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STRATÉGIES MANUFACTURIÈRES INTÉGRANT LA PRODUCTION, L'APPROVISIONNEMENT ET LE CONTRÔLE DE QUALITÉ POUR DES CHAÎNES D'APPROVISIONNEMENT NON FIABLES

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STRATÉGIES MANUFACTURIÈRES INTÉGRANT LA PRODUCTION, L'APPROVISIONNEMENT ET LE CONTRÔLE DE QUALITÉ POUR DES CHAÎNES D'APPROVISIONNEMENT NON FIABLES

Rached HLIOUI

RÉSUMÉ

Ce mémoire élabore des politiques de commandes optimales intégrant les décisions de production, d'approvisionnement et de contrôle de qualité de la matière première à la réception par échantillonnage dans un contexte de gestion d'une chaîne d'approvisionnement à trois niveaux. Cette chaîne est constituée d'un fournisseur dont la qualité des lots livrés est imparfaite, un manufacturier non-fiable et un client final, produisant un seul type de produit. Le manufacturier est l'entreprise principale dans la prise de décisions dans la chaîne d'approvisionnement. Le problème est formulé par un modèle de programmation dynamique stochastique.

Cette chaîne fait face à un nombre considérable d'événements à savoir des délais d'approvisionnement aléatoires et des périodes de non disponibilité. Étant donné la variabilité de prise de décisions de cette chaîne et son niveau stochastique élevé, une approche expérimentale basée sur la simulation, les plans d'expérience et la méthodologie de surface de réponse a été utilisée. Cette approche nous a permis de reproduire le comportement dynamique de la chaîne, de déterminer les valeurs optimales des différents paramètres de contrôle et de procéder à des analyses de sensibilité profondes.

Dans la littérature, les études qui appliquent le contrôle de la qualité à la réception par plan d'échantillonnage dans un contexte de gestion d'une chaîne d'approvisionnement à trois étages sont presque inexistantes. Or, pour que le décideur assure une meilleure performance de sa chaîne, une coordination des différentes décisions est nécessaire.

Dans la première partie de ce mémoire, nous avons étudié le cas où le manufacturier applique à la réception un plan d'échantillonnage simple (n, c) et dont les paramètres sont connus.

Nos résultats montrent qu'en combinant à la fois une décision de retour au fournisseur et une décision d'inspection à 100 % et de rectification des items non-conformes d'un lot refusé à la réception, assure une meilleure performance de la chaîne d'approvisionnement.

Dans la deuxième partie de ce travail, nous nous sommes intéressés à un problème où le fournisseur offre l'amélioration de la qualité d'un lot rejeté par le manufacturier et où le manufacturier applique un plan d'échantillonnage simple de type $(n, 0)$. L'objectif est d'étudier d'abord l'effet de l'optimisation du paramètre du plan de contrôle sur les différentes décisions de production, d'approvisionnement et d'inspection ; ensuite, de déterminer l'impact du dégré d'implication du fournisseur dans le choix de la meilleure politique d'inspection : impliquer ou non le fournisseur. Ainsi, des outils d'aide à la décision sont proposés.

Dans la dernière partie, nous nous sommes intéressés à proposer une politique de contrôle intégrant les activités de la production, de l'approvisionnement et de contrôle de la qualité dans un contexte où une pièce non-conforme de matière première peut affecter le processus de production en causant des pannes additionnelles. L'objectif est de déterminer la meilleure stratégie d'inspection à adopter permettant d'équilibrer la production et l'approvisionnement dans ce contexte.

Ce travail, ainsi présenté, montre l'importance de la coordination des décisions de contrôle à la réception avec celle de la production et d'approvisionnement.

Mots clés: Chaîne d'approvisionnement, plan d'échantillonnage, commande optimale stochastique, simulation, méthodologie de surface de réponse, coordination.

MANUFACTURING STRATEGIES INTEGRATING PRODUCTION, REPLENISHEMENT AND QUALITY CONTROL FOR UNRELIABLE SUPPLY CHAIN

Rached HLIOUI

ABSTRACT

The work of this thesis is to develop optimal control policies integrating production, supply and quality control of the raw material by sampling decisions in supply chain management context. The supply chain consists of imperfect supplier, unreliable manufacturer producing one part type and a final customer. All decisions are taken by the manufacturer. This problem is formulated by a stochastic dynamic programming model.

This supply chain faces a considerable number of events namely random lead-time, unavailability period, inspection delay, and acceptance and rejection decisions of the delivered lot. Given the high variability in decision making and the high stochastic level of the considered supply chain, an experimental approach based on simulation modelling, experimental design and Response surface methodology has been used. This approach allowed us to reproduce the dynamic behavior of the supply chain, to determine the optimal values of control parameters ant to carry out deep sensitivity analysis.

In the literature, studies that apply the acceptance sampling plan at reception in the context of managing a three-stage supply chain are almost nonexistent. However, to ensure that the decision maker achieves better performance, the coordination of different decisions is needed.

In the first part of this thesis, we have studied the case where the manufacturer applies a single sampling plan (n, c) whose parameters are known. Ours results show that the integration of discarding decision and 100% inspection and rectification decisions guarantees a better performance of the supply chain.

In the second part of this work, we are interested in an issue where the supplier is committed to improve the quality of each rejected lot and the manufacturer applies a single sampling plan $(n, 0)$. The objective here is to first study the effect of optimization of sampling plan parameter and then to determine the impact of the involvement degree of the supplier in the selection of the best inspection policy: involving or not the supplier. Thus, a decision making support tools are presented.

In the final part, we are interested to propose an integrated production, replenishment and quality control in a situation where a non-conforming raw material can affect the production process by causing additional failures. The objective is to determine the best inspection strategy to adopt to balance production and supply activity.

This work presented thus, shows the importance of coordinating quality control decision at the reception with the production and supply activities.

Keywords: Supply chain, Acceptance sampling, Stochastic optimal control, Simulation, Response surface methodology, Coordination.

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LISTE DES SYMBOLES ET UNITÉS DE MESURE

c	Critère d'acceptation
c_R	Coût unitaire d'achat de matière première
c_R^H	Coût unitaire de stockage de matière première
c_{RF}^T	Coût unitaire de production
c_F^H	Coût unitaire de stockage du produit fini
c_F^B	Coût unitaire de pénurie en produit fini
c_{insp}	Coût unitaire d'inspection
c_{rect}^R	Coût unitaire de rectification
c_{rep}^F	Coût unitaire de remplacement d'item non-conforme vendu au client
c_{rej}^R	Coût unitaire de rejet de la matière première
dem	Taux de la demande en produit fini
n	Taille de l'échantillon
p	Pourcentage d'items non-conformes de matière première dans un lot livré
P_a	Probabilité d'acceptation d'un lot de matière première après échantillonnage
Q	Taille du lot de la matière première
s	Point de commande de la matière première
t	Temps
u^{max}	Taux de production maximal
W	Coût de lancement de commande en matière première
$x(t)$	Niveau d'inventaire de la matière première à l'instant t
$y(t)$	Niveau d'inventaire du produit fini à l'instant t
τ_{insp}	Temps unitaire d'inspection de la matière première
τ_{rect}	Temps unitaire de rectification d'item non-conforme
δ	Délai de livraison de la matière première
ξ_i^-	Temps du début de l'opération d'inspection du $i^{éme}$ lot livré
ξ_i^+	Temps du fin de l'opération d'inspection du $i^{éme}$ lot livré

π	Probabilité qu'un item non-conforme de matière première cause l'arrêt du processus de production
ω	Degré d'implication d'un fournisseur dans l'amélioration de la qualité d'un lot retourné
Ω	Séquence des ordres en matière première (s, Q)

INTRODUCTION

Dans la pratique, les entreprises font face à de nombreux événements aléatoires qui peuvent perturber leurs opérations. Ces événements peuvent être soit internes (panne des machines, détérioration de la qualité, opération de maintenance…) soit externes (délais de livraison de la matière première, demande finale du client…). Face à ces incertitudes, les industries ont besoin d'une gestion adéquate de leur chaîne d'approvisionnement afin d'améliorer leur compétitivité. Cependant, le problème de gestion de la chaîne d'approvisionnement devient plus complexe lorsque les lots de matière première livrés contiennent des anomalies de conformité. Comparé à une situation où la qualité est parfaite, les entreprises n'auront pas besoin d'implanter des procédures de contrôle de qualité à la réception. Ils n'ont pas à se soucier des conséquences de ces décisions d'acceptation ou de refus; de l'impact des items non conformes sur le bon fonctionnement du système de production, ou des décisions vis-à-vis à leurs fournisseurs.

En se basant sur cette présentation, nous notons la complexité de la modélisation de cette chaîne. La prise de décisions doit être dynamique pour réagir au différent type d'incertitudes. De plus, les industriels doivent coordonner les différentes politiques de gestion (production, approvisionnement, inspection…) afin d'assurer une meilleure intégration de tous les intervenants pour atteindre leurs objectifs.

Au cours des dernières années, plusieurs auteurs ont développé des stratégies de commande optimale intégrant l'activité de production et d'approvisionnement, leur permettant de s'adapter en temps réel aux changements des conditions de production et d'approvisionnement. Cependant, ces modèles ont considéré que la qualité de la matière première est parfaite. Cette constatation constitue la motivation de notre recherche que nous allons développer dans ce mémoire.

Reconnaissant l'importance de l'intégration et la coordination des différentes décisions pour assurer une meilleure gestion d'une chaîne d'approvisionnement, l'objectif de ce mémoire est de développer des politiques de commande optimale d'une chaîne d'approvisionnement à trois niveaux en échelons dans un contexte de présence de matières premières non-conformes. Nous penserons à l'intégration des décisions de production, d'approvisionnement et de contrôle de qualité de la matière première et la minimisation des coûts liés à la gestion de ces opérations.

Ce mémoire comprend quatre (4) chapitres. Le premier présente une revue de la littérature. Il aborde également une analyse critique de la littérature, la problématique et les objectifs de notre recherche. Le deuxième chapitre présente un premier article scientifique intitulé respectivement « *Replenishement, production and quality control strategies in three-stage supply chain* » soumis à « *International Journal of Production Economics* ». Un deuxième article intitulé « *Integrated quality strategy in production and raw material replenishment in a manufacturing-oriented supply chain* » est présenté dans le chapitre 3. Ce dernier a été soumis à « *International Journal of Advanced Manufacturing Technology* ». Le chapitre 4 présente un troisième article scientifique intitulé « *An integrated production, replenishment and raw material quality control strategies with imperfect supplied items that may cause failures* » qui sera soumis prochainement.

CHAPITRE 1

REVUE DE LITTÉRATURE

1.1 Introduction

Dans ce premier chapitre, nous aborderons la structure de la chaîne d'approvisionnement faisant l'objet de notre étude. Nous nous intéresserons, par la suite, aux principaux travaux de recherche liés à notre problématique. Nous présenterons ensuite une critique de la littérature. Cette étude nous permettra de positionner notre recherche d'étude par rapport aux résultats obtenus. Dans une étape ultérieure, nous aborderons la problématique et les objectifs de recherche. Enfin, ce premier chapitre s'achèvera par une présentation de la méthode de résolution adoptée dans ce projet de recherche.

1.2 Structure de la chaîne d'approvisionnement étudiée

Dans un contexte stochastique et dynamique, pour déterminer conjointement les décisions optimales de production, d'approvisionnement et de contrôle de qualité de la matière première à la réception, il est important de définir certains mots clés, utilisés en gestion de la chaîne d'approvisionnement et de contrôle de la qualité.

1.2.1 Définition des mots clés-Terminologie

1.2.1.1 Chaîne d'approvisionnement

La chaîne d'approvisionnement « supply chain » est un réseau de fournisseurs, fabricants, distributeurs et détaillants qui vise à soutenir la circulation des produits, des informations et des flux financiers depuis la commande des matières premières de chez le fournisseur jusqu'à la livraison des produits finis au client final (Nakhla, 2009) et (Heizer, 2011).

1.2.1.2 Gestion de la chaîne d'approvisionnement

La gestion de la chaîne d'approvisionnement « supply chain management » a pour objectif de coordonner les activités et les flux depuis les fournisseurs jusqu'au client final (Nakhla, 2009) et d'améliorer l'efficacité opérationnelle, la rentabilité de l'entreprise et la relation entre les différents membres de la chaîne (Mahnam *et al.* (2009)).

1.2.1.3 Prise de décision

La coordination des décisions dans une chaîne d'approvisionnement peut être de deux types : centralisée ou décentralisée. La décision « centralisée » consiste dans le fait qu'il existe un seul décideur dans la chaîne d'approvisionnement qui a comme objectif de minimiser (maximiser) le coût (le profit) total de la chaîne. La décision « décentralisée » implique plusieurs décideurs qui ont des objectifs conflictuels (Jaber *et al.*, 2010).

1.2.1.4 Chaîne d'approvisionnement stochastique

Une chaîne d'approvisionnement est dite stochastique si, au moins un de ses paramètres est caractérisé par la présence de phénomènes aléatoires (délai de livraison, panne et réparation des unités de production…) (Min et Zhou, 2002).

