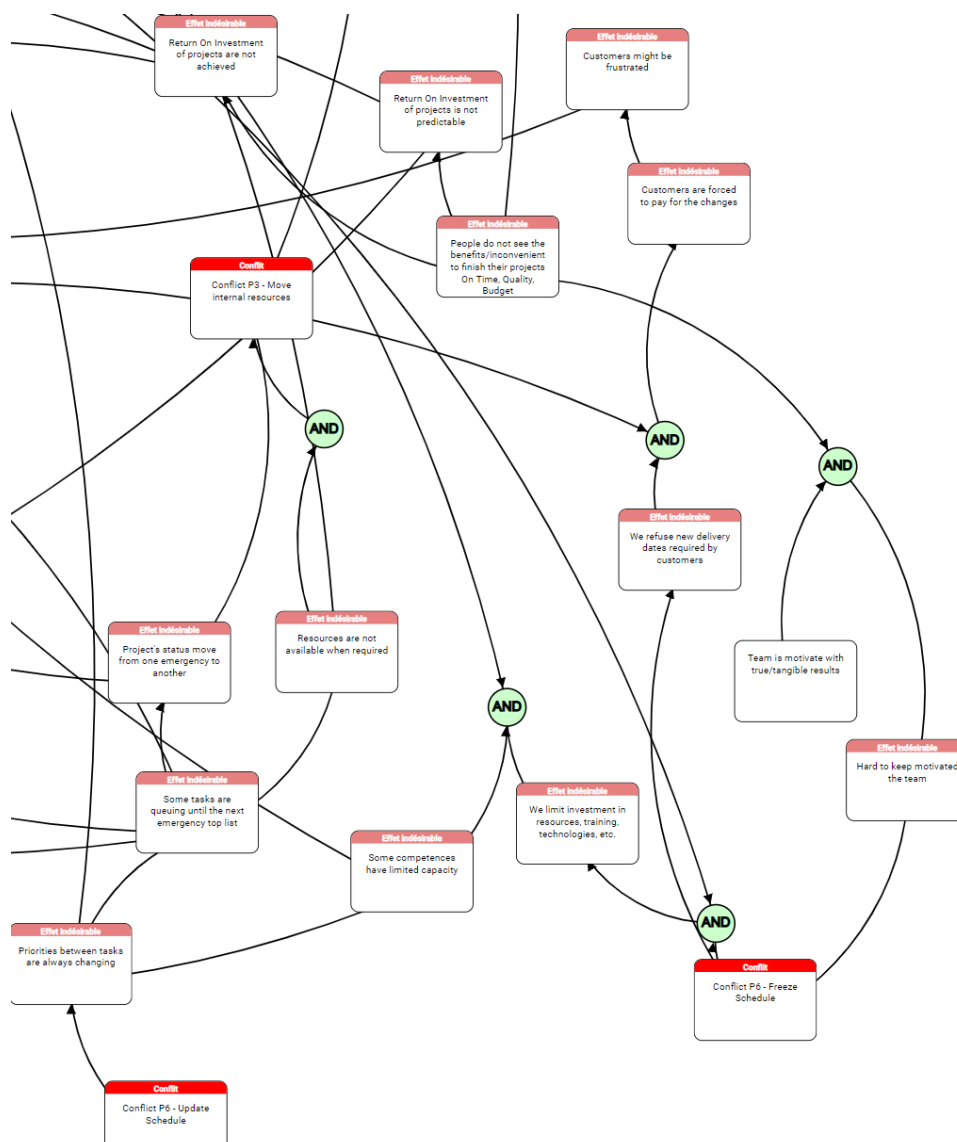


Figure 82. ETO conflict branch: Freeze or update the project schedule

On the one hand, by constantly updating the project schedule, the company generates very frequent changes in priorities. These changes cause the queue to increase because some tasks will wait for the new priority to run.

These increases generate a lack of availability of resources because they are called upon in dealing with the new priorities. The increase in waiting times means that the project is being prolonged and endangers the achievement of the project and therefore its return on investment.

On the other hand, by freezing the schedule, the customer will refuse any change of delivery date. In addition, working with the knowledge that the schedule will not be kept will cause a loss of motivation for the teams. When the client refuses any change of date but the project shifts, then the client will be forced to accept these changes which will also cause them frustration.

The last branch represents the conflict over controlling the launch of projects or not. It is shown in the figure below. When there are too many projects in the work in progress, this means that the number of tasks to be performed increases. When the amount of work in progress increases, it generates significant queues in the project flow. This increase in queues leads to tasks that take longer to be completed. When tasks take longer to complete, the execution of the project becomes more difficult, which generates delays in the achievement of the project objectives.

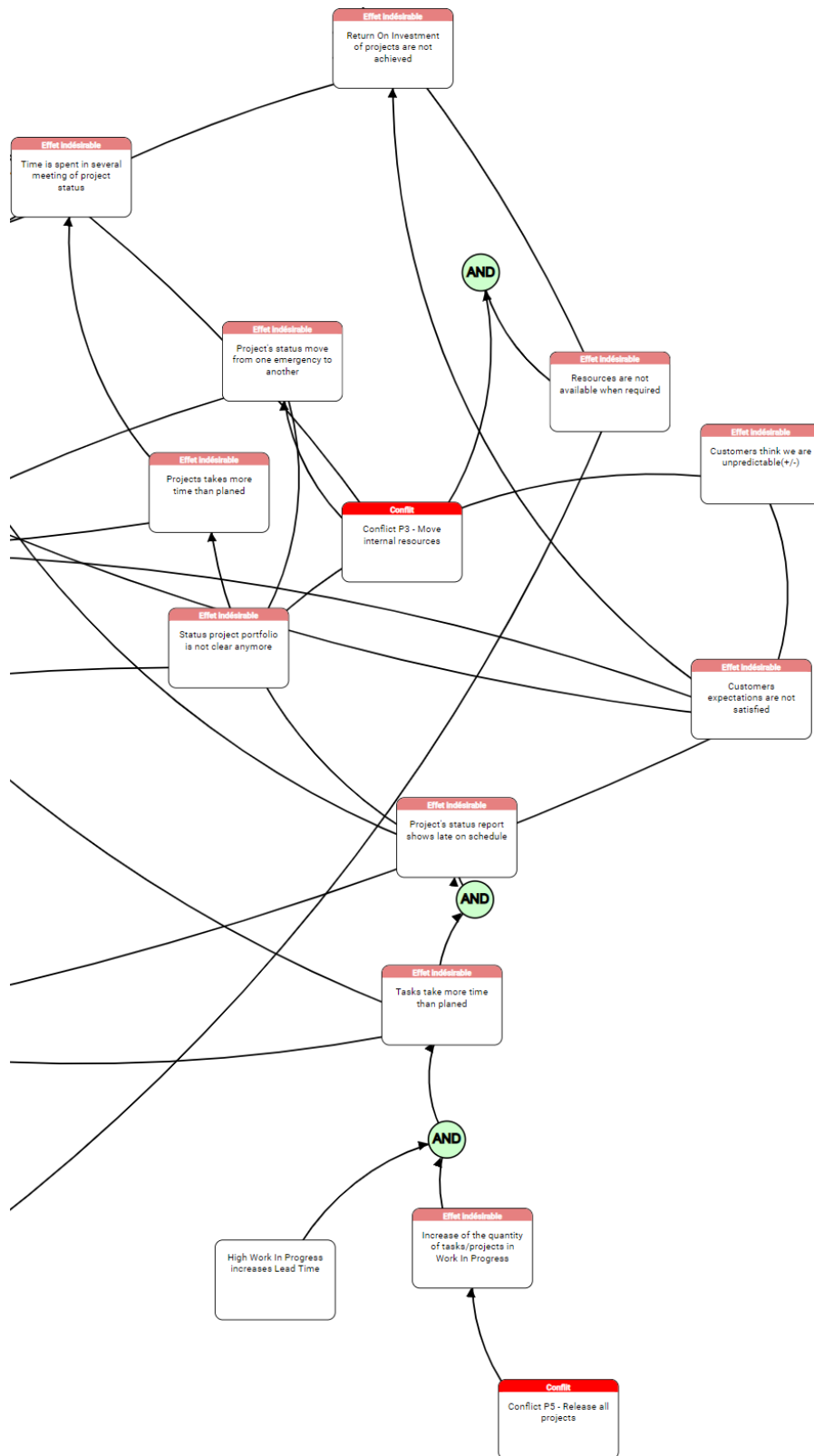


Figure 83. ETO conflict branch on starting projects

Since the team was systematically present at all stages, the tree did not have to undergo any modifications. Indeed, the questioning points were progressively clarified as we went along.

3. Summary of the implementation

In terms of implementation, it took less than an hour to complete the entire diagnostic process, helped by the presence of all the stakeholders at the working session. Specifically, 37 minutes were needed for informal exchanges, and 17 minutes for the use of the DOSSARD tool.

The analysis of the relevance of the results will be developed in section 2. However, we can already indicate that here too, the audited team was able to confirm that the three conflicts identified by the DOSSARD system were indeed the main source of their problems.

2. Validation of the results

The purpose of this section is to study the validity of our diagnostic approach in different environments. This section is divided into three main parts:

- The first part is intended for the presentation of the characteristics of the experimental plan carried out with the DOSSARD tool;
- This utilization will allow us to arrive at numerical results on the speed of the diagnoses and the relevance of their results. Thus, this will allow us to update our comparative table of methods (see Chapter II) and carry out an analysis of the information we have been able to collect;
- Finally, the last part will discuss the validity and limitations of the proposal.

1. Presentation of the characteristics of the conducted experimental plan

1. The context

As part of the Industry of the Future program developed by the *Occitanie* region (<https://www.laregion.fr/parcours-industrie-du-futur>) and in the context of the economic crisis related to COVID-19, we were able to test our approach on a large scale. Indeed, this program aims to help industrial companies in the region evolve towards a more digitalized environment of their activities. Thus, the program was divided into 2 parts:

- An industrial diagnosis lasting 3 days. These 3 days could be done remotely or face-to-face. These 3 days could be consecutive or not. The deliverable of the diagnosis was a qualified inventory and an associated action plan;
- An optional post-diagnosis accompaniment to carry out the implementation of what had been noted during the diagnostic phase.

The purpose of the diagnosis is to assess the industrial and digital maturity of the company. Through this diagnosis, the company seeks to measure the state of its industrial practices in relation to good practices and the competition. Digital maturity is assessed through the IT tools and technologies in place within companies.

For the company to benefit from this program, it must meet 3 criteria which have been defined, imposed and applied by French authority:

- Have an entity based in the region;
- Be an entity with fewer than 3,000 employees;
- Complete a grant application with the region.

To carry out the diagnoses and the implementation of the optional support actions, the *Occitanie* region called on the following actors:

- 10 consulting companies, including AGILEA;
- 57 independent consultants.

All these players are experts in the field of operations management, supply chains and continuous improvement.

AGILEA, which is one of the actors involved, has agreements with 13 of the 57 independent consultants who can intervene on its behalf. It is therefore with AGILEA consultants and its network of 13 independent consultants that we were able to carry out a wide-ranging experiment of DOSSARD.

In addition, it should be noted that I have not, as an individual, carried out any of the diagnoses associated with this operation. My only role was to accompany the users in the handling of the tool and the associated approach.

Finally, it should be noted that at the end of the diagnostic step, each company could choose whether to not validate the proposed action plan, to validate it and to decide to implement it by itself, or to validate it and be accompanied by one of the consulting firms involved in the operation.

2. The key players involved

We made the DOSSARD tool available to AGILEA consultants and its 13 partners so that they could carry out, in complete autonomy, the industrial diagnoses relating to the operation carried out by the region.

The persons concerned had the following characteristics:

- None of the consultants knew about the *Thinking Processes* method beforehand;
- Their knowledge of the *Theory of Constraints* was basic;
- We trained them for 2 hours in the use of DOSSARD as well as in the construction and interpretation of a Conflict Cloud, as mentioned in the first chapters of this thesis.

In addition, we left the consultants free to choose whether or not to use the DOSSARD tool for carrying out their diagnoses. We simply collected the results in order to learn from them. In particular, we checked whether the deliverables requested by the customers were received, i.e., carrying out a diagnosis as well as an associated action plan. Above all, we noted whether companies were inclined to continue the post-diagnosis phase with the consultant. Indeed, if the company continued, we can conclude that it was satisfied with the diagnosis (its relevance) and the way in which it was conducted.

The project lasted 8 months, from April 2020 to December 2020:

- 73 diagnoses were carried out by all the firms and independent consultants;
- 25 diagnoses were carried out by AGILEA or its network of partners;
- 18 of these diagnoses were made with DOSSARD.

Within the AGILEA consortium, the representation and use of DOSSARD can be represented by the following figure:

Company	Typology of flow	Use of DOSSARD	Next step of the company
Company 01	MTO/MTS	Yes	Support required
Company 02	MTO/MTS	Yes	Support required
Company 03	MTO/MTS	Yes	Support required
Company 04	MTO/MTS	Yes	Support required
Company 05	MTO/MTS	Yes	Support required
Company 06	MTO/MTS	Yes	Support required
Company 07	MTO/MTS	Yes	Support required
Company 08	MTO/MTS	Yes	End of the project
Company 09	MTO/MTS	Yes	End of the project
Company 10	MTO/MTS	Yes	End of the project
Company 19	MTO/MTS	Yes	End of the project
Company 20	MTO/MTS	Yes	End of the project
Company 21	MTO/MTS	Yes	Support required
Company 22	MTO/MTS	Yes	Support required
Company 23	ETO	Yes	Support required
Company 24	ETO	Yes	End of the project
Company 25	ETO	Yes	Support required
Company 11	MTO/MTS	No	Support required
Company 12	MTO/MTS	No	Support required
Company 13	MTO/MTS	No	Support required
Company 14	MTO/MTS	No	End of the project
Company 15	MTO/MTS	No	End of the project
Company 16	MTO/MTS	No	End of the project
Company 17	MTO/MTS	No	End of the project
Company 18	MTO/MTS	No	End of the project

Figure 84. Summary of the use of DOSSARD in the diagnostic phase of the experiment

2. Quantitative and qualitative analyses of the results obtained

In order to evaluate the results obtained, we proceeded as follows:

Regarding the quantitative results first, we asked DOSSARD users to record the time spent using DOSSARD in the diagnostic phase as well as to characterize the way in which the diagnosis was carried out. This included several pieces of information:

- How much time was spent using DOSSARD?
- How did you collect symptoms? In one-on-one interviews or group interviews?
- How long did it take you to finalize the diagnosis?

From a qualitative point of view, we used a questionnaire approach to assess the teams' adherence to the use of DOSSARD. We asked the following questions:

- Based on your experience, how do you assess the speed of diagnosis with DOSSARD? Faster, same speed, or slower than traditional methods?
- When you were able to go faster, what did you do with the time you saved?
- How do you judge the relevance of the questions suggested by the tool?
- At what level of confidence do you estimate your diagnosis to be?

To all these elements, we made the choice to add a criterion related to the appropriation of the tool by the consultant: the rate of reuse of DOSSARD, whether within the framework of the project of the *Occitanie* region or not. The idea of this criterion was to see if, outside any favorable framework, the consultant would continue to use the tool. Indeed, I hypothesized that a consultant who joined the AGILEA consortium could have biased behavior due to certain facts:

- That a tool was made available to the consultant free of charge;
- That this relationship was generating activity for the consultant in the context of a significant economic crisis;
- That there was a stake for the consultant to continue the implementation of the actions in the company.

Thus, the purpose of this last indicator was to put forward the idea that a consultant who used the approach outside this regional framework was completely free in his choices, and probably convinced of the interest of the tool vis-à-vis his activity.

Before going into the details of these evaluations, here are some overall results obtained:

- 100% of the diagnoses carried out by the AGILEA consortium respected the 3-day limit recommended by the *Occitanie* region;
- The AGILEA consortium had the highest conversion rate of the 10 consulting firms (detailed data not provided by the *Occitanie* region). This means that the companies diagnosed by the consortium went more often to the implementation phase than the others;
- Within the AGILEA consortium, when the consultant used DOSSARD, the conversion rate to the support stage was 70.5% on average;
- Within the AGILEA consortium, when the consultant did not use DOSSARD, the conversion rate was 37% on average.

Subsequently, considering that the objective of any decision support system is to contribute to maximizing the added value produced, we propose to evaluate the scope of our proposal according to the dimensions of Costs, Quality, Delays and Service. (Johansson et al., 1993) indicate that the value produced aims to maximize Quality and Service while minimizing Costs and Delays.

1. Delays

In the first instance, we studied the temporal component associated with the uses of DOSSARD. The following graph shows in particular the speed of execution of the diagnoses (excluding the time for conducting the interviews and possible visits) according to the type of flow.