1.2.1.5 Contrôle par attribut

Le contrôle par attribut consiste à qualifier les individus (unités statistiques) comme « bons » ou « défectueux » ou encore « conformes » ou « non-conformes » (Baillargeon, 2013).

1.2.1.6 Contrôle statistique de la qualité : plan d'échantillonnage simple par attribut

Le contrôle de la qualité d'un lot de matière (première, semi-finie, finie) par un plan d'échantillonnage a pour objectif de recommander son acceptation ou son rejet (non-acceptation) en se basant sur la qualité d'un échantillon (Baillargeon, 2013). Le plan d'échantillonnage simple par attribut consiste à prendre au hasard un certain nombre d'items afin de vérifier leur conformité à des spécifications préalablement définies. Si le nombre d'items non-conformes est inférieur ou égal à un critère d'acceptation prédéfini, le lot est accepté. Sinon, le lot est rejeté.

1.2.2 Chaîne d'approvisionnement étudiée

La chaîne d'approvisionnement tel que définie à la Figure 1.1 est constituée de trois échelons (un fournisseur, un manufacturier et un client final) et de deux entrepôts de capacité infinie. Le premier entrepôt est utilisé pour stocker la matière première et le deuxième pour stocker le produit fini. Nous considérons que le manufacturier est non-fiable (peut être non-disponible à cause des pannes et des réparations aléatoires) et que toutes les décisions seront prises à ce niveau.

Lorsque le manufacturier lance une commande de matière première, le fournisseur lui livrera après un délai de livraison aléatoire. Cependant, ces lots seront formés par une matière première de bonne et mauvaise qualité. À la réception, le manufacturier examinera la qualité des lots livrés à l'aide d'un plan d'échantillonnage simple par attribut. Dans ce mémoire, nous utiliserons les termes « conforme » et « non-conforme » dans la classification des items inspectés. Ce plan est caractérisé par une taille d'échantillon et un critère d'acceptation. Suite à l'inspection de la qualité de l'échantillon, le manufacturier décidera d'accepter ou de refuser ce lot. Le lot accepté est placé dans le stock de la matière première suite à la rectification des items non-conformes détectés dans l'échantillon. Le lot rejeté est soit examiné à 100 % avec des opérations de rectification, soit retourné au fournisseur.

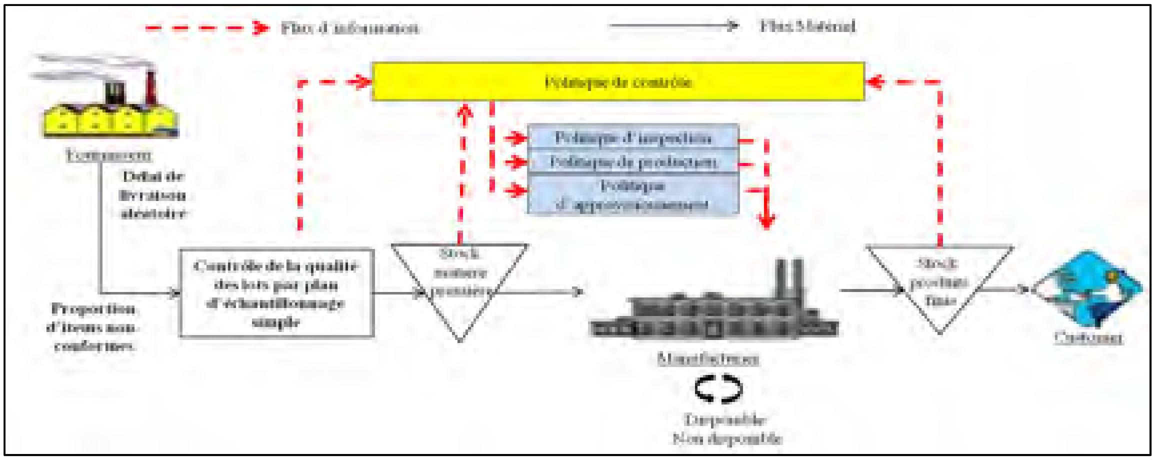

Figure 1.1 Structure d’une chaîne d’approvisionnement à trois échelons

Cette chaîne d’approvisionnement traitera un seul type de matière première et de produit fini. Pour répondre à la demande du client, le manufacturier transforme la matière première en produits finis avec un taux de production.

Le comportement du système est décrit par une composante continue (stocks de la matière) et une composante discrète (modes de système de transformation). La composante continue est constituée par les variables continues qui sont le stock en matière première et le stock en produits finis. Le système de transformation peut être soit disponible ou non-disponible.

1.2.3 Hypothèses de travail

- Tous les coûts sont connus;
- Le taux de la demande est constant et continu;
- Les délais de livraison, la disponibilité et la non-disponibilité du manufacturier sont aléatoires;
- Le processus de transformation est parfait. En d’autres termes, la qualité du produit fini est équivalente à celle de la matière première.
- L’opération d’inspection est dite « error-free ». Cette dernière suggère que la procédure de contrôle est parfaite.

1.3 État de l'art

Dans ce paragraphe, nous présenterons les principaux travaux de recherche liés à notre système. Nous considérons les auteurs qui ont traité : d'abord des systèmes manufacturiers non-fiables; ensuite, la coordination des décisions de production et d'approvisionnement dans un contexte de gestion d'une chaîne d'approvisionnement et, enfin, les politiques de contrôle de la qualité de la matière première.

1.3.1 Gestion des systèmes manufacturiers non-fiables

Pour déterminer des stratégies de commande optimale des systèmes manufacturiers non-fiables (sujet à des pannes et réparations), plusieurs auteurs ont adopté la théorie de commande stochastique. Cette approche leur a permis de tenir compte des différents phénomènes et de la dynamique de leurs systèmes.

1.3.1.1 Optimisation de la production

Kimemia et Gershwin (1983) ont montré, en se basant sur la formulation de Rishel (Rishel, 1975), que la politique de commande optimale pour un système manufacturier non-fiable à une structure spécifique appelée politique à seuil critique « *Hedging Point Policy (HPP)*». Cette politique stipule que le taux de la production de la machine peut prendre trois niveaux: si le niveau du stock du produit est inférieur au niveau du seuil critique, la machine produit au taux maximum; si le niveau du stock est égale à ce seuil, la machine produit au taux de la demande et, mais si le niveau du stock est supérieur à ce seuil, la machine est arrêtée. Dans la prolongement de leur formulation, Akella et Kumar (1986) ont déterminé une première solution analytique pour un cas particulier d'une seule machine produisant un seul type de produit. Les auteurs ont considéré que le taux de la demande est constant et que les réparations et les pannes suivent une distribution exponentielle. Sharifnia (1988) a étudié le même problème en considérant plusieurs états de la machine. Il a démontré que la politique de production optimale à une structure de seuil critique multiple (MHPP).

Boukas et Haurie (1990) ont établi les conditions d'optimalité décrites par les équations de Hamilton-Jacobi-Bellman (HJB) pour un système fabricant plusieurs produits. Étant donné qu'il est difficile de résoudre ces équations analytiquement, les auteurs ont adopté une méthode numérique basée sur l'approche de Kushner (Kushner et Dupuis, 1992) pour déterminer la structure de la politique de commande sous-optimale. Feng et Yan (2000) ont montré que la politique de contrôle est sous la forme d'une politique à seuil critique dans le cas d'un système manufacturier soumis à des pannes et réparations aléatoires et d'une demande aléatoire. Kenné et Gharbi (2001) ont proposé une nouvelle approche de résolution des problèmes de contrôle de la production combinant des méthodes analytiques, la simulation et la méthodologie de surface de réponse. Grâce à cette approche, ils ont déterminé la valeur optimale des différents paramètres de contrôle d'un système manufacturier composé de plusieurs machines, produisant plusieurs produits.

De nos jours, plusieurs auteurs se sont investis dans le développement des politiques de commande optimale pour des systèmes manufacturiers non-fiables plus complexes. Gharbi *et al.* (2008) ont traité la relation entre les opérations de production et de réutilisation « *remanufacturing* ». Kouedeu *et al.* (2011) ont étudié l'intégration des décisions de maintenance préventive et corrective avec les activités de production. Bouslah *et al.* (2012) ont, pour leur part, considéré un système de production par lot avec des délais de transport des produits finis vers le stock final. D'autres chercheurs se sont intéressés à l'intégration de l'aspect de production avec ceux de qualité ou d'approvisionnement. Ces travaux seront présentés plus en détail dans les paragraphes suivants.

1.3.1.2 Intégration de la qualité à la production

Au vu de grandes exigences des clients, nombreux auteurs se sont intéressés à développer des politiques de commande optimale plus réalistes. Ces modèles considèrent un système manufacturier non-fiable produisant une proportion d'items de qualité imparfaite. Mhada *et al.* (2011) ont étendu le travail de Bielecki et Kumar (1988) constitué d'un système non-fiable composé par une machine et un type de produit, et qui satisfait un taux de demande constant où la machine peut produire une proportion de produit défectueux. Dans ce travail, ils ont montré que la structure de la politique de commande est à seuil critique.

Hajji *et al.* (2012) ont adopté la méthode de résolution de Kenné et Gharbi (2001) pour un système manufacturier non-fiable et imparfait, composé d'une seul machine produisant plusieurs produits. Sous l'approche de commande optimale stochastique, ils ont déterminé conjointement la décision de production et de spécification de la qualité des produits finis.

Rivera-Gómez *et al.* (2013) ont étudié l'effet de détérioration de la machine de production sur la qualité des produits finis. Pour résoudre ce problème, les auteurs ont combiné l'approche numérique et l'approche de simulation basée sur les plans d'expérience et la méthodologie de surface de réponse.

Bouslah *et al.* (2013b) ont considéré un système manufacturier non-fiable produisant une proportion de produit fini non-conforme. Pour contrôler la qualité de cette matière avant sa vente, ils ont adopté une politique d'inspection basée sur un plan d'échantillonnage simple. Leur modèle a été résolu par une approche basée sur la simulation, les plans d'expérience et la méthodologie de surface de réponse.

1.3.1.3 Gestion simultanée de la production et de l'approvisionnement

Face à un environnement incertain, les manufacturiers sont de plus en plus motivés par la coordination efficace de leurs décisions de production et d'approvisionnement pour réduire le coût total de leur chaîne et mieux répondre à la demande de leur client. Dans ce contexte, Hajji *et al.* (2009) ont considéré une chaîne à trois échelons, composée par un fournisseur et un manufacturier soumis à des périodes de disponibilité et de non-disponibilité. Leur objectif était de coordonner la prise des décisions et de minimiser le coût total de la chaîne composée par les coûts de stockage de la matière première, les coûts de pénurie et du stockage des produits finis, le coût de commande et le coût de transformation de la matière. Ces auteurs ont détermié les conditions d'optimum à l'aide des équations HJB et ils ont montré que la solution analytique de ce système est difficile. Pour déterminer une approximation de la politique optimale, les auteurs ont alors utilisé une méthode numérique basée sur la méthode de Kushner (Kushner et Dupuis, 1992).

Berthaut *et al.* (2009) ont déterminé la politique optimale d'approvisionnement et de production d'un système de réfection « *remanufacturing* ». En se basant sur les résultats de Hajji *et al.* (2009), les auteurs ont utilisé la combinaison d'un modèle de simulation, des plans d'expérience et la méthodologie des surfaces de réponse. Il en est résulté que le taux de production suit une politique de seuil critique multiple (MHP) et que la politique d'approvisionnement est de type (s, Q).

Hajji *et al.* (2011a) ont traité l'impact des délais d'approvisionnement aléatoires sur les prises des décisions d'approvisionnement et de production. Pour étudier des situations complexes pour différentes distributions de délais de livraison, les auteurs ont combiné l'approche numérique et l'approche de simulation basée sur les plans d'expérience. Ils ont démontré que la politique de commande optimale de la production est de type seuil critique (HPP) et que la politique d'approvisionnement est de type (s, Q).

Hajji *et al.* (2011b) ont étendu le travail de Hajji *et al.* (2009) en considérant plusieurs fournisseurs. Un modèle stochastique et dynamique est alors proposé pour déterminer la politique de commande optimale. Leur modèle a permis de joindre les décisions d'approvisionnement, de production et de sélection du fournisseur. Ils ont montré qu'il était nécessaire de considérer une prise de décision intégrée.

1.3.2 Intégration des décisions d'approvisionnement et de production

Au cours des dernières années, plusieurs études ont montrées que l'intégration des décisions de production et d'approvisionnement dans une chaîne d'approvisionnement à plusieurs échelons est indispensable afin d'assurer une meilleure performance. Dans ce contexte, Mukhopadhyay et Ma (2009) ont établi la structure optimale des décisions d’approvisionnement et de production pour un système hybride de production/ réutilisation « *manufacturing/remanufacturing* » qui satisfait une demande stochastique.

Sawik (2009) a proposé une approche de programmation mixte pour une chaîne d’approvisionnement à trois échelons. L’objectif était de coordonner les opérations d’approvisionnement, de fabrication et d’assemblages de produit fini afin de minimiser le coût total de la chaîne composée par les coût de stock, de production et d’expédition.