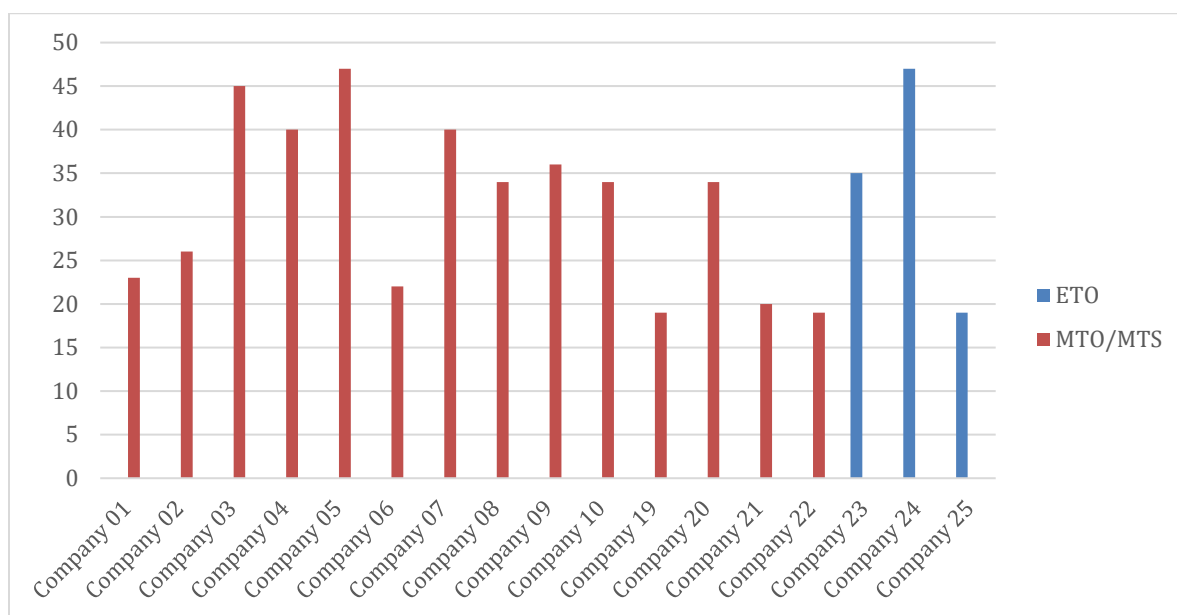


Figure 85. Representation of the time spent using DOSSARD

It can be seen that for an MTO/MTS activity (Appendix J), the average time for using DOSSARD for the completion of a diagnosis was 31.36 minutes for MTS/MTO environments and 33.67 minutes for ETO environments. The average time for all environments was 31.76 minutes. This average time observed is much lower than the average time observed for carrying out a diagnosis with traditional methods. Indeed, as we have seen in Chapter II, the usual methods can take from several hours to several days to be implemented, including when the method of *Thinking Processes* is used. From this point of view, it can be said that the approach used in the DOSSARD tool significantly improves the speed of execution of the diagnosis.

In addition, we looked at the impact of how symptoms were collected. The following figure shows that the execution time of the DOSSARD system was 35% faster when collecting symptoms in a grouped manner (see the ETO-type application case presented previously).

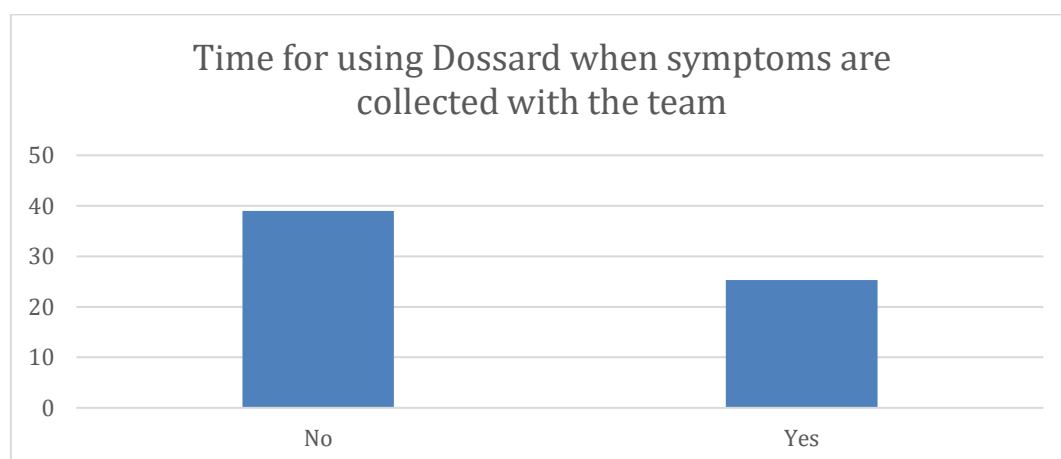


Figure 86. Representation of the time spent using DOSSARD according to the type of symptom collection

The preceding figure reads as follows: the “No” column indicates the time spent making the diagnosis using DOSSARD when the symptoms were collected individually through interviews.

The “Yes” column shows the time spent when the entire team was gathered at the same time to share the symptoms. Thus, the good practice of using the tool suggests carrying out this symptom collection through a collective exercise.

When we asked the consultants who used DOSSARD to carry out their diagnoses what their feelings were in terms of the speed of the diagnosis, we obtained the following results:

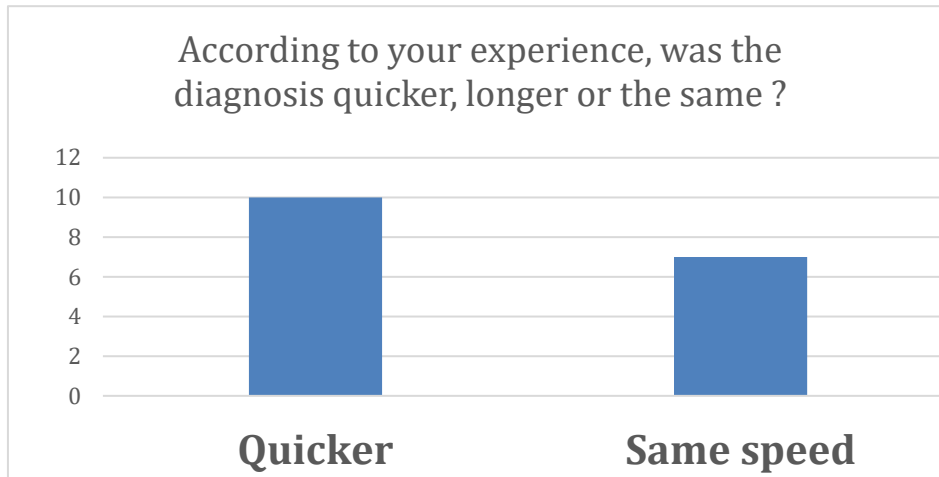


Figure 87. Estimation of the time spent performing the diagnosis using DOSSARD

58% believed that they were quicker in carrying out their diagnostic project with the proposed tool, while 42% believed that they were at the same speed as with traditional methods and none considered that the use of DOSSARD extended the intervention time. It should be noted that this evaluation covers the entire diagnostic process, i.e., including the data collection phases (interviews and visits), reporting and feedback. Nevertheless, although these results seem to confirm the time savings of the proposal, they temper it a little in terms of proportion.

2. Costs

In our study, the notion of cost is understood in terms of time reused to perform other tasks. In other words, it is a question of assessing whether the use of DOSSARD improves productivity and minimizes costs. Thus, if we make the assumption that DOSSARD saves time, we can question the way in which this time was utilized. The consultants who used DOSSARD in the case of our experiment responded according to the following options:

- More time with the team → We hear here that the consultant used his time to go into more detail about certain aspects of the diagnosis. This can be the valuation of certain elements.
- More time on the report → Time was spent building a more consistent diagnostic feedback report.
- Just time saved → The consultant was quicker and spent time on another topic not related to this diagnosis.

The results obtained are presented in the following figure:

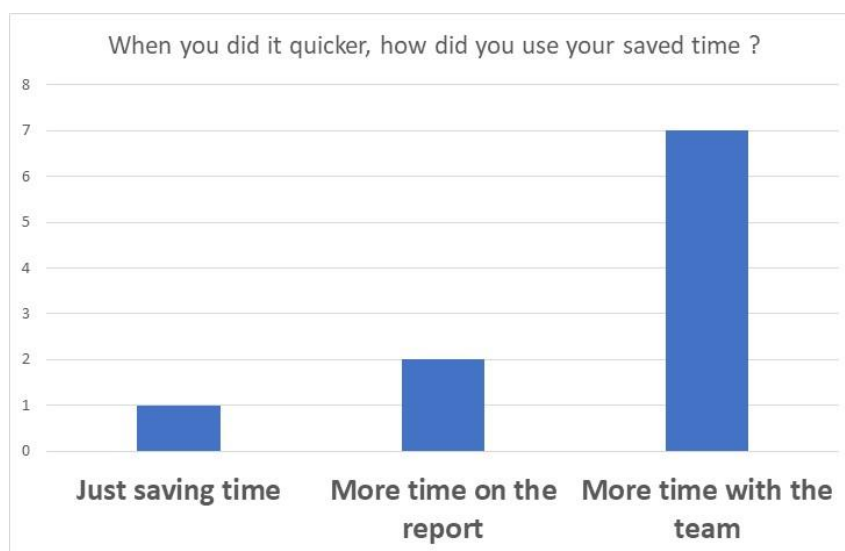


Figure 88. Utilization of the time saved by using DOSSARD (quantity)

This shows that 70% of the consultants used the time saved to spend more time with the teams to better understand the situation and the associated issues.

20% of them devoted this gain to better formatting of the concluding report. Finally, 10% of the respondents were content to save this time to work on other tasks independent of the project.

This illustration may partly explain the difference between the time saved in DOSSARD (Figure 88) and the feeling about the time spent on the project which ultimately remains similar (Figure 89). Indeed, the time saved seems to have been directly reinvested to improve the understanding of the organization and therefore the diagnosis itself. Consequently, it is possible here to make an assumption of a better quality of diagnosis via the use of DOSSARD. That is what we will seek to confirm.