Pal *et al.* (2012) ont présenté une méthode analytique pour optimiser le taux de production et la taille du lot à commander pour une chaîne d’approvisionnement formée par un manufacturier, un fournisseur et un détaillant. Dans ce travail, ils ont considéré que la qualité de la matière première et de produits finis était imparfaite.

Pal *et al.* (2013) ont déterminé la taille du lot d’approvisionnement et le taux de production optimal pour une chaîne d’approvisionnement à trois échelon en considérant la présence d’un contrat d’assurance-crédit.

Sana *et al.* (2014) ont étudié une chaîne d’approvisionnement à trois échelons formé par plusieurs fournisseurs, plusieurs manufacturiers et plusieurs détaillants. Cette chaîne fait face à la présence de produits défectueux de matières premières et de produits finis. Dans leur étude, ils ont montré qu’un système collaboratif « *Collaborating system* » assure un meilleur résultat que l’approche de Stakelberg.

1.3.3 Contrôle de la qualité de la matière première

Dans la plupart des cas, une entreprise s’approvisionne de matières premières auprès de fournisseurs extérieurs ou encore doit utiliser, dans l’assemblage de ses produits certaines pièces fabriquées par un sous-traitant (Baillargeon, 2012). Dans cette situation, elle peut alors envisager soit un contrôle à 100 % de toutes les pièces d’un lot, soit un contrôle par échantillonnage afin de s’assurer que la livraison est conforme ou non à la qualité exigée.

1.3.3.1 Inspection 100 %

Bien que la littérature soit riche en travaux sur le contrôle à 100 % du lot de la matière première à la réception, la plupart des modèles ont adopté les hypothèses de Salameh et Jaber (2000). Ces auteurs ont proposé une nouvelle version du modèle de gestion des stocks, quantité économique de commande « *Economic Ordering Quantity (EOQ)* » où les lots reçus sont de qualité imparfaite. Ils ont considéré que la proportion d'items de qualité imparfaite suit une variable aléatoire définie par une fonction de densité de probabilités connue. À la fin du processus d'inspection à 100 %, ces items sont retirés et placés dans un seul lot et seront vendus dans un marché secondaire avec un prix réduit. Dans ce travail, Salameh et Jaber (2000) ont pu déterminer la taille du lot optimal de matière première. Ils ont démontré que le pourcentage des items de qualité imparfaite augmente lorsque la taille du lot économique augmente.

En se basant sur cette approche, Khan *et al.* (2010) ont fait l'extension du modèle de Salameh et Jaber (2000) à un modèle dont les délais d'inspection des items de qualité imparfaite suit une courbe d'apprentissage. Alors que Khan *et al.* (2011a) ont étendu l'hyothèse d'une procédure d'inspection parfait « *error-free* » appliquée par Salameh et Jaber (2000) à un procédure d'inspection imparfaite, en adoptant l'approche de Raouf *et al.* (1983). D'autres chercheurs ont adopté les hypothèses de Salameh et Jaber (2000) dans le cadre de la gestion de la chaîne d'approvisionnement à deux échelons Huang (2002) et Ouyang *et al.* (2006), et à plusieurs étages Sana (2011) et Pal *et al.* (2012). Nous référons le lecteur à l'article de Khan *et al.* (2011b). Ils ont présenté une revue récente des différents travaux basée sur le modèle de Salameh et Jaber (2000).

Dans la littérature, d'autres considérations ont été prises vis-à-vis les items de qualité imparfaite. Rosenblatt et Lee (1986) ont proposé un modèle EOQ où les items de qualité imparfaite seront retravaillés instantanément avec un coût. Jaber *et al.* (2013) ont pour leur part proposé un modèle EOQ avec deux politiques d'inspection dans le cas d'un fournisseur très distant et qu'il n'est pas possible de remplacer les items imparfaits avec un ordre supplémentaire depuis le même fournisseur. La première politique est que les items imparfaits seront envoyés dans un atelier de réparation avec un coût additionnel. La deuxième est que les items imparfaits seront remplacés par des produits de bonne qualité livrés par un fournisseur local. Gholami-Qadikolaei *et al.* (2013) ont présenté un modèle stochastiques de gestion des stocks multi-objectif et multi-contrainte. Suite à un contrôle à 100 % du lot, les items imparfaits seront soit retravaillés avec un coût et un délai, soit complètement écartés.

1.3.3.2 Plan d'échantillonnage

Pour assurer une bonne coordination entre le fournisseur et son acheteur, Starbird (1997) a examiné l'impact du plan d'échantillonnage simple par attribut sur la qualité et les décisions de production du fournisseur. Dans ces différents travaux, il a montré que, plus le degré de sévérité du plan d'échantillonnage augmente, plus la pression sur le fournisseur à améliorer la qualité de ses produits augmente. Toutefois, Wan *et al.* (2013) ont considéré que la qualité des produits reçus par le fournisseur est mesurée par une variable continue qui suit une distribution normale. Dans tous ces travaux, une décision de retour au fournisseur a été adoptée lorsqu'un lot est rejeté.

Selon Hsu et Hsu (2012), les tables de contrôle de la qualité par plan d'échantillonnage dans les différents livres de qualité ne sont pas économiques dans un contexte de gestion d'une chaîne d'approvisionnement à deux échelons. Ces auteurs ont alors conçu un modèle économique afin de déterminer le plan d'échantillonnage optimal tout en considérant les risques du vendeur et de l'acheteur.

D'autres travaux ont réussi à introduire la procédure de contrôle avec un plan d'échantillonnage dans le modèle EOQ. Cependant, cette considération a reçu une attention très limitée (Moussawi-Haidar *et al.*, 2014). Peters *et al.* (1988) ont développé un algorithme pour déterminer conjointement la taille de lot à commander, le point de commande et les paramètres optimaux d'un plan d'échantillonnage. Ces auteurs ont montré que l'intégration des décisions de gestion de stock et de contrôle de qualité est plus avantageuse qu'une prise de décision indépendante. Dans les travaux de Ben-Daya *et al.* (2006) et Ben-Daya et Noman (2008), un plan d'échantillonnage avec attribut a été appliqué pour le contrôle de la qualité de la matière livrée. Concernant les items de qualité imparfaite, ils ont considéré deux modèles : le premier est que les items seront remplacés par des produits de bonne qualité, alors que la deuxième est qu'ils seront écartés avec une décision de non remplacement. Al-Salamah (2011) a proposé un modèle EOQ où la nature du produit commandé exige l'application d'un plan d'échantillonnage avec des tests destructifs. Dans cette étude, il a considéré que tous les produits de lot rejetés par inspection seront vendus à un prix réduit. Moussawi-Haidar *et al.* (2013) ont pour leur part déterminé simultanément la taille de lot optimale à commander, le point de commande et les paramètres du plan d'échantillonnage. Les auteurs ont considéré que les paramètres du plan d'échantillonnage seront déterminés sous la contrainte d'une qualité moyenne limite après contrôle (AOQL). En se comparant au modèle de Salameh et Jaber (2000), les auteurs ont démontré que la politique de contrôle par plan d'échantillonnage assure un meilleur résultat qu'une inspection à 100 %.

1.4 Critique de la littérature

Au cours des dernières années, plusieurs modèles intégrant la coordination des décisions de gestion de la production et de l'approvisionnement ont été publiés pour assurer une meilleure gestion de leur chaîne d'approvisionnement. Tous ces modèles ne traitent pas le problème dans un contexte continu, dynamique et stochastique, ne tiennent pas compte de la qualité de la matière première, des méthodes d'inspection par plan d'échantillonnage simple par attribut et la coordination des décisions d'inspection avec ceux de la production et de l'approvisionnement.

Dans un contexte stochastique et dynamique, les chaînes d'approvisionnement avec un système manufacturier non-fiable ont été approximées par des modèles à flux-continus (Hajji *et al.* 2009 et Hajji *et al.* 2011a). Ces différentes études ont réussi à mettre en évidence l'importance de coordonner les décisions du manufacturier afin d'assurer une meilleure gestion de la chaîne d'approvisionnement. Cependant, ils ont considéré certaines hypothèses pour simplifier la modélisation et la résolution. Une de ces hypothèses est que la qualité de la matière première livrée est parfaite. Cela dit, une proportion d'items non-conformes peut être livrée. Ainsi, le manufacturier doit intégrer des procédures de contrôle de la qualité de la matière première avant de l'accepter et la placer dans son entrepôt de stockage de matière. À notre connaissance, aucun modèle de contrôle n'a été proposé pour des chaînes d'approvisionnement stochastiques et dynamiques avec des lots de matière première imparfait.

Certains auteurs, comme Sana (2012), Pal *et al.* (2012) et Sana *et al.* (2014), ont supposé qu'un fournisseur peut livrer des items imparfaits dans un contexte de gestion d'une chaîne d'approvisionnement à trois niveaux. Cependant, ils ont considéré que le manufacturier appliquera à la réception, une politique de contrôle à 100 %. Une telle politique peut s'avérer une solution idéale pour détecter tous les items non-conformes, mais elle ne peut pas être recommandée lorsque le test est destructif, coûteux ou bien la durée d'inspection est importante (Schilling et Neubauer, 2009). De plus, selon Duncan (1986), un contrôle à 100 % peut ne pas être aussi efficace comme il était généralement pensé. En effet, les items non-conformes peuvent passer l'inspection lorsque le pourcentage de ces items dans un lot est important. À notre connaissance, aucun modèle intégrant le contrôle de la qualité de la matière première avec un plan d'échantillonnage n'a été proposé dans un contexte de gestion de la chaîne d'approvisionnement.

Dans la littérature, la procédure de contrôle de la qualité à la réception par un plan d'échantillonnage a été établie dans un contexte où les opérations d'approvisionnement et de production sont absentes. De ce fait, l'application d'un plan d'échantillonnage présente trois limitations :

1. <u>Au niveau de la prise de décision :</u> Dans la plupart des modèles intégrant le contrôle de qualité par un plan d'échantillonnage, une seule décision vis-à-vis des lots rejetés a été considérée. Ce lot est soit inspecté à 100% (Ben-Daya *et al.*, 2006) soit retourné au

fournisseur (Wan *et al.*, 2013). Il serait peu réaliste que la décision du manufacturier vis-à-vis d'un lot de matière première rejeté suite à un contrôle de qualité par plan d'échantillonnage soit figée dans un contexte où la demande, les opérations de production et d'approvisionnement varient. Une décision d'inspection à 100 % du lot rejeté assurera la présence continue de la matière première avec une bonne qualité. Cependant, le décideur doit supporter deux types de coûts additionnels. Le premier est le coût total lié aux différentes opérations d'inspection. Le deuxième est le coût de stockage additionnel en matière première lorsque le stock de produit fini est suffisant pour répondre à la demande du client. Une décision de retour au fournisseur d'un lot rejeté permettra au décideur d'exclure tous les coûts additionnels d'inspection. Cependant, cette option entrainera l'augmentation des délais de livraison de la matière première. En conséquence, le risque de rupture de stock de matière première peut augmenter, entrainant ainsi l'augmentation du risque d'interruption du processus de production. Dans cette situation, le décideur devra supporter l'augmentation du coût de pénurie en produits finis suite à la non-satisfaction de la demande du client.

2. <u>Au niveau de l'optimisation des paramètres d'un plan d'échantillonnage</u> : Plusieurs auteurs ont déterminé les paramètres optimaux d'un plan d'échantillonnage. Cependant, ces modèles ne prennent pas en considération les activités de la production.

3. <u>Au niveau de l'acceptation des items non-conformes suite à un contrôle de qualité</u> : En adoptant une inspection par plan d'échantillonnage, une proportion d'items non-conformes peut passer l'inspection. Dans la littérature, l'acceptation de cette matière n'entraine aucun effet sur le processus de production. Cependant, selon l'étude des causes de panne d'une station d'emballage d'une usine de production du gâteau au chocolat, Akbarov *et al.* (2008) ont montré que la qualité de cartons d'emballage et des produits intrants représente la deuxième source de panne de la station. Il faut ainsi tenir compte de l'effet d'acceptation de tels items sur la disponibilité du processus de transformation.

1.5 Problématique de recherche

Pour assurer une meilleure gestion de la chaîne d'approvisionnement, le décideur doit coordonner ces différentes décisions en fonction des caractéristiques de sa chaîne et des différentes informations qu'il dispose. Suite à la critique de la revue de la littérature, plusieurs questions peuvent être posées en ce qui concerne la coordination des décisions de production, d'approvisionnement et de contrôle de la qualité de la matière première par plan d'échantillonnage :

1. Tout d'abord, quelle est la politique de commande optimale stochastique d'une chaîne d'approvisionnement où la qualité de la matière première livrée est imparfaite?

2. Quand doit-on lancer une commande au fournisseur? En quelle quantité? Quand doit-on produire pour répondre à la demande du client?

3. Quelle est la meilleure politique de contrôle à appliquer à la réception d'un lot de matière première permettant de minimiser le coût total de la chaîne sur un horizon infini?