3. Quality

The first criterion we sought to assess is the perception of the usefulness of the system for the expert consultants who have used it. In this hypothesis, we sought to verify whether the questions suggested by the DOSSARD system were relevant to the diagnosis. The idea was to ask users how they found the questioning of the tool:

- Helpful → This answer reflects questions that are useful or that the consultant would not have thought to ask.
- As I was expecting → This answer indicates consistency between the symptoms observed and the suggested questions. Thus, this type of response indicates that the tool is able to confirm statements.
- Useless → The questions were of no use in carrying out the diagnosis.

The results to this question are shown in the following graph:

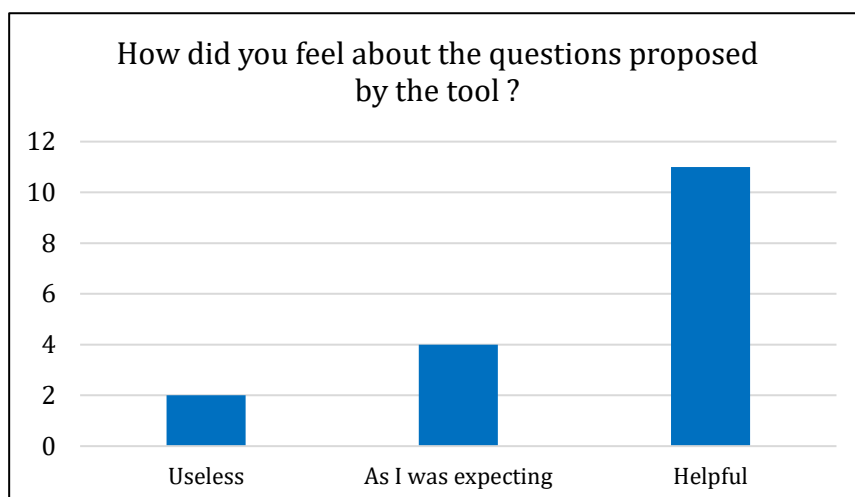


Figure 89. Quantity of responses to the questions proposed by DOSSARD

We note that 64% of the respondents perceived the questioning of DOSSARD as coherent and complementary to their reasoning. 24% of respondents considered the questioning consistent with their know-how and the context of the diagnosis. And 12% considered it useless. Through these figures we can consider that the questioning of DOSSARD is globally relevant and brings a real “plus”.

We also note that it was the respondents who found the DOSSARD questioning useful and complementary who also said that they had reinvested the time saved in the implementation on the deepening of the diagnoses. Indeed, if DOSSARD asks additional questions, then the consultant will spend more time with the team to understand the symptoms. We know, however, that this extra time significantly increases the teams' commitment to the diagnosis and the implementation of actions.

It is obviously difficult to judge the quality of a diagnosis, whatever the field of application. In our case, we interviewed the recipients of the diagnoses established through the use of the DOSSARD system in order to ask them what level of confidence they had in the diagnosis produced. The results are presented in the following figure and read as follows:

- < 50%: low confidence rate in the diagnosis;
- Between 60 and 80%: good confidence rate in the diagnosis;
- Above 80%: very good confidence rate in the diagnosis.

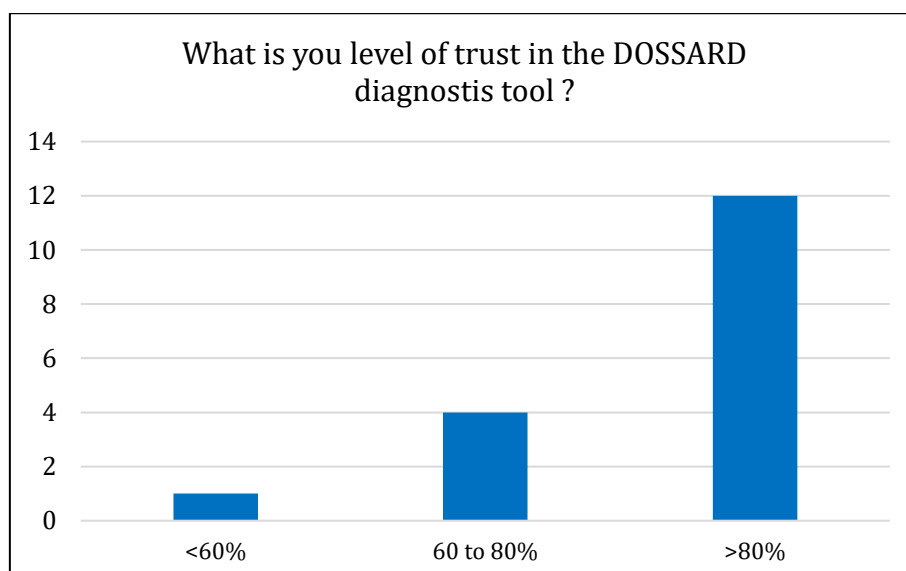


Figure 90. Quantity of level of satisfaction with DOSSARD by the users

This shows that the vast majority of respondents have significant confidence in the results of the diagnosis produced. This reinforces the idea that the DOSSARD system can produce consistent results.

Another way to ensure the quality of the deliverables of the system is to analyze the number of beneficiary companies that have decided to trust the product diagnosis enough to initiate an ad hoc improvement project. In this regard, it should be noted that 64% of the companies that benefited from the DOSSARD system have decided to continue the support and to initiate the resolution of the problems noted. On the other hand, only 34% of companies that benefited from a diagnosis not supported by the DOSSARD system have undertaken an improvement project. This indicator tends to demonstrate the appropriation by the beneficiary companies of the results produced by the DOSSARD system.

In addition, we note that consultants who reinvested the time saved to spend more time with the diagnosed team had a transformation rate that went up to 85%.

4. Service

The Service dimension is analyzed in our study through the prism of the appropriation of the system from the consultants who had access. We consider here that if these consultants continued to use (without any particular incentive) the system beyond the “imposed” experiment, it means that they were convinced by its interest and relevance. The graph below represents the number of diagnoses supported by DOSSARD carried out by independent consultants (i.e., external to AGILEA) beyond the project in the region.

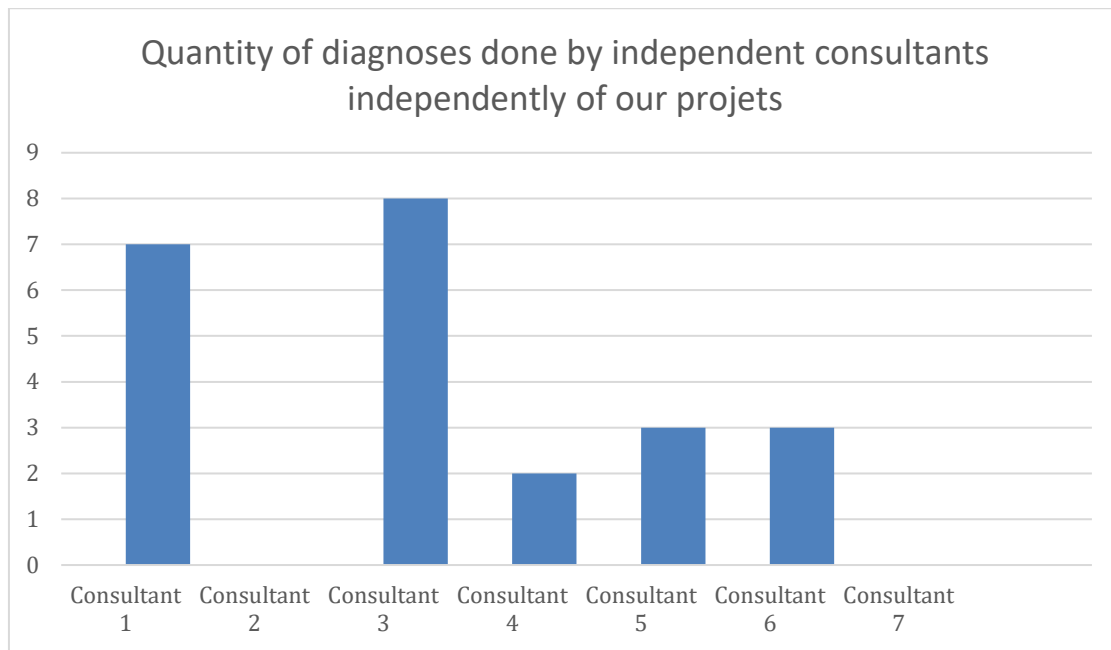


Figure 91. Level of reutilization of DOSSARD by consultants after the project in the region

We find that 71% of users reused DOSSARD for other diagnoses. In addition, we note that DOSSARD was used to accompany 23 additional diagnoses, in a time interval equivalent to the initial experiment, thus almost the double.

3. Discussion on the value of the proposal

In view of the results presented above, we can summarize and compare the use of the DOSSARD system with the traditional approach of the *Thinking Processes* as follows:

Diagnosis Criteria	Classical Current Reality Tree	Make To Order/Stock Dossard	Engineering To Order Dossard
Results	High	High	?
Required competencies	High	Low	Average
Duration	3 to 5 days	<1h	?
Level of discussion with the team	High	High	High
Easy to use	Hard	Easy	Average
Visual	No	No	?
Category of causes	Non	Partial	?