4. Comment un décideur doit intégrer les différentes informations disponibles pour assurer une meilleure coordination des différentes décisions de production, d'approvisionnement et de contrôle de qualité?

1.6 Objectifs de la recherche

Ce mémoire a pour objectif de développer des politiques de commande optimale d'une chaîne d'approvisionnement à trois échelons, en considérant un délai de livraison aléatoire, un système de transformation non-fiable et une procédure d'inspection par plan d'échantillonnage à la réception de la matière première.

Ce travail nous permettra ainsi de planifier d'une façon optimale les différentes décisions d'approvisionnement, de production et de contrôle de la qualité à la réception pour réduire le coût total de la chaîne composé principalement par : le coût de stockage de la matière première, le coût de stockage de produits finis, le coût de pénurie en produits finis, les coûts de qualité et/ou les coûts de lancement de commande.

Nous développerons dans ce projet les trois modèles suivants :

1. Dans le premier modèle, nous allons étudier une chaîne d'approvisionnement produisant un seul type de produit, constitué d'un fournisseur, d'un manufacturier non-fiable et d'un client final. À la réception de la matière première, le manufacturier examinera la qualité du lot avec un plan d'échantillonnage dont les paramètres sont connus. Les deux objectifs principaux de ce modèle sont de déterminer : d'abord, la structure de la politique de contrôle intégrant les opérations de production, d'approvisionnement et de contrôle de qualité; ensuite, la meilleure stratégie de contrôle de qualité vis-à-vis d'un lot de matière première rejeté au niveau de l'inspection. Ces stratégies seront : une inspection à 100 %, un retour au fournisseur et une combinaison de ces deux dernières.

2. Dans le deuxième modèle, nous allons proposer une chaîne d'approvisionnement à trois échelons produisant un seul type de produit, constituée d'un fournisseur qui offre l'amélioration de la qualité de chaque lot rejeté par le manufacturier, un manufacturier non-fiable et un client final. À la réception de la matière première, le manufacturier examinera la qualité du lot avec un plan d'échantillonnage caractérisé par un critère d'acceptation nul. Les variables de décision sont la séquence d'approvisionnement, le taux de production et la taille de l'échantillon. Dans ce travail, nous étudierons l'effet de l'optimisation de la taille de l'échantillon dans la prise de décisions d'inspection du manufacturier. Nous nous intéressons par la suite à l'effet de l'intégration des informations fournies par un fournisseur sur la décision (retour au fournisseur du lot ou une inspection à 100 %) du manufacturier vis-à-vis d'un lot de matière première.

3. Dans le troisième modèle, nous proposerons une chaîne d'approvisionnement à trois échelons produisant un seul type de produit, constitué d'un fournisseur, d'un

manufacturier non-fiable et d’un client final. Dans ce travail, le processus de production peut être bloqué suite au traitement de matière première non-conforme. L’objectif de ce travail est d’étudier l’effet d’acceptation de ces produits sur les différentes décisions de production et d’approvisionnement, et l’avantage d’application d’une procédure de contrôle de qualité basée sur un plan d’échantillonnage.

Afin d’apporter une réponse à la problématique de coordination des décisions d’approvisionnement, de production et de contrôle de qualité de la matière première, et au choix de la meilleur politique d’inspection, nous présentons, dans le paragraphe suivant, la méthode de résolution.

1.7 Méthode de résolution

Dans ce mémoire, les chaînes d’approvisionnement considérées présentent un dégrée important d’incertitude dont la résolution analytique ou numérique est difficile. Nous allons alors adopter une approche de résolution basée sur la simulation, les plans d’expérience et la méthodologie de surface de réponse.

Dans la sphère de la théorie de contrôle, Kenné et Gharbi (1999) ont été les premier à appliquer cette méthode. Ils ont déterminé les valeurs optimales d’une politique de contrôle dérivée de la politique HPP, « *Age-Dependent Hedging Point Policy* ». Kenné et Gharbi (2001) ont reformulé plus tard cette approche pour un système manufacturier composé par plusieurs machines, produisant plusieurs produits. Pour résoudre ce problème, les auteurs ont considéré : en premier lieu, l’approche de Boukas et Haurie (1990) pour établir la structure de la politique de contrôle, et, en deuxième lieu, l’approche de Kenné et Gharbi (1999) pour obtenir les valeurs optimales des paramètres de contrôle. Comme extensions de travail de Kenné et Gharbi (2001), Berthaut *et al.* (2009), Hajji *et al.* (2012) et Assid *et al.* (2014) ont adopté une approche purement expérimentale où leur politique de contrôle heuristique a été inspirée par les anciens résultats de recherche.

Dans la suite de ces travaux, les différentes étapes de l'approche de résolution expérimentale sont présentées dans la Figure 1.2 :

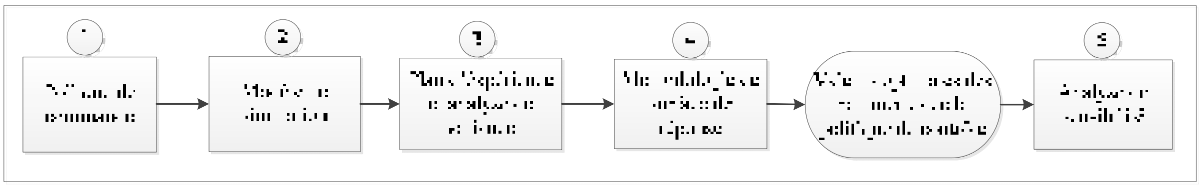

Figure 1.2 Diagramme de la méthode de résolution

- Étape 1 : Politique de commande

Tout d'abord, nous allons assimiler le contrôle de la qualité de la matière première par un plan d'échantillonnage simple et les opérations de production et d'approvisionnement pour une chaîne d'approvisionnement à trois niveaux. Par la suite, la dynamique et les contraintes du système seront présentées. Enfin, la structure de la politique de commande à appliquer sera introduite. Cette étape nous permettra ainsi de définir tous les paramètres de la politique de contrôle à optimiser.

- Étape2 : Modèle de simulation

Un modèle de simulation discret/continu sera développé pour représenter la dynamique de la chaîne d'approvisionnement considérée. Ce modèle sera développé en utilisant le langage ARENA avec des routines C++. En effet, Lavoie *et al.* (2010) ont montré que cette approche permet de bien représenter les aspects stochastiques et dynamiques d'un système, ainsi que la réduction du temps de simulation. Au cours de cette étape, les paramètres de contrôle définis dans l'étape précédente sont utilisés comme des entrées du modèle de simulation. Suite à la simulation du modèle, le coût total sera alors obtenu.

- Étape 3 : Plan d'expériences et analyse de variance

En utilisant le logiciel STATGRAPHICS, nous élaborerons des combinaisons des différents paramètres de contrôle sous forme d'un plan d'expérience. À l'aide du modèle de simulation développé dans l'étape 2, le coût total encouru pour chaque combinaison sera déterminé. Nous utiliserons par la suite, l'analyse de la variance (ANOVA) afin d'identifier les facteurs et leurs interactions qui ont un effet significatif sur le paramètre de sortie (le coût total).

- Étape 4 : Méthode des surfaces de réponse

Cette méthode permet d'établir la relation entre le coût et les principaux facteurs et les interactions jugées comme significatifs. À partir de cette relation, la valeur optimale des paramètres de la politique de commande et celle de coût peut être déterminée.

- Étape 5 : Analyse de sensibilité

Cette analyse nous permettra de confirmer la robustesse de l'approche de résolution. À la suite de la variation des paramètres de système, nous analyserons les différents résultats afin de s'assurer de la bonne variation de notre modèle.

1.8 Conclusion

Ce chapitre, nous a tout d'abord permis de présenter la structure générale de la chaîne d'approvisionnement considérée dans ce travail. Ensuite, nous avons abordé une revue des différents travaux relatifs à la détermination d'une politique de commande optimale pour des systèmes manufacturier non-fiables; l'intégration des décisions de production et d'approvisionnement pour assurer une meilleure gestion de la chaîne d'approvisionnement et le contrôle de la qualité de la matière première. Dans tous les cas discutés, les auteurs s'intéressent peu à l'intégration de contrôle de la qualité de la matière première par un plan d'échantillonnage dans un contexte de gestion d'une chaîne d'approvisionnement. Cet aspect, nous intéresse pour se rapprocher plus de la réalité.

Il a également permis de présenter la problématique et les objectifs de recherche, ainsi que la méthode de résolution appliquée dans ce mémoire. Grâce à l'approche de résolution expérimentale, nous développerons, dans un contexte dynamique et stochastique, des politiques de commande optimale d'une chaîne d'approvisionnement en présence d'un système manufacturier non-fiable et un procédé de contrôle par plan d'échantillonnage. Il nous permettra également de montrer l'importance de l'interaction des différentes décisions pour assurer une meilleure performance de la chaîne.

CHAPITRE 2

REPLENISHMENT, PRODUCTION AND QUALITY CONTROL STRATEGIES IN THREE-STAGE SUPPLY CHAIN

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Abstract: In this paper, we propose to jointly integrate and coordinate production, replenishment and quality inspection decisions in a three-stage supply chain control problem. The transformation stage produces one final product type and responds to a stable market demand. After a random lead time, the supplier delivers raw materials in batches which may contain a certain proportion of defective items. When a lot of raw materials is received, a lot-by-lot acceptance sampling plan is applied, and then a decision is taken with regards to a 100% screening or discarding of the sampled lot. In this article, we focus on the existing interaction between the applicable quality control decisions and the replenishment and production control decisions. The objective is to determine a control policy for production, replenishment and quality activities which minimizes the total cost, including purchasing costs, production and quality inspection costs, as well as the inventory/backlog costs. A simulation model and a response surface methodology are used to find the optimal parameters of the proposed policy. The obtained results show that the integration of 100%

screening or discarding decisions in a new "hybrid" one is more beneficial, and guarantees a better coordination at a lower cost.

Keywords: Stochastic optimal control, Unreliable manufacturers, Imperfect quality, Acceptance sampling, Simulation, Response Surface Methodology.

2.1 Introduction

In today's economy, an adequate management of a supply chain is necessary in order to ensure the survival of industries, and allow them to increase their competiveness. Several recent studies have shown that decision making models incorporating raw material procurement in manufacturing activities perform better in terms of average total cost than those tackling the decisions involved separately (Lee, 2005). In this context, Ben-Daya et Al-Nassar (2008) studied a coordinated inventory and production problem in a three-layer supply chain involving suppliers, manufacturers and retailers. Sawik (2009) developed a mixed integer programming approach where manufacturing, supply and assembly schedules are determined simultaneously. Pal *et al.* (2010) suggested an integrated procurement production and shipment planning for a three-echelon supply chain. Sajadieh *et al.* (2013) considered an integrated production-inventory model for a three-stage supply chain in which lead times to retailers are stochastic. All these studies provide valuable contributions to the scientific literature; however, they do not consider the dynamic evolution of manufacturing activities and the impact of this evolution on complete decisions.

Many research studies have tackled the problem in a dynamic stochastic context where the control theory has been one of the most significant approaches used to solve such problems. In the context of the planning problem for unreliable manufacturing systems, several approaches have been developed (Kenné et Gharbi, 2000) based on the hedging point policy (HPP) concept. This policy consists in building an optimal safety stock level during periods of excess capacity in order to meet demand when the manufacturing system is no longer available due to machine failure. Sethi et Zhang (1999) suggested a solution for an optimal production planning where multiple distinct part types are produced. Kenné *et al.* (2003) considered an integrated production and corrective maintenance problem. Pellerin *et al.* (2009) developed a production control problem for multi-production-rate remanufacturing systems. Rivera-Gómez *et al.* (2013) studied an integrated production, overhaul and preventive maintenance problem.

Following the works of Lee (2005), Hajji *et al.* (2009) addressed an integrated production and supply control problem for a three-stage supply chain with one unreliable supplier and one unreliable transformation stage. Hajji *et al.* (2009) showed that the optimal control policy is a "modified state-dependent multi-level base stock policy" (MBSP) for production activities, combined to a "state-dependent economic order quantity" (SD-EOQ) policy for replenishment decisions. The developed policy allows the identification of the best decision to undertake as a function of the whole system state. Berthaut *et al.* (2009) determined a control policy for both supply and remanufacturing activities, composed of a multi-hedging point policy (MHPP) and an (s,Q) policy. Song (2009) considered a supply chain with supplier, manufacturer and customer with stochastic lead-time, processing time and demand and determined the optimal integrated ordering and production policy that minimise the expected total cost subject to finite capacitated warehouses. Hajji *et al.* (2011a) studied a joint production and delayed supply control problem. They showed that the control policy is a combined (HPP) and (s,Q) policy. Hajji *et al.* (2011b) extended the model of Hajji *et al.* (2009) to a multiple supplier case. These research studies showed the advantages considering the production and supply activities in a dynamic stochastic context in an integrated manner. Song (2013) studied several stochastic supply chain systems and determined the optimal production control policies and the optimal ordering policies in the case of supply chains with backordering and, a supply chain with multiple products, etc. However, they all assume raw materials to be in perfect quality. This assumption is unrealistic, as has been argued by many research studies (Konstantaras *et al.*, 2012) and (Khan *et al.*, 2014). In fact, the lot received may contain a fraction of non-conforming parts. Therefore, to identify and separate bad purchased items from good ones, the inspection/screening process becomes an indispensable step.