Figure 92. Summary of the results of the use of DOSSARD compared to a traditional approach

Most of the issues identified in Chapters I and II of this manuscript seem to find a satisfactory answer in the DOSSARD proposal. This is particularly the case for MTS/MTO environments and it also seems promising for ETO environments even though for the moment there is still a lack of application results. In particular, we note that the proposed system makes it possible to make accessible to a large number of people the method of the *Thinking Processes* traditionally

Validation of the results

reserved for experienced and highly trained people. The proposal also makes it possible to speed up the time needed for carrying out an industrial diagnosis, making it possible either to reduce the associated costs (in better productivity and a reduction in the time spent) or to further deepen the accuracy and granularity of the diagnoses produced (better productivity and control of the time spent). Finally, the proposal seems to produce very convincing results in relation to existing methods, both from the point of view of users (consultants) and from the point of view of beneficiaries (production companies).

However, these results deserve to be discussed in at least three dimensions:

- Representativeness;
- Risk of bias;
- An ETO environment.

As far as the representativeness of the experiments is concerned, we were able to test our decision support system on 25 cases. While this figure is consistent with other research, it is rather difficult to draw precise conclusions about the results we have obtained. Several aspects of the experiment reinforce this point:

- The 25 cases were conducted in different environments (MTO/MTS/ETO). This difference thus leads to a dilution of the results in the figures we observed;
- The 25 cases were made in the context of a crisis (COVID-19). It is possible to think that outside this context of this health crisis, the symptoms would have been different.

In addition, the context in which these diagnoses were made may have led to an acceptance bias. Indeed, the fact that the *Occitanie* region financed diagnoses with companies has, admittedly, facilitated access to many experimental fields, and it may be that these have been subject to some bias. For example, the fact that public subsidies were made conditional to the carrying out of the industrial diagnoses may have led some companies to be conciliatory towards the results of the diagnoses. Moreover, the fact that the diagnosis was fully financed by the region may have led to the same conciliation bias. However, this bias could be limited because the results observed between the users of DOSSARD and those who did not use it were quite different.

Finally, the last limit involves the ETO environment. Indeed, beyond the more limited number of cases carried out in this environment, it should be noted that our ETO approach suffers from several imperfections:

- The construction of the tree is a totally original research proposal which, unlike the generic MTS/MTO tree, has a pre-existing experimental basis;
- The literature review is based more on project environments (research, development) than on pure production environments.

With these 3 aspects, it is important to be prudent about the scope of the results obtained on ETO environments.

CHAPTER VI. CONCLUSION AND FURTHER RESEARCH

“You reproached me for thinking I was always right. And I realized that you were right. Well,
I think so. But we’ll see if I’m right!”

Dr. House

In this research, we found that systems for the production of goods or services were constantly evolving and that this instability and its intrinsic changes tended to accelerate. This acceleration creates significant challenges for companies, particularly in terms of the adaptability of organizations in facing these changes. This need to continually adapt their organization to the new needs and challenges of their activity and their environment requires them to be able to know the characteristics, strengths and weaknesses of their systems at all times. This is the role of industrial diagnostics.

In the work carried out in this doctoral thesis, we found in Chapter II in particular, that most of the existing diagnostic methods were based on quantitative data which unfortunately now tend to be valid only for very short periods. That is to say, when it comes to using this data to conduct an organizational diagnosis, it has often already become obsolete. In addition, the acquisition of such data, as well as the implementation of associated methods, are often very time-consuming. Other approaches advocate conducting the industrial diagnostics of systems for the production of goods or services mainly through qualitative approaches. Unfortunately, the findings are not much more satisfactory than for quantitative methods. Indeed, the existing methods also require a significant amount time to implement. In addition, they often require technical expertise and very significant business experience. Finally, they have the disadvantage of having a very low level of quality, and are highly dependent on the people who carry out the diagnoses.

However, among the qualitative methods, it appears that the method of the *Thinking Processes* from the Theory of Constraints shows much better results than its competitors. But it suffers from several major pitfalls:

- The skill level required to carry out the diagnosis is particularly high;
- The duration of implementation is very long;
- Teams that have had to use this approach find it inconvenient.

Thus, our research topic was to find a way to accelerate industrial diagnosis based solely on qualitative information. Thus, the research questions were as follows:

- How to help to objectively and quickly diagnose organizations producing goods or services?
- How to structure qualitative data in a knowledge base in order to facilitate its implementation?
- How to create and execute inference rules to perform the diagnosis?

In response to these research questions, several contributions were developed as part of this doctoral thesis work:

- First, we designed, structured and developed a decision support system to carry out organizational diagnoses of production systems based on qualitative data. This decision support system, directly inspired by the *Thinking Processes*, includes a functional dimension, an implementation process and a complete technical architecture, instantiated in the framework of a software prototype.
- Secondly, in order to give substance to our decision support system, a specific knowledge base was designed to support the reasoning mechanisms proposed as part of the decision support system. This knowledge base develops in particular a generic Current Reality Tree to identify and link the main symptoms and conflicts generally existing in production systems. More precisely, two versions of this tree are proposed, one dedicated to Make to Stock (MTS) and Make to Order (MTO) environments, the other dedicated to Engineer to Order (ETO) environments. If the first one consisted in a consolidation and validation of an already existing knowledge, the second one consisted in a totally new development.
- Finally, a rich experimental plan was conducted to assess the validity, scope and limits of the theoretical proposals made. Dozens of industrial cases were conducted as part of the Industry of the Future program of the *Occitanie* region in France. This resulted in significant gains vis-à-vis the methods traditionally used, both in terms of time, productivity (cost), quality and service. These results are particularly positive for MTS/MTO environments.

These contributions also offer additional research opportunities:

1/ Development of the approach in different flow organizations

Indeed, our field of research was limited to MTO/MTS/ETO environments but there are many other categories of industrial flows, such as distribution or ATO (Assemble To Order) or pure distribution environments. It could be interesting to replicate the approach taken in this manuscript to these areas. The interest lies in the fact that this manuscript writes the steps for creating a generic tree. Thus, the work will consist in documenting the literature review to constitute the generic trees specific to these domains in order to enrich the DOSSARD tool. During our field experiments, we were able to exchange with companies that combined the environments of our research scope with distribution networks. We then found that some of the symptoms of the distribution networks were the same as those of the MTO/MTS/ETO environments, but their scope or relevance could not be guaranteed. Moreover, the conflicts are most likely different from those studied in this doctoral thesis. Thus, if the proposed approach was to be extended to all other industrial environments, this would make it possible to consolidate certain aspects of the knowledge bases already developed, but more importantly, it would make it possible to extend the perspectives of the diagnosis to any industrial system. In particular, if this research led to more generic trees, these trees could be linked together to provide a wider scope of diagnosis. One way to do this would then be to develop a meta- web spider of conflicts that would record and synthesize all the conflicts present in the different types of companies and on a wider scope. Finally, it should be noted that although our study was limited to studying systems for the production of goods or services, in supply chain environments, other functions of the company could quite naturally benefit from the approach developed in this manuscript. Thus, a similar approach could be imagined for functions such as marketing, sales, quality, etc. These elements will consolidate the systemic view of diagnosis at the level of an entire company.

2/ Potential of intelligence algorithms

The trees used in our work can be likened to neural networks. We could imagine utilizing this information network in order to influence the questioning even more with users. In addition, we could imagine DOSSARD being linked to market trend information that would help identify potential symptoms. This would give users the opportunity to anticipate the actions to be implemented. Companies are subject to variations related to the market (demand) as well as to their suppliers. Our approach in this research was to determine the endogenous symptoms of companies producing goods or services but we ultimately studied rather little of the inter-company interfaces, as fundamental as they are in the performance of a company today. Thus, we could work on the question of how exogenous events influence the performance of a company, and therefore its diagnosis. For example, if a supplier's surface treatment shop burns, our tool could highlight the potential symptoms of this event in order to limit the probability of its occurrence and/or the associated consequences on the company's internal performance. In a similar register, we know that the carrying out of the analyses of causalities will become more and more complex as the industrial cases multiply and the studied scopes expand. For example, how can the link be made between a supplier fire and the manufacturing policy of a customer workshop? It would then be interesting to ask whether the collection of information from past diagnoses could not serve as input data for an intelligence algorithm (probably based on machine learning mechanisms) capable of:

- Freeing itself from questions to ask if it has acquired sufficient experience of past diagnoses and/or knowledge through the constitution of new generic Current Reality Trees;
- Simulating the appearance of possible symptoms and evaluating, *a priori*, their potential consequences on the organization. Thus, this list of symptoms could serve as a beacon for the company in identifying when the system is being endangered, through means such as “what-if” approaches.

3/ Analysis of diagnostic results

This third focus of research is related to the previous one. Indeed, the use of DOSSARD is quite significant and regular with users. Thus, the knowledge base of DOSSARD is developing. One line of research could be to study the recurrences of symptoms and conflicts according to the typologies of companies diagnosed (Sector of activity, Volume, Variability of products, etc.). These analyses could lead to the consolidation of the knowledge base and perhaps to its development as well. In practice, we have had the opportunity to benefit from a number of use cases to apply our diagnostic approach. We used speed and quality information to validate our approach. However, we have paid little attention to the links existing between the contents of the diagnoses themselves. There are perhaps (or surely?) correlations based on the sector of activity, the size of the company or the geographical location that will make it possible to make the tree easier to read or the diagnosis faster to analyze. We could thus use the statistical approaches of Bayesian models to create additional rules of inference between symptoms. In the logic of simplifying the reading and interpretation of the result tree, we could also observe the recurrence of certain symptoms or conflicts. This would result in symptom/conflict maps that are more readable and easier for users to understand.