This paper proposes to study this issue through the integration of production, replenishment and raw material quality control in a three-stage supply (Supplier-Manufacturer-Customer) chain. Upon the lot being received, the manufacturer performs a single acceptance sampling plan. Such a policy has indeed been largely adopted in the industry (Schilling et Neubauer, 2009). Starbird (1997) and Starbird (2005) analyzed the impact of a buyer's acceptance plan on a supplier's quality and production decisions. Ben-Daya et Noman (2008) established integrated inventory inspection models with and without replacement of non-conforming items. They proposed a comparative study between different inspection policies: *no inspection*, *sampling inspection* and *100% inspection*. Al-Salamah (2011) studied an EOQ model where the quality of the received lot is controlled by a destructive acceptance sampling. Wan *et al.* (2013) studied the incentive effect of acceptance sampling plans in a supply chain with endogenous product quality. More recently, a few articles have studied supply chain problems with non-conforming raw materials, but however, with the focus solely a full inspection policy (Sana, 2011), (Pal *et al.*, 2012) and (Sana *et al.*, 2014).

It should be noted that when an acceptance plan is applied, the inspected raw materials lot may be refused. However, in all of the previous research studies, only one of the two decisions was taken with respect to the rejected lots: either 100% inspection or the entire lot is returned to the supplier. While this assumption may be reasonable for certain circumstances, it could present limitations if considered jointly with the production process and the customer demand stage. As a three stage supply chain is considered, the quality decision should not be taken independently of the whole system. The question then becomes how the decision maker should proceed in taking such inspection decisions? On the one hand, returning a lot to the supplier reduces the total cost of the inspection operation, but it increases the lead time, and results in an important finished product shortage risk. On the other hand, although a 100% inspection decision may assure the presence of better quality raw materials, the system will face high inspection costs. To arrive at a compromise between the advantages and disadvantages of a full return and 100% inspection decisions, in this article, we propose that quality inspection decisions be coordinated with production and replenishment activities to ensure better control at minimal cost.

The rest of this paper is organised as follows. In section 2, we present a formulation of the production, supply and inspection problem. In section 3, we propose a control policy of the system. We report a resolution approach in section 4 and a simulation model in section 5. In section 6, we give an example to present the numerical results. In section 7, we illustrate a comparative study between different inspection policies. Finally, conclusions are given in section 8.

2.2 Problem formulation

The purpose of this section is to introduce the considered problem which consists of an integrated unreliable manufacturing system supplied by an upstream supplier with random lead time, using a sampling plan to control received raw materials.

2.2.1 Notations

The notations used in this paper are summarized as follows:

dem	:	Finished product demand rate (units/time)
u^{max}	:	Maximum manufacturing production rate (units/time)
Q	:	Raw material lot size
s	:	Raw material ordering point
n	:	Sample size
c	:	Acceptance number
d	:	Number of non-conforming raw material items in a sample
p	:	Proportion of non-conforming items in the received lot
P_a	:	Acceptance probability of a lot
δ	:	Replenishment delay
τ_{insp}	:	Inspection delay per unit (time/unit)
τ_{rect}	:	Raw material rectification time (time/unit)

W	:	Ordering cost
c_R	:	Raw material cost ($/unit)
c_R^H	:	Raw material holding cost ($/time/unit)
c_{RF}^T	:	Cost of raw material transformation into finished product ($/unit)
c_F^H	:	Finished product holding cost ($/time/unit)
c_F^B	:	Finished product backlog cost ($/time/unit)
c_{insp}	:	Raw material inspection cost ($/unit)
c_{rect}^R	:	Raw material rectification cost ($/unit)
c_{rep}^F	:	Non-conforming finished product replacement cost ($/unit)

2.2.2 Problem statement

The system under study (Figure 2.1) consists of one supplier, one manufacturer and one customer. The manufacturer (stage 2) orders a batch of products from an upstream supplier, with an ordering cost W and a purchasing price c_R per unit. The supplier (stage 1) delivers the lot after a random lead time δ. We assume that each delivered lot contains a fixed fraction p of non-conforming items and that the manufacturer (stage 2) could be unavailable due to failures and repair operations.

After the raw materials are transformed into finished products, the manufacturer sells them to the final customer (stage 3) and responds to a continuous and constant demand rate dem.

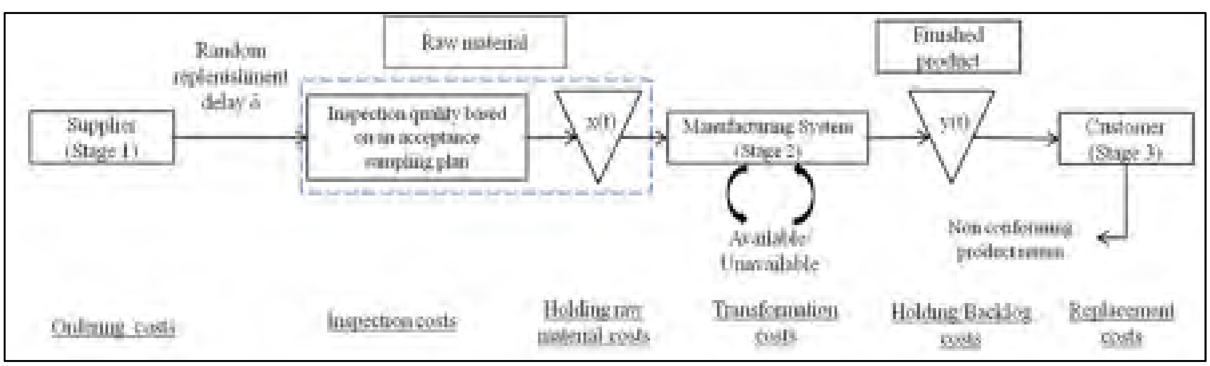


Figure 2.1 System under study

When the lot is delivered, the manufacturer inspects its quality using a lot-by-lot single acceptance sampling plan with attributes. Because a sampling plan is adopted, some unsafe product may pass inspection. These items could be transformed into a finished product, and thus sold to the final customer. In this case, it is assumed that the customer can detect and return them to be replaced with a c_{rep}^{F} per unit cost.

The whole state of the considered supply chain at time t is described by a hybrid state where both a discrete and a continuous component are used, namely:

- A continuous part $y(t)$ which describes the cumulative surplus level of the finished product (inventory if positive, backlog if negative). This part faces a continuous downstream demand.

- A piecewise continuous part $x(t)$ which describes the cumulative surplus level of the raw material. This part faces a continuous downstream demand (i.e., a manufacturing production rate) and an impulsive upstream supply after a lot-by-lot sampling inspection.

- A discrete part $\alpha\,(t)$ which describes the state of the manufacturing system. This state can be classified as "manufacturing system is available", denoted by $\alpha(t) = 1$, or "manufacturing system is unavailable", denoted by $\alpha(t) = 2$.

Assuming a perfect production process, we consider that the quality of our raw material and finished product are equivalent. Thus, the dynamic of the stock levels $x(t)$ and $y(t)$ is given by the following differential equations:

$$\dot{y}(t) = u(t,\alpha) - \frac{dem}{1 - AOQ(t)}, y(0) = y_0 \;\; \forall t \geq 0 \tag{2.1}$$

$$\dot{x}(t) = -u(t,\alpha), x(0) = x_0 \;\; \forall t \in \,]\xi_i, \xi_{i+1}[$$

$$x(\xi_i^{+}) = x(\xi_i^{-}) + Q_i \; \forall\, i = 1 \dots N \tag{2.2}$$

where y_0, x_0 denote the initial stock levels, dem denotes the demand rate, $u(t, \alpha)$ denotes the manufacturing system production rate in mode α, $AOQ(t)$ denotes the average outgoing quality of the raw material, and ξ_i^-, ξ_i^+ denote the negative and positive boundaries of the N receipt instants after an inspection operation, respectively.

2.3 Structure of control policies

In this section, we present the structure of the control policies for the considered system. The production and supply policies are based on the findings of Hajji *et al.* (2011a) and Bouslah *et al.* (2013a). Regarding the quality control policy, we will study three different inspection decisions which will be presented later. In this study, our main objective is to determine the production rate, a sequence of supply decisions and the best quality control policies, in order to minimize the total expected supply, production, quality inspection, raw material holding, holding/backlog final product costs and the defective finished product replacement cost.

2.3.1 Production and supply policies

For the same class of supply chain in a stochastic dynamic context, where the manufacturing system is facing a delayed supply, and without consideration of quality, Hajji *et al.* (2011a) determined the optimum decision variables consisting of the production rate $u(.)$ and the sequence of supply orders denoted by $\Omega = \{(\theta_0, Q_0), (\theta_1, Q_2), \ldots\}$, where Q_i is the order quantity derived at time θ_i. Indeed, Hajji *et al.* (2011a) showed that the optimal control policy for a joint production and replenishment problem is defined by a combined Hedging Point Policy (HPP) and (*s*, *Q*) policies.

Recently, Bouslah *et al.* (2013a) jointly considered the production control policy and a single sampling plan design for an unreliable batch manufacturing system. By considering an imperfect production system, they showed that their production policy is controlled by a "Modified Hedging Point Policy" (MHPP).

According to the findings of Hajji *et al.* (2011a), the raw material inventory and the final product should be maintained at an excess level in order to face supply operations, quality control operations, and capacity shortage. However, as some unsafe raw materials may pass inspection, the production policy is controlled by the MHPP policy rather than the HPP policy. Consequently, more appropriate supply and production control policies, where the supplied lot contains non-conforming items is proposed as follows:

Production policy (MHPP):

$$u(.) = \begin{cases} u^{max} \text{ if } (\ y(t) < Z) \text{ and } (x(t) > 0\ ) \text{ and } (\alpha = 1) \\ \frac{dem}{1-AOQ(t)} \text{ if } (y(t) = Z) \text{ and } (x(t) > 0) \text{ and } (\alpha = 1) \\ 0, \text{ otherwise.} \end{cases} \tag{2.3}$$

Supply policy (s, Q):

$$\Omega(.) = \begin{cases} Q \text{ if } \ x < s\ , Q \in \mathbb{N} \\ 0, \text{ otherwise.} \end{cases} \tag{2.4}$$

With constraint: $Z \geq 0, Q > s \geq 0.$ (2.5)

Where: u^{max} denotes the maximum production rate, s the ordering point, Q the lot size, and Z the finished product hedging level.

2.3.2 Inspection policies

A single sampling plan is characterized by two parameters, *n* and *c*, which are the sample size and the acceptance number, respectively. If the number of defective items d, found in this sample, is equal to or less than c, the lot will be accepted, otherwise it will be rejected. In this study, we consider the following three scenarios: a single sampling plan with 100%

inspection and rectification operations (100% policy), a single sampling plan with return decision (Ret policy), and a single sampling plan leading to a combination of the two last decisions, called the Hybrid policy (Hyb policy).

Given the aforementioned quality control parameters (n, c, d, p), the probability of acceptance of the received lot P_a can be calculated using the binomial probability distribution (Schilling et Neubauer, 2009) which is given as follows:

$$P_a = P\{d \leq c\} = \sum_{d=0}^{c} \frac{n!}{d!\,(n-d)!}\, p^d (1-p)^{n-d} \tag{2.6}$$

2.3.2.1 Description of the 100 % policy

Figure 2.2 presents the evolution of an i^th lot from the launch of an order θ_i to its admission in the raw materials stock ξ_i and the incurred quality costs in the case of the 100% policy. As soon as the lot is received at instant $\omega_i = \theta_i + \delta$, a sample size n is screened with $n.\tau_{insp}$ delay and $n.c_{insp}$ costs, where τ_{insp} is the inspection delay per unit and c_{insp} is the inspection cost per unit. Inspired by the works of (Rosenblatt et Lee, 1986) and (Gholami-Qadikolaei *et al.*, 2013), we assume that non-conforming items are reworked with a τ_{rect} delay per unit and a c_{rect}^{R} per unit cost. According to inspection decisions, the instant ξ_i may take two values (Figure 2.2). If the lot is accepted, $\xi_i = \omega_i + n\tau_{insp} + d\,\tau_{rect}$. Otherwise, $\xi_i = \omega_i + Q.\tau_{insp} + p.Q.\tau_{rect}$, where $p.Q$ is the number of non-conforming items in lot Q. Indeed, if the lot is refused, it will be subject to a 100% screening process and, all non-conforming items will be reworked (Figure 2.2-A).