4/ Development of diagnostics in the ETO environment

Finally, during the creation of the generic ETO tree, we were able to clearly identify a reference imbalance in terms of diagnosis. Although the literature is explicit in MTO/MTS environments, we had to partially use the project management literature to arrive at a generic ETO tree. This leads us to propose several lines of thought around this field, such as the development of the knowledge of symptoms in ETO as well as the review and validation of the generic tree and these associated conflicts in order to arrive at a real diagnostic tool consolidated from the academic point of view and used by practitioners. Indeed, when we carried out the diagnostics of ETO environments, we became aware of the specificities of their operations. These specificities made the initial generic tree obsolete. During the research, we chose to create a generic tree dedicated to this environment. However, the literature analysis allowed us to arrive at a number of observations:

- The notion of diagnosis in ETO environments is rarely documented;
- Despite the proximity between the ETO environment and the project world, there are few documented links between these two worlds;
- Diagnosis of project environments is also limited and focuses more on proposals for solutions than diagnosis, although the symptoms have been clearly identified;
- Despite the construction of the tree and the cases we were able to test, we still have too little hindsight to validate the relevance of this research axis.

Thus one or more complementary research topics could consist in working on the following actions:

- Producing consolidated documentation of the symptoms and challenges of project environments. This would involve conducting a more complete literature review of the symptoms we observed as well as validating/invalidating/adding links in the proposed generic tree;
- Developing the experimentation of the generic tree “project” in order to consolidate its content and scope. Indeed, although the proximity between ETO environments and projects is obvious, we have for the moment made the assumption of total concordance, while finally considering only pure ETO environments. This obviously needs to be discussed, and a greater emphasis on the project management side could lead to different outcomes.

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Appendix A: Representation of the symptoms in the diagnostic tool

Bearing Company

Propagation

Refining

Results

Conflict

Undesirable effect

Intermediate effect

Add an element

Suggestions

priority

x | v

Conflict

No conflict

Undesirable effect

Suppliers are late

Effet indésirable

System will put pressure to recover the late internally (overtime, temporary, etc.)

Effet indésirable

Customer ordering is at risk

Effet indésirable

Systems bought higher quantities than required (through safety stock)

Effet indésirable

Inventory is increasing

Effet indésirable

OEE is lower

Effet indésirable

Priorities may change

Effet indésirable

Intermediate effect

No intermediate effect

Appendix B: List of questions posed by DOSSARD

System is late compared to demand

—

Work in progress is mixing complete and incomplete orders

—

Conflict #2 - Run larger batches (earlier release, big batch)

—

Work in progress is higher than planned

—

Raw material inventory is increasing

—

Cycle time will be updated and longer

—

System will create security inside the system

—

The system buys higher quantity based on demand or forecast

—

Sales flow is slower than planned

—

Raw Materials synchronization is threatened

—

Internal Lead Time is longer than planned

—

Production has less time to produce what is planned

Conflict #3 - Buy only what's needed

—

Conflict #8 - Ship partial orders

—

System will apply pressure to recover the delay at supplier level (Express shipment

—

Return on investment is under pressure

—

Conflict #5 - Lower price to get order

—

Contribution margin is negatively impacted

—

Conflict #7 - Run order on any capable resource

—

Local cost per unit at resource level is going to increase

—

Procurement can challenge Make versus Buy of the current system with outsourcing

—

Variable costs are higher than expected

—

Validation of the results

Profit & Loss expenses are higher than planned

Shortages may occur

Operating expenses are higher than expected

Systems will generate Purchased Orders with shorter Suppliers Lead Time

Raw Materials synchronization is threatened

System will make more shipment than planned

Conflict #6 - Authorize overtime

Obsolete inventory may be at risk

At a certain point, Suppliers Lead Time is longer than planned (Cross curve)

Conflict #4 - Maintain only when broken

Conflict #7 - Run order on optimal resource

System can overload a non-critical resource

System may see needs in resource to hire, buy, etc.

Conflict #9 - Release incomplete orders

Raw Materials are consumed quicker than sold/required

Appendix C: List of validated and deleted symptoms

System can overload a non-critical resource

Validated

Conflict #5 - Lower price to get orderConflict

Validated

Local cost per unit at resource level can reduced

Validated

Conflict #4 - Do routine maintenanceConflict

Validated

Raw Materials are consumed quicker than sold/required

Validated

Conflict #9 - Release incomplete ordersConflict

Deleted

System may see needs in resource to hire, buy, etc.

Validated

Conflict #3 - Buy only what's neededConflict

Validated

Conflict #8 - Ship partial ordersConflict

Validated

System will apply pressure to recover the delay at supplier level (Express shipment

Validated

Return on investment is under pressure

Validated

Contribution margin is negatively impacted

Validated

Conflict #7 - Run order on any capable resource

Validated

Local cost per unit at resource level is going to increase

Validated

Procurement can challenge Make versus Buy of the current system with outsourcing

Deleted

Variable costs are higher than expected

Validated

Profit & Loss expenses are higher than planned

Validated

Shortages may occur

Deleted

Operating expenses are higher than expected

Validated

Systems will generate Purchased Orders with shorter Suppliers Lead Time

Validated

System will make more shipments than planned

Validated

Conflict #6 - Authorize overtimeConflict

Validated

Obsolete inventory may be at risk

Validated

At a certain point, Suppliers Lead Time are longer than planned (Cross curve)

Validated

Conflict #7 - Run order on optimal resource

Validated

Conflict #5 - Maintain the priceConflict

Validated

Validation of the results

Conflict #9 - Release complete ordersConflict

Deleted

Loss time will increase

Validated

System will take action to decrease expenses

Validated

Conflict #6 - Do not authorize overtime

Validated

Work Orders are not released on time

Validated

Conflict #4 - Maintain only when broken

Deleted

Queue times are increasing

Validated

Conflict #3 - Buy in volumeConflict

Validated

Conflict #1 - Build to stockConflict

Validated

Conflict #1 - Build to orderConflict

Validated

Allocated times in the routine are overdue

Validated

Raw materials stay longer in the inventory

Validated

Conflict #2 - Run smaller batchesConflict

Validated

Safety time will be included in the Lead Time

Validated

System is going to split batch

Validated

Scale approaches are used to follow expenses

Validated

Raw material inventory can increase

Validated

Suppliers deliver a bigger batch than needs

Validated

Upstream delay is not compensated

Validated

Production has less time to produce what is planned

Validated

Internal Lead Times are longer than planned

Validated

Raw Materials synchronization is threatened

Deleted

Sales flow is slower than planned

Validated

The system buys higher quantity based on demand or forecast

Validated

System will create security inside the system

Validated

Cycle time will be updated and longer

Validated

Raw material inventory is increasing

Validated

Work in progress is higher than planed

Validated

Conflict #2 - Run larger batches (earlier release, big batch)

Validated

Work in progress is mixing complete and incomplete orders

Deleted

System is late compared to demand

Validated

Priorities may change

Validated

OEE is lower

Validated

Inventory is increasing

Validated

Systems bought higher quantities than required (through safety stock)

Validated

Customer ordering is at risk

Validated

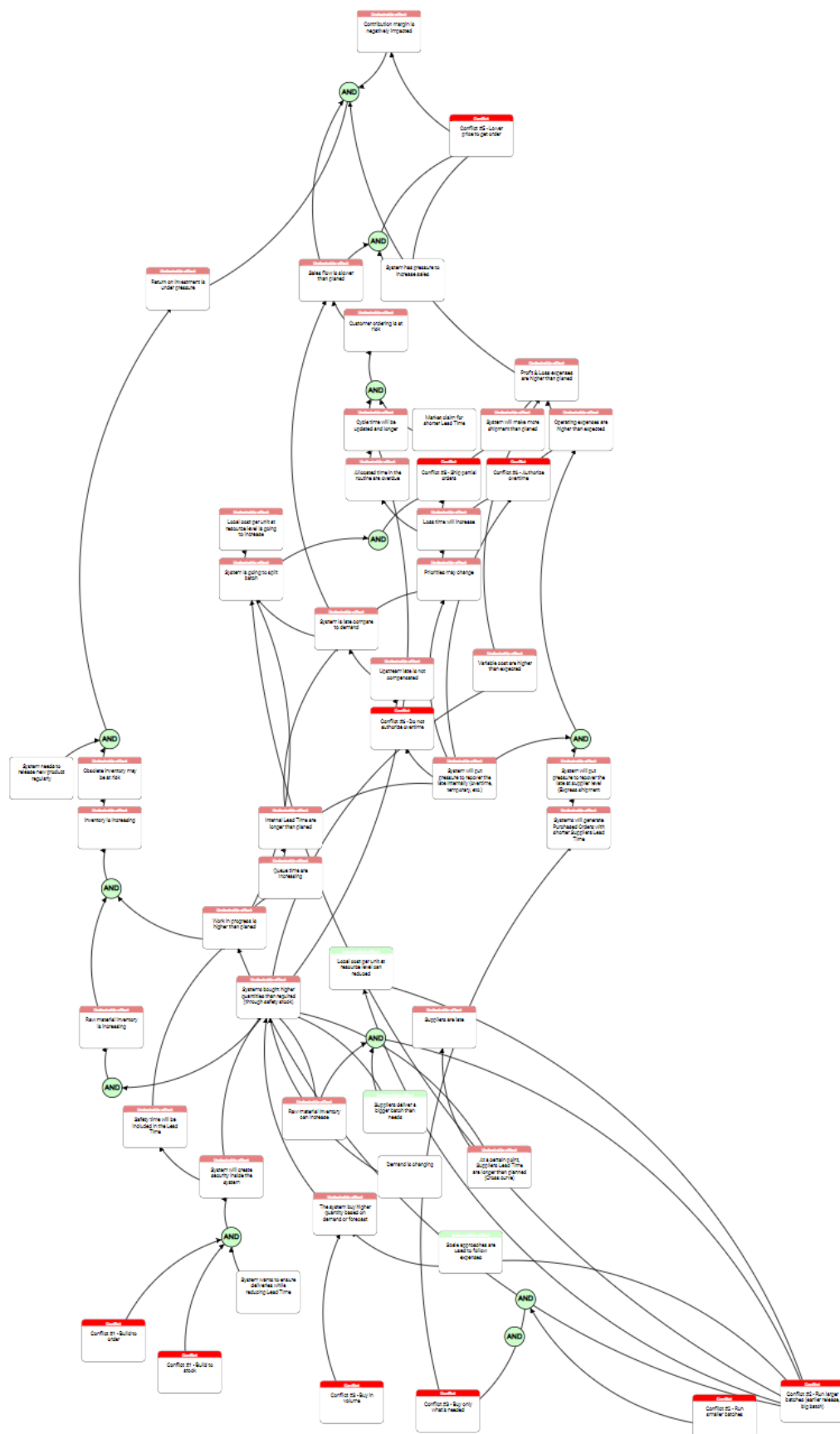
System will apply pressure to recover the delay internally (overtime, temporary, etc.)

Validated

Suppliers are late

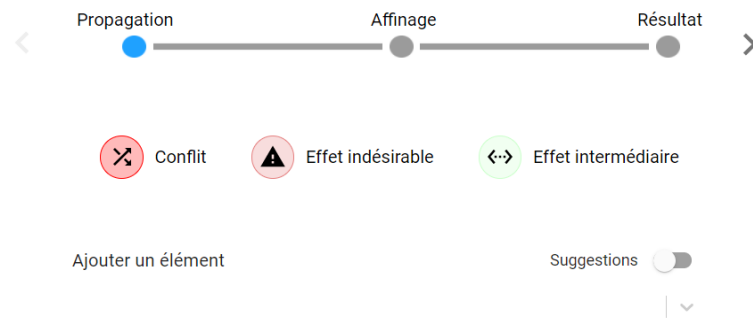
Validated

Appendix D: Current Reality Tree of the Proof of Concept





Appendix E: Symptoms in the ETO case study







Pump Factory



Conflit

-  **Conflict P6 - Update Schedule**
Conflit
-  **Conflict P6 - Freeze Schedule**
Conflit

Effet indésirable

-  **Project's status report shows late on schedule**
Effet indésirable
-  **Resources are not available when required**
Effet indésirable
-  **We are not satisfying market requirement**
Effet indésirable
-  **Hard to keep motivated the team**
Effet indésirable
-  **Status project portfolio is not clear anymore**
Effet indésirable
-  **Customers think we are unpredictable(+/-)**
Effet indésirable

Effet intermédiaire

Pas d'effet intermédiaire

Appendix F: List of questions proposed by the DOSSARD tool

Customer expectations are not satisfied

Project's status moves from one emergency to another

Conflict P1 - Focus On Tasks

Priorities between tasks are always changing

Return On Investment of projects are not achieved

We fight among each other for critical resources

Tasks take more time than planned

Project execution is at risk

Despite similarities between projects, they are longer and longer

Not my fault behaviors increase

Conflict P3 - Hire Extra Resource

We limit investment in resources, training, technologies, etc.

Conflict P5 - Release all projects

Scope of the project is chaining based on customer's demand

Conflict P4 - Start Kits incomplete

For same kind of projects, task estimations are different

Teams are under pressure to reduce time estimation by time organization

Some projects are cancelled before the end

We are deducing the scope of the project

Despite similarities between projects, they are longer and longer

Customers are putting pressure on the current projects (OTD, Quality, Budget)

Tasks/projects take longer because of external events

Some projects have a clear impact on the Return On Investment while other have less

Conflict P2 - Have detail tasksConflict

Appendix G: Answers to DOSSARD questions by the company

Conflict P2 - Have detail tasks

Validate

Some projects have a clear impact on the Return On Investment while other have less

Validate

Tasks/projects take longer because of external events

Validate

Customers are putting pressure on the current projects (OTD, Quality, Budget)

Validate

Teams are under pressure to reduce time estimation by time organization

Validate

We are deducing the scope of the project

Supprimé

Conflict P8 - Do not decrease Lead Time to get the bid

Supprimé

We refuse new delivery dates required by customers

Validate

Customers are forced to pay for the changes

Validate

Customers might be frustrated

Validate

Customer's Return On Investment is endangered for this project

Validate

Conflict P1 - We focus on the project as whole

Validé

Conflict P2 - Do not detail tasksConflit

Validé

Customers will put pressure on price/Return On Investment for the next projects with us

Validé

Conflict P5 - Do not release all projects

Supprimé

Conflict P4 - Start kit completeConflit

Supprimé

Conflict P7 - Protect TasksConflit

Validé

Time estimations are reduced at the beginning of the projects

Supprimé

Tasks are missing in our project plan

Validé

Conflict P8 - Reduce Lead Time to get the order

Validé

Return On Investment of projects is not predictable

Validé

Some projects are so late that recovery actions have to be taken(On Time, Sub Contracting, etc.)

Validé

Time is consumed

Validé

For same kind of projects, task estimations are different

Validé

Conflict P4 - Start Kits incomplete

Validé

Scope of the project is chaining based on customer's demand

Validation of the results

Validé

Conflict P5 - Release all projectsConflit

Validé

We limit investment in resources, training, technologies, etc.

Validé

Conflict P3 - Hire Extra Resource

Validé

Not my fault behaviors increase

Supprimé

Despite similarities between projects, they are longer and longer

Supprimé

Project's execution is at risk

Validé

Projects take more time than planed

Validé

Team is focusing on short duration (giving focus)

Validé

Lots of rework on tasks

Validé

Increase of the quantity of tasks/projects in Work In Progress

Validé

Some competences have limited capacity

Validé

Operating expenses of the project are higher than planed

Validé

Invoices of projects are irregular

Validé

A change in scope may have negative impact on sales for the market

Supprimé

People do not see the benefits/inconveniences in finishing their projects On Time, Quality, Budget

Validé

Some projects are cancelled before the end

Supprimé

Time is spent in several meetings of project status

Validé

Some tasks are queuing until the next emergency top list

Validé

We refuse change request from customers

Supprimé

Conflict P3 - Move internal resourcesConflit

Validé

New ideas are developed slower

Pas d'avis

Tasks take more time than planned

Validé

We fight among each other for critical resources

Validé

Return On Investment of projects is not achieved

Validé

Priorities between tasks are always changing

Validé

Conflict P1 - Focus On Tasks

Pas d'avis

Project's status moves from one emergency to another

Validé

Customer expectations are not satisfied

Validé

Customers think we are unpredictable (+/-)