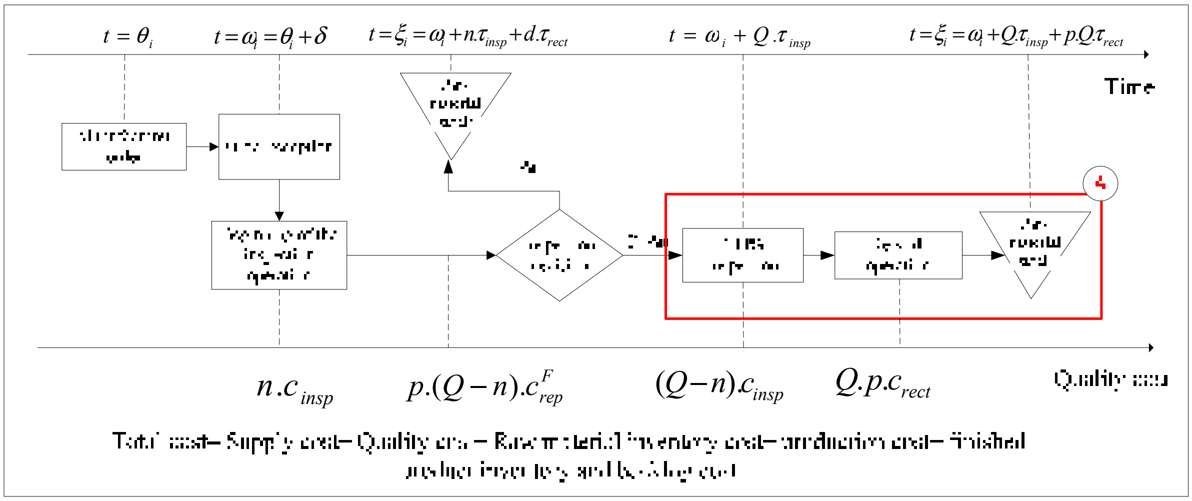


Figure 2.2 100% policy

2.3.2.2 Description of the Ret policy

Figure 2.3 presents the evolution of an ith lot from the launch of an order θ_i to its reception in the raw materials stock ξ_i and the incurred quality costs in the case of the Ret policy. As soon as the lot is received at instant $\omega_i = \theta_i + \delta$, the manufacturer controls the quality of a sample size n. If the inspected lot is accepted, non-conforming items are reworked with a τ_{rect}. Thereafter, it is added to the raw materials stock (Figure 2.3-) at $\xi_i = \omega_i + n.\tau_{insp} + d\ \tau_{rect}$. However, if the lot is rejected, the supplier picks it up and a new order is placed. In that situation, we assume that the manufacturer will not pay the supplier (no ordering and purchasing costs). After an additional delay δ, a new lot is delivered and an additional quality control is performed. Thus, $\xi_i = \omega_i + N^i_{rej}.\delta + (N^i_{rej} + 1)\ n.\tau_{insp} + d\ \tau_{rect}$, where N^i_{rej} is the number of times the ith lot is rejected.

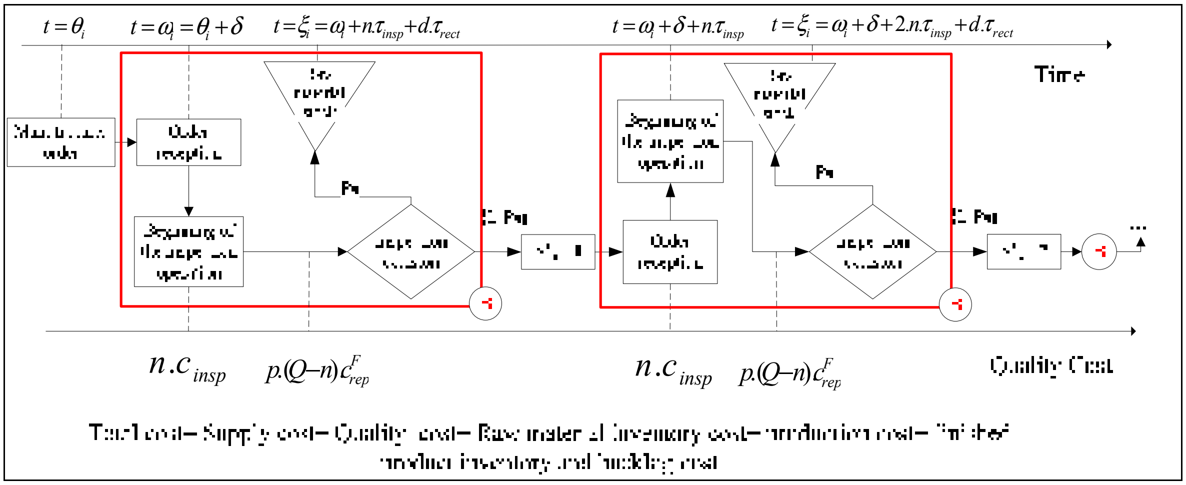


Figure 2.3 Ret policy

2.3.2.3 Description of the Hyb policy

As shown in Figure 2.3, the return decision causes an increase in the delivery delay. Therefore, this decision may reduce the availability of raw materials, leading to a stoppage of the production process due to starvation and an increase in the backlog cost of the final product due to continuous customer demand. In a different context, performing a 100% inspection on each refused lot (Figure 2.2) could considerably increase the inspection and rectification costs. Nevertheless, if there is a significant stock of finished products, no additional raw materials are needed. Thus, it would be better to return the refused lot in order to avoid such additional costs. That is why it is reasonable to assume that it would be more appropriate to decide whether or not to return the rejected lot, depending on the finished product level. If the finished product stock level is above a threshold Z_2, the manager considers that the system has enough finished products to reduce the risk of backlog and returns the refused lot to the supplier (Figure 2.4-). Otherwise, the manager will opt for a 100% inspection and rectification operations to ensure the continuity of the production process. Figure 2.4 presents the evolution of an ith lot from the launch of an order θ_i to its reception in the raw materials stock ξ_i and the incurred quality costs in the case of the Hyb policy.

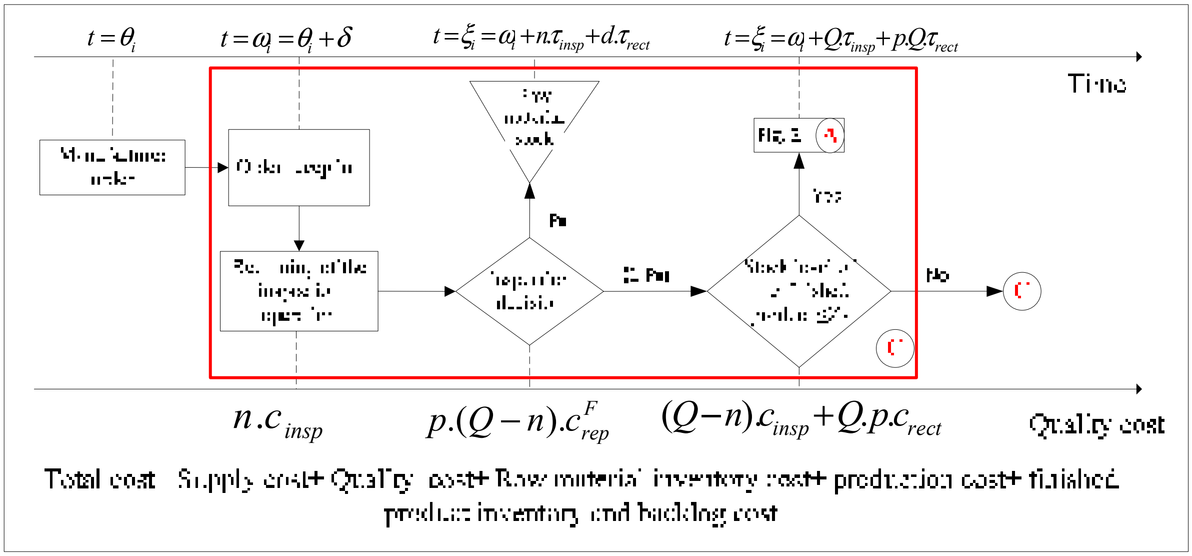


Figure 2.4 Hyb policy

According to the inspection policy, the $AOQ(t)$ equation is as follows:

$$AOQ(t) = \begin{cases} AOQ_{100\%}(t) = \dfrac{\sum_{i=1/a^i=1}^{N(t)} p(Q-n)}{\sum_{i=1}^{N(t)} Q} \\ AOQ_{Ret}(t) = p \\ AOQ_{Hyb}(t) = AOQ_{100\%}.\Pr(y(t) \leq Z_2) + AOQ_{Ret}.(1 - \Pr(y(t) \leq Z_2)) \end{cases} \tag{2.7}$$

where $N(t)$ represents the number of inspected lots at time t, $a^i = 1$, if the i^{th} lot is accepted, and $a^i = 0$ otherwise, and $\Pr(y(t) \leq Z_2)$ denotes the probability that the level of the finished product $y(t)$ is under a threshold Z_2.

To summarize, the different quality control policies break down as follows:

$$\text{100\% policy: } \begin{cases} \text{Inspection limited to the sample } n \text{, if } d \leq c. \\ \text{Full inspection and rectification operation, otherwise.} \end{cases}$$

$$\text{Ret policy: } \begin{cases} \text{Inspection limited to the sample } n \text{, if } d \leq c. \\ \text{Return of the lot, otherwise.} \end{cases} \qquad (2.8)$$

$$\text{Hyb policy: } \begin{cases} \text{Inspection limited to the sample } n \text{, if } d \leq c. \\ \text{Otherwise, } \begin{cases} \text{Full inspection and rectification operation,} \\ \quad \text{if}(y(t) \leq Z_2), \\ \text{Return of the lot, otherwise.} \end{cases} \end{cases}$$

With constraint: $Z \geq Z_2$, $\mathrm{c} \geq 0$. (2.9)

where Z_2 denotes the hedging level of finished production for the selection of quality decision.

Figure 2.5 shows the dynamics of the raw material $x(t)$ and finished products $y(t)$ stock levels according to the joint production and supply control policy where the hybrid inspection policy is adopted. When the production system is available and $x(t) > 0$, the raw material is transformed to finished products. Then, if $y(t)$ is below Z, the manufacturer produces at the maximal rate. When the production system is unavailable or $x(t) = 0$, the production process is stopped until the repair of the system (after repair delay) or the introduction of a new order of raw materials to the raw materials stock . At the same time, when the raw material $x(t)$ level crosses the ordering point , the manufacturer orders a batch of raw materials from the supplier. This lot is delivered after a lead time δ. Once the sample of size n is inspected after delay, the manufacturer decides to accept or to refuse this lot. If the lot is accepted, it is transferred to the final raw materials stock, at which point we note an increase in the $x(t)$ level with Q items. Otherwise, if the lot is refused, the manufacturer checks the finished product level. If $y(t)$ is under Z_2 1, the manufacturer performs a full inspection of the lot and reworks all non-confirming items with a delay. Otherwise, the lot is returned to the supplier. In this case, the manufacturer must wait for another lead time δ until the new lot is delivered.

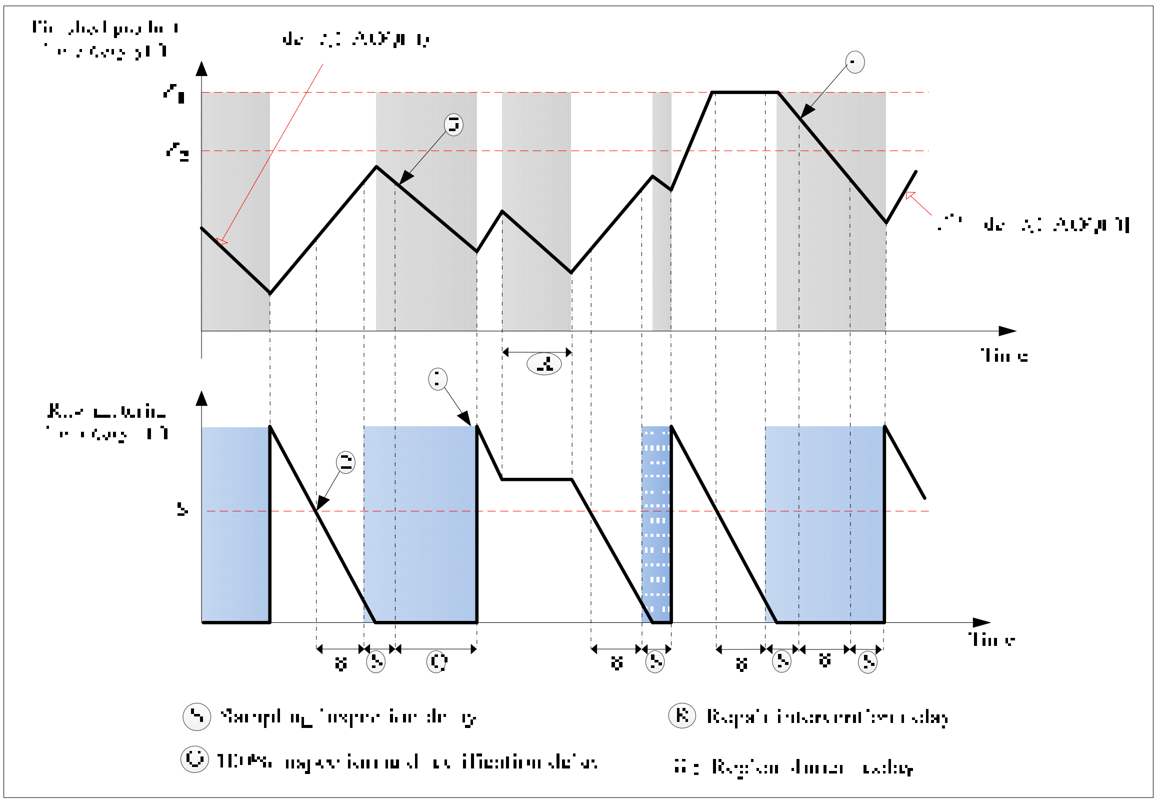


Figure 2.5 Evolution of raw material inventory $x(t)$ and finished product inventory $y(t)$ under the joint production, supply and hybrid inspection policies

The supply chain system under consideration in this study is subject to random lead time and random availability of the production system. It is also subject to a high variability represented in the decisions made in the context of the inspection policies (determination of $\Pr(y(t) \leq Z_2)$ when the hybrid policy is applied or N_{rej} for the Ret policy). For these reasons, it is difficult to come up with a mathematical formulation. Therefore, we propose an experimental determination of the optimum control parameter (s, Q, Z) or $(s,\ Q, Z,\ Z_2)$ that gives the best long-term expected total cost, which includes the ordering cost, the raw material cost, the raw material holding cost, the finished product holding/backlog costs, the cost of sampling, the costs of 100% inspection and rectification (Case 100% and Hyb policies) and the cost of replacing non-confirming finished products.