Validé

Status project portfolio is not clear anymore

Validé

Hard to keep motivated the team

Validé

Conflict P6 - Freeze ScheduleConflit

Validé

Conflict P6 - Update ScheduleConflit

Validé

We are not satisfying market requirement

Validé

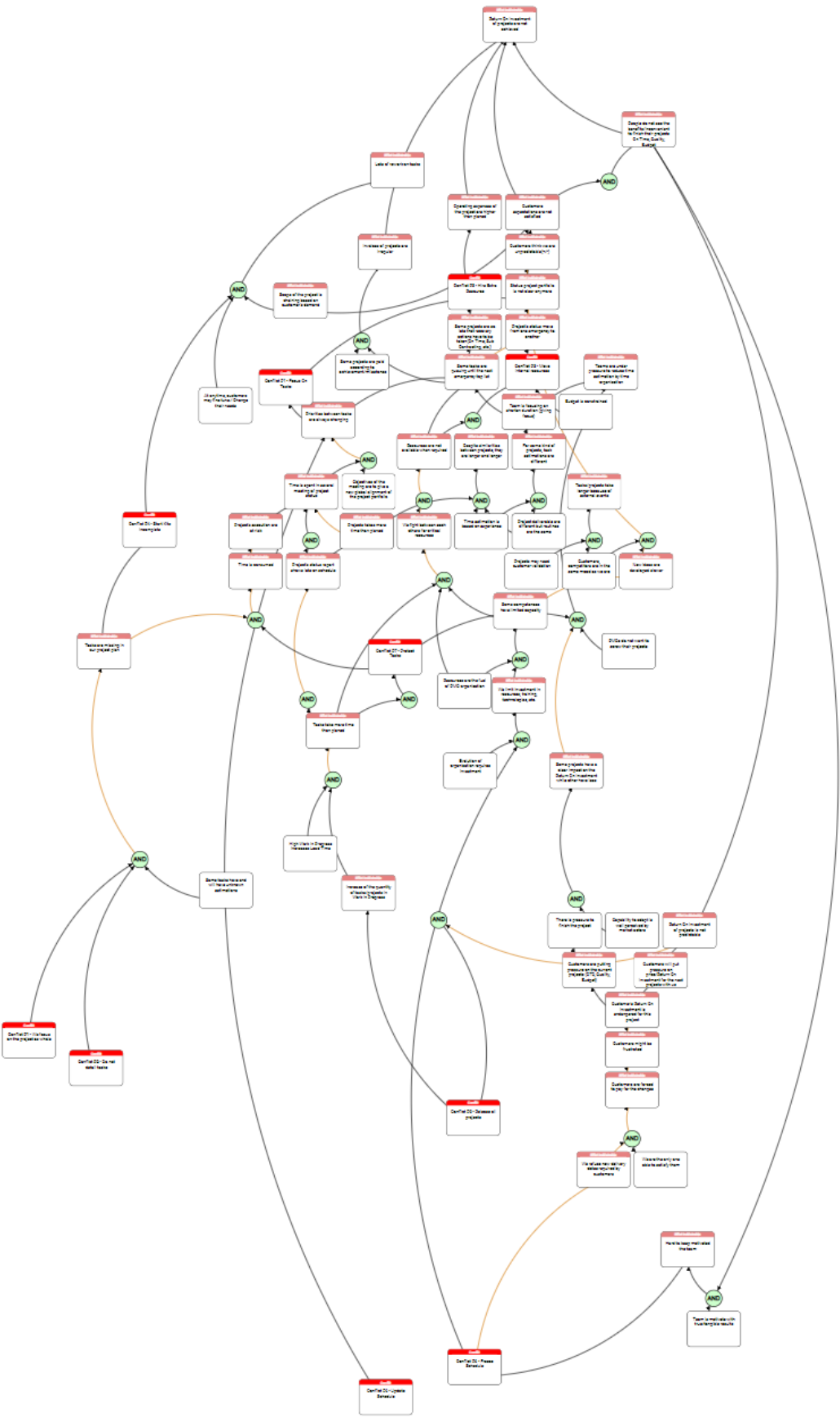
Resources are not available when required

Validé

Project's status report shows late on schedule

Validé

Appendix H: Current Reality Tree of the ETO Pump company



SYSTEME D'AIDE A LA DECISION POUR LE DIAGNOSTIC INDUSTRIEL QUALITATIF

Les entreprises industrielles sont soumises depuis plusieurs années maintenant à une pression sans précédent pour s'adapter aux différentes variations de la demande, aux aléas fournisseurs ou tout simplement à leurs changements intrinsèques. Ce besoin d'adaptation nécessite d'avoir la capacité de pouvoir analyser rapidement et efficacement l'état de santé actuel de l'entreprise. Or, le temps de collecte, traitement et restitution de données et informations quantitatives nécessaires à de tels diagnostics, est plus lent que les changements auxquels sont confrontés les entreprises. C'est pourquoi le but de ce travail de recherche a été de proposer une méthodologie de diagnostic industriel rapide, qui soit basée sur une approche semi-automatisée et des informations qualitatives.

Après avoir réalisé dans un premier chapitre un état de l'art sur les méthodes existantes en termes de diagnostic industriel, nous avons finalement fait le choix d'axer notre proposition scientifique et technique sur la méthode des Thinking Processes issue de la Théorie des Contraintes. Cette méthode qui hérite des fondements théoriques associés à la théorie des graphes et aux réseaux bayésiens, présente de nombreux atouts potentiels pour mener un diagnostic qualitatif d'un système de production de biens ou de services. Malheureusement, elle présente aussi de nombreux écueils tels que le haut niveau d'expertise et d'expérience requis pour la mettre en œuvre ou le délai très long nécessaire à son déploiement.

Le second chapitre s'intéresse ainsi à la formalisation et à la structuration d'une démarche originale de diagnostic industriel inspiré de la méthode des Thinking Processes. Il développe également une architecture fonctionnelle et une architecture technique originales permettant de structurer un système d'aide à la décision capable d'accompagner la démarche développée. Enfin, il définit et développe un prototype logiciel appelé DOSSARD permettant de concrétiser les éléments définis dans le système d'aide à la décision précédent.

Le troisième chapitre, lui, formalise sous forme de base de connaissances orientée graphe, la validation et l'enrichissement d'un arbre des réalités actuelles générique adapté à la caractérisation des systèmes de production de type fabrication sur stock (MTS). Il élabore également un arbre des réalités actuelles générique (base de connaissances), totalement nouveau, adapté aux systèmes de production de type fabrication sur commande ou projet (ETO).

Le quatrième chapitre décrit comment ces contributions ont été testées et validées sur une cinquantaine de cas industriels afin de démontrer leur valeur ajoutée et d'identifier également leurs limites. Il en résulte que la démarche proposée et le système d'aide à la décision associé permettent bien d'atteindre les résultats escomptés. Notamment ils permettent d'accélérer très significativement la vitesse de diagnostic tout en améliorant la pertinence et la robustesse du livrable produit.

Enfin, dans un dernier chapitre conclusif, le manuscrit propose un ensemble de perspectives de recherche prometteuses. D'abord, si de nombreuses expérimentations terrain ont pu être menées dans le cadre de ce travail de recherche, l'essentiel des cas portaient sur des systèmes de production sur stock (MTS). La proposition faite reste donc à valider plus largement sur des cas de production sur commande ou projet (ETO) et surtout, elle reste à étendre aux nombreux autres systèmes existants tels que l'assemblage à la commande (ATO), la configuration à la commande (CTO) ou encore la distribution par exemple. Enfin, même si le nombre de cas industriels mobilisés pour cette étude est élevé, il demeure beaucoup trop limité pour envisager éprouver véritablement les bases de connaissances et les règles d'inférence associées.

Mots clés : Chaîne logistique, Diagnostic, Industrie, Théorie des contraintes, Processus de pensée.

INDUSTRIAL QUALITATIVE DIAGNOSIS SUPPORT SYSTEM

Over the past several years, industrial companies have been under unprecedented pressure to adapt to different variations in demand, supplier problems or simply their own intrinsic changes. This need for adaptation requires the ability to be able to quickly and effectively analyze the current state of health of the company. However, the collecting, processing and reporting of the data and the quantitative information necessary for such diagnoses is much slower than the speed of change now challenging companies. This is why the aim of this research work is to propose a rapid industrial diagnostic methodology, which is based on a semi-automated approach and qualitative information.

After having carried out a state of the art on the existing methods in terms of industrial diagnosis in the first chapter, we chose to focus our scientific and technical proposal on the Thinking Processes method from the Theory of Constraints. This method, which inherits the theoretical foundations associated with graph theory and Bayesian networks, has many potential advantages for conducting a qualitative diagnosis of a production system of goods or services. Unfortunately, it also has many pitfalls, such as the high level of expertise and experience required to implement it, or the excessive amount of time required for its deployment.

The second chapter thus focuses on the formalization and structuring of an original approach to industrial diagnosis inspired by the Thinking Processes method. It also develops an original functional architecture and a technical architecture to structure a decision support system capable of supporting the developed approach. Finally, it defines and develops a software prototype called DOSSARD to concretize the elements defined in this decision support system.

The third chapter formalizes, in the form of a graph-oriented knowledge base, the validation and enrichment of a generic Current Reality Tree adapted to the characterization of production systems that use manufacturing to stock (MTS). It also develops a generic Current Reality Tree (knowledge base) that is completely new, adapted to production systems that use manufacturing to order or project (ETO).

The fourth chapter describes how these contributions were tested and validated on about fifty industrial cases in order to demonstrate their added value and also identify their limitations. The proposed approach and the associated decision support system were successful in achieving the expected results. In particular, they made it possible to significantly accelerate the speed of diagnosis while improving the relevance and robustness of the final product.

In the concluding chapter, the manuscript offers a set of promising research perspectives. First, while many field experiments were conducted as part of this research work, most of the cases concerned stock production systems (STDs). The proposal made therefore remains to be validated more widely on cases relating to production to order or project (ETO) and above all, it could be extended to the many other existing systems, such as assembly to order (ATO), configuration to order (CTO) or distribution, for example. Finally, even though the number of industrial cases mobilized for this study was high, it was still too limited to consider an in-depth testing of the knowledge bases and associated inference rules.

Keywords: Supply Chain, Diagnosis, Industry, Theory of Constraints, Thinking Processes.