2.4 Resolution approach

The experimental approach adopted to solve the problem is a combination of simulation modelling, experimental design and surface methodology. The reader is referred to Rivera-Gómez *et al.* (2013) for more details. The main sequential steps of this approach are:

1. Development of a simulation model to describe the dynamics of the simultaneous production planning, replenishment and quality control problem by considering the control policy as input (Eqs. (2.3), (2.4) and (2.8)).

2. Development of an appropriate experimental design with a minimal set of simulation runs. Data are then collected to perform a statistical analysis in order to determine the effects of the main factors, their quadratic effects, and their interactions (i.e., ANOVA analysis of variance) on the response (the cost).

3. Determination of the relationship between the incurred cost and the significant main factors and/or interactions using the Response Surface Methodology (RSM). From this estimated relation, known as the regression equation, the optimal values of the control policy parameters, called (s^*, Q^*, Z^*) or $(s^*, Q^*, Z^*, Z_2{}^*)$ and the optimal cost value are determined.

2.5 Simulation model

To reproduce the dynamic behaviour of the considered supply chain and decision process, a combined discrete/continuous model was developed using the SIMAN simulation language with C++ subroutines (Pegden, 1995). The model was developed on ARENA simulation software. Using such a combined approach allows a reduction of the execution time and offers more flexibility to integrate the continuous tracking of system parameters (Lavoie *et al.*, 2010). The simulation model in the case of a Hyb policy is presented in Figure 2.6.

1. Block 0: This block initializes the values of the different parameters and variables of the problem, such as (s, Q, Z, Z_2), production rates, the lead time, and inspection parameters. We also assign the simulation time T_∞ at this step.

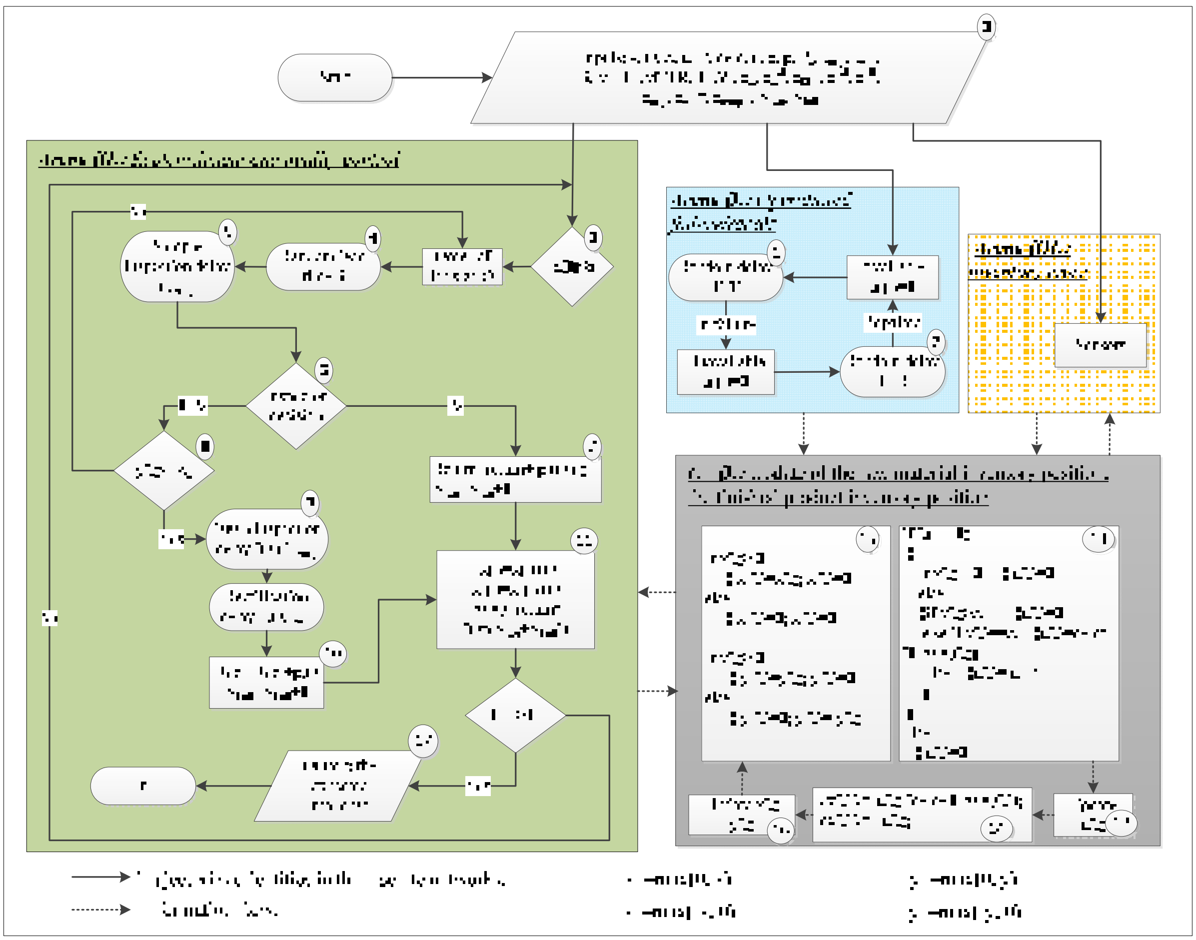


Figure 2.6 Simulation block diagram (case of Hyb policy)

2. Arena (I): It models the operational failure and repair events. At the beginning of the simulation, the production process is set to available (α=1). Depending on the position of the entity, the manufacturer could be operational if the entity is held in the TTF delay

block 1, or not operational, if it is in the TTR block 2. We note that our simulation model is developed to accept any possible probability distribution.

3. Arena (II): It models the supply control policy (Eq. (2.4)) 3 and the quality control policy (Eq. (2.8)). When the lot is delivered after a δ delay 4, a sample size is inspected 5 and an inspection decision is taken 6. Thanks to the probabilistic BRANCH block of SIMAN, only P_a (Eq. (2.6)) lot will be accepted. In this case 7, the number of accepted lots and the cumulative returned quantity are updated by the discrete variables N_{acc} and Return, respectively. Otherwise, $(1 - P_a)$ lots are rejected. If $y(t)$ is under Z_2 8, the lot is submitted to 100% inspection and rectification operations 9. At this point 10, the number of lots subject to full inspection and the cumulative rectified quantity are updated by the discrete variables, N_{Full} and Rect, respectively. When the lot is received in the raw materials stock 11, the inventory level (Eq. (2.2)) and the average outgoing quality $AOQ(.)$ (Eq. (2.7)) are updated.

4. Arena (III): It continuously verifies whether or not the raw material or finished product inventory cross a threshold. It is presented by the DETECT block in SIMAN.

5. C^{++}(I): Using C language inserts, three operations are defined: First, an update of the production rate 12 according to the control production policy 13 defined by (Eq. (2.3)). Secondly, there is the introduction of the dynamic of the production system 14 defined by (Eq. (2.1)). Then, the inventory position of raw material $x(t)$ and finished product $y(t)$ are integrated continuously 15. Finally, we have an instantaneous update of the surplus and backlog levels of finished product and the surplus of the raw material by the routine 16.

6. Finally, when the current time of the simulation T_{Now} exceeds T_{∞}, the simulation is stopped. Based on the different outputs, the total cost is calculated.

2.6 Experimental design and Response Surface Methodology

This section applies the aforementioned approach to develop a regression equation aimed at determining the input parameters which affect the response, the relationship between the cost and significant factors, and finally, the optimal values of estimated factors.

2.6.1 Numerical example & RSM

Our first case study considers the following values of the operational and cost parameters characterising the supply chain and inspection operations:

Table 2.1 Cost and production parameters

Parameter	u^{max}	dem	TTF	TTR	W	c_R	c_R^H	c_{RF}^T	c_{insp}	c_F^H	c_F^B	c_{remp}^F	c_{rect}^R
Values	360	215	Expo(15)	Expo(1.65)	300	0.5	1	0.5	12	1	40	90	65

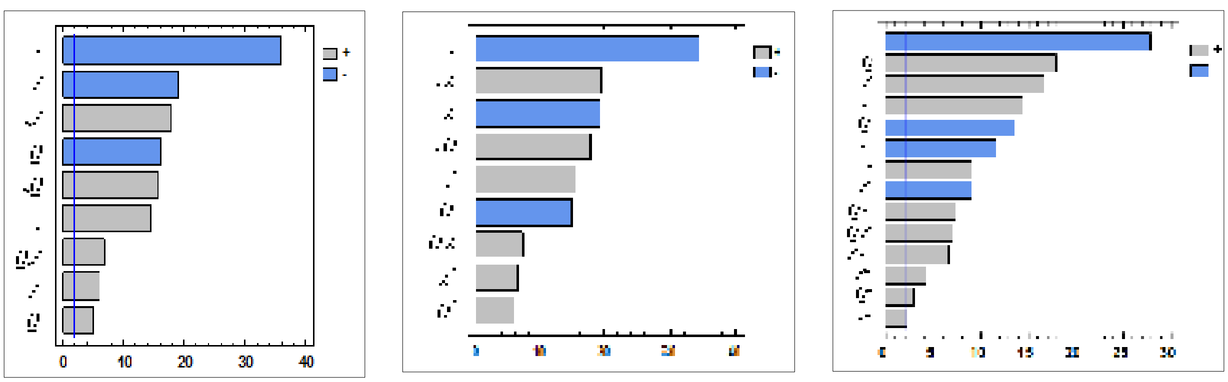
Table 2.2 Inspection and delay (per day) parameters

Parameter	n	c	$\%p$	δ	τ_{insp}	τ_{rect}	T_{∞}
Values	125	3	2.5%	Expo(2)	5.10^{-4}	0.001	950,000

Since we have four independent variables (s, Q, Z, Z_2) for the Hyb Policy (three independent variables (s, Q, Z) for 100% and Ret policies, respectively), a Face-Centered Central Composite design FCCCD (2^4 + 8 star points + 4 center points) is selected (3^3-response surface design for the 100% and Ret policies, respectively). For each design, five replications were conducted, and therefore, 140 (28*5) simulation runs were completed for the Hyb Policy ($135(3^3 * 5)$ simulation runs were completed for the 100% and Ret policies, respectively). Furthermore, the common random number technique (Law, 2007) was used to reduce the variability from one configuration to another.

Using a statistical software application such as STATGRAPHICS, a multi-factor analysis of the variance (ANOVA) of the simulated data was conducted. This analysis aimed to quantify the effect of the independents variables (s, Q, Z) or (s, Q, Z, Z_2) and their interactions on the dependent variable (the cost).

Based on a Pareto plot (Figure 2.7), we found that all the factors of the different policies, their quadratic effect and their interaction are significant at the 95% level of significance. Furthermore, we noticed that all the R_{adj}^2 values (Figure 2.7) of the proposed regression models were greater than 95%. Over 95% of the total variability is thus explained by the models (Montgomery, 2013).



R^2_{ajs} =95.39% R^2_{ajs} =95.48% R^2_{ajs} =96.19%

(a) Ret (b) 100% (c) Hyb

Figure 2.7 Standardized Pareto plot for the total cost ($\%p = 2.5\%$)

To verify the adequacy of the models, a residual analysis was conducted. The analysis consisted in testing the homogeneity of the variances and the residual normality using the residual versus predicted value plot and normal probability plot, respectively. We conclude that the models for the different policies are satisfactory. From STATSGRAPHICS, the second-order models of the total cost for each inspection policy are given by:

$$\mathrm{Cost}_{\mathrm{Ret}}\,(\mathrm{s},\mathrm{Q},\mathrm{Z}) = 38003.3 - 16.474.\mathrm{s} - 9.10348.\,\mathrm{Q} - 9.00821.\,\mathrm{Z} + 0.00240846.\,\mathrm{s}^2 + 0.0019288.\mathrm{s}.\,\mathrm{Q} + 0.00209273.\,\mathrm{s}.\,\mathrm{Z} + 0.000915866.\,\mathrm{Q}^2 + 0.000850717.\mathrm{Q}.\,\mathrm{Z} + 0.00099188.\mathrm{Z}^2. \tag{2.10}$$

$$\mathrm{Cost}_{100\%}(s,Q,Z) = 25372.3 - 15.9824.\,s - 8.83754.Q - 7.45347.Z + 0.00358277.s^2 + 0.00297361.\,s.Q + 0.0026577.\,s.Z + 0.00141921.Q^2 + 0.00102811.Q.\,Z + + 0.00105296.Z^2. \tag{2.11}$$

$$\mathrm{Cost}_{\mathrm{Hyb}}(\mathrm{s},\mathrm{Q},Z,\mathrm{k}) = 25173.4 - 10.8384.\mathrm{s} - 5.66342.\mathrm{Q} - 8.17662.Z - 6525.83.k + 0.00180302.\mathrm{s}^2 + 0.00146689.\,\mathrm{s}.\,\mathrm{Q} + 0.00165998.\mathrm{s}.Z + 1.66332.\mathrm{s}.\,\mathrm{k} + 0.000591633.\mathrm{Q}^2 + 0.000716081.\mathrm{Q}.\,Z + 0.871479.\mathrm{Q}.\,\mathrm{k} + 0.00128123.Z^2 + 0.948431.Z.\,\mathrm{k} + 946.265.\,\mathrm{k}^2. \tag{2.12}$$

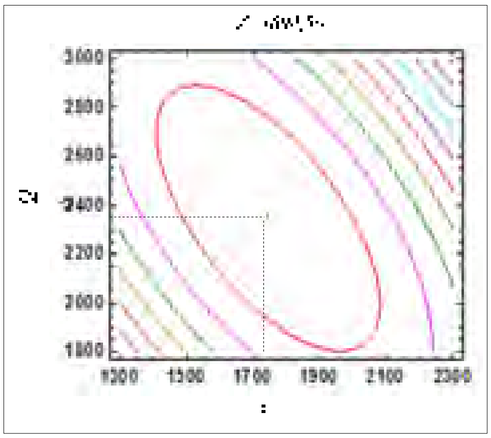
Where $k = Z_2/Z$ (To make sure that $Z_2 \leq \mathrm{Z}$).

Based on the relationship between the dependent (the cost) and the independent variables (s, Q, Z) or (s, Q, Z, Z_2), in Figure 2.8, we present the projection of the response surface of the cost function in a two-dimensional plan. Figure 2.8 shows the parameter corresponding to the minimum total cost for the three policies: s^*=1744.35, $Q^* = 2346$ and Z^*=1694.56 (Figure 2.8.(a)); s^*=1091.1, $Q^* = 1442$ and Z^*=1458.27 (Figure 2.8.(b)) and s^*=1166.13, $Q^* = 1764$ Z^*=1652.83 and Z_2^*=1293.82 (Figure 2.8.(c)).

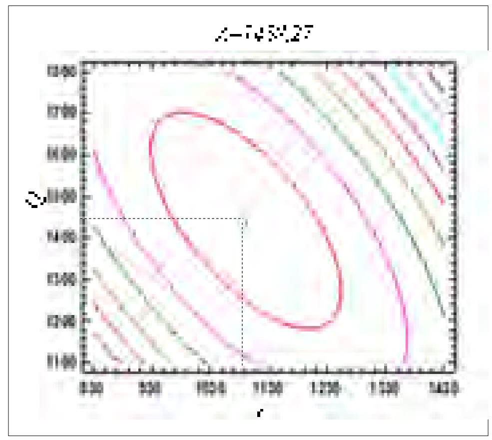
Furthermore, to confirm the validity of our models, we established the confidence interval at 95% using (Eq. (2.13)). By running $h = 20$ extra replications using optimal parameters, we noticed that the minimum cost of each inspection policy is within the confidence interval (Table 2.3).

$$\bar{C}^*(h) \pm t_{\frac{\alpha}{2},h-1}.\sqrt{S^2(h)/h} \tag{2.13}$$

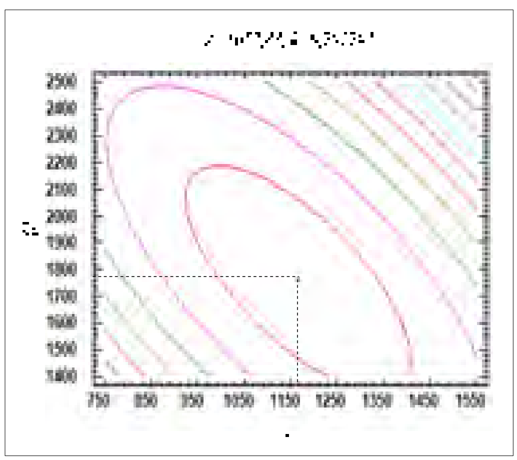
where $\overline{C}^*$ is the average optimal cost, S the sample standard deviation and $(1-\alpha)$ the confidence level.



(a) Ret



(b) 100%



(c) Hyb

Figure 2.8 Cost response surface

As shown in Table 2.3, these results illustrate the superiority of the Hyb policy as compared to the Ret and 100% policies, which help ensure a lower optimal total cost. This is due to its structure, with which the decision maker coordinates the inspection decision with the production and replenishment decisions, depending on the finished product stock level. To illustrate the robustness of this resolution approach for ranges of systems parameters, a sensitivity analysis will be performed.

Table 2.3 Confidence interval and optimal parameters and cost results

Policies	Optimal Parameters				Optimal Cost	CI (95%)
	s^*	Q^*	Z^*	$k^* = Z_2{}^*/Z^*$		
Ret	1744.35	2346	1694.56	-	5323.41	[5312.33, 5387.58]
100%	1091.1	1442	1458.27	-	4845.85	[4828.88, 4875.81]
Hyb	1166.13	1764	1652.83	0.782791	4547,58	[4539.49, 4575.16]

Furthermore, since a sampling plan was adopted, we compared these policies to a full control policy (Full). In fact, the full policy is a particular case of the sampling policy where the probability of acceptance $P_{\boldsymbol{a}} = 0$. We found that the $Cost_{Full}^{*} = 6155.86$. Based on this result, we can conclude the advantage of a sampling plan control policy as compared to full policy.

2.6.2 Sensitivity analysis

Sensitivity analyses are necessary to ensure a full understanding of the effect of a given parameter variation on the entire system and to make sure that all variations make sense. In this study, we concentrated our efforts on operational parameters judged the most appropriate. Hence, the inspection plan; the replenishment delay; positive inventory, backlog, ordering and inspection costs are considered in conducting the sensitivity analysis. The results obtained (Table 2.4) show the impact of this variation on the optimal control parameters $(s^*, Q^*, Z^*, Z_2{}^*)$ when a Hyb policy is considered.

2.6.2.1 Case 1: Variation of the ordering cost W

When the cost W increases, the decision maker had to order a larger lot size (Q^* increases), but less frequently (s^* decreases). Indeed, by ordering higher quantities, the system keeps a higher level of raw materials (R.M), allowing on the one hand it to decrease the finished product (F.P.) threshold Z^*, and on the other, to promote return decisions (${Z_2}^*$ decreases) in order to avoid an high inventory costs. When the cost W decreases, we note an opposite variation.

2.6.2.2 Case 2: Variation of the raw material holding cost $\mathbf{c_R^H}$

When the c_R^H cost increases, the manager had to decrease the raw material stock level by ordering less frequently (s^* decreases) in order to reduce inventory costs. In this situation, the manufacturer had to promote more 100% inspection decisions on refused lots than decisions to return to the supplier (${Z_2}^*$ increases). Consequently, Q^* decreases to reduce total inspection cost. At the same time, Z^* increases. In fact, this variation aimed to increase the transformation of R.M. into the final product (F.P.) to meet a continuous demand and increase the stock-out frequency of R.M. When the c_R^H cost decreases, we note an opposite variation of the optimal parameters.

2.6.2.3 Case 3: Variation of the inspection cost $\mathbf{c_{insp}}$

When the c_{insp} cost increases, the manager had to reduce the total inspection cost, which included sampling and 100% inspection costs. For this reason, the manufacturer had to promote return decisions (${Z_2}^*$ decreases). At the same time, s^* and Q^* increase to ensure the presence of enough R.M, and Z^* increases to ensure the presence of enough F.P. When the c_{insp} cost decreases, we note an opposite variation of the optimal parameters.

Table 2.4 Sensitivity analysis data and results of the Hyb policy

Case	Parameter	Variation	Optimal Parameters				$\text{Cost}^*_{\text{Hyb}}$	$\text{Cost}^*_{100\%}$	$\text{Cost}^*_{\text{Ret}}$	Impact on Hyb policy
			$s*$	$Q*$	Z^*	Z_2^*				
Base	-	-	1166.13	1764	1652.83	1293.82	4547.58	4845.85	5323.41	-
1	W	**500**	1158.08	1789	1651.78	1285.69	4572.16	4875.95	5342.14	s*↓ Q*↑ Z*↓ Z_2^*↓ Cost*↑
		100	1175.18	1737	1653.56	1300.9	4522.49	4815.47	5304.68	s*↑ Q*↓ Z*↑ Z_2^*↑ Cost*↓
2	c_R^H	**1.35**	1064.39	1634	1728.41	1487.57	4999.30	5282.29	6058.25	s*↓ Q*↓ Z*↑ Z_2^*↑ Cost*↑
		0.65	1289.16	896	1574.3	1059.63	4041.20	4378.00	4540.69	s*↑ Q*↑ Z*↓ Z_2^*↓ Cost*↓
3	c_{insp}	**24**	1273.15	2153	1668.98	834.25	5 017.45	5978.17	5546.31	s*↑ Q*↑ Z*↑ Z_2^*↓ Cost*↑
		6	1149.09	1596	1643.35	1486.41	4232.37	4 277.37	5208.65	s*↓ Q*↓ Z*↓ Z_2^*↑ Cost*↑
4	c_F^H	**1.1**	1181.9	1768	1604.07	1255.14	4687.77	4 970.90	5470.07	s*↑ Q*↑ Z*↓ Z_2^*↓ Cost*↑
		0.9	1151.07	1759	1700.42	1333.90	4403.11	4713.29	5168.78	s*↓Q*↓ Z* ↑ Z_2^*↑ Cost*↓
5	c_F^B	**52**	1175.05	1728	1709.75	1482.70	4668.22	4 971.91	5506.79	s*↑ Q*↓ Z*↑ Z_2^*↑ Cost*↑
		28	1120.01	1788	1552.97	1109.01	4384.02	4673.71	5090.58	s*↓ Q*↑ Z*↓ Z_2^*↓ Cost*↓
6	$\%p$	**3%**	1287.54	1685	1695.92	1368.84	4944.30	5252.64	6633.85	s*↑ Q*↓ Z*↑ Z_2^*↑ Cost*↑
		2%	1103.87	1866	1525.72	1149.88	4285.15	4404.27	4548.25	s*↓ Q*↑ Z*↓ Z_2^*↓ Cost*↓
7	c	**4**	1123.19	1595	1545.93	1089.26	4212.46	4448.39	4557.42	s*↓ Q*↓ Z*↓ Z_2^*↓ Cost*↓
		2	1261.11	1827	1826.86	1518.91	5034.59	5339.85	6762.16	s*↑ Q*↑ Z*↑ Z_2^*↑ Cost*↑
8	δ	**Expo(2.5)**	1526.63	2030	1756.45	1477.79	5039.55	5291.51	6196.43	s*↑ Q*↑ Z*↑ Z_2^*↑ Cost*↑
		Expo(0.75)	400.09	1347	1297.73	449.413	3509.54	4004.74	3646.33	s*↓ Q*↓ Z*↓ Z_2^*↓ Cost*↓

2.6.2.4 Case 4: variation of the finished product holding cost $\mathbf{c_F^H}$

When the c_F^H cost increases, the optimal threshold Z^* decreases in order to reduce the inventory costs. By keeping a lower level of F.P., the manufacturer had to ensure the continuity of the production process by reducing the stock-out frequency of R.M (s^* and Q^* increase). At the same time, the manufacturer promoted the return option (${Z_2}^*$ decreases) to avoid high R.M holding costs. When the c_F^H cost decreases, we note an opposite variation of the optimal parameters.

2.6.2.5 Case 5: variation of the finished product backlog cost $\mathbf{c_F^B}$

When the c_F^B cost increases, the manufacturer increases the Z^* in order to ensure enough F.P. and meet customer demand. In this situation, the manufacturer had to ensure a higher R.M. stock level by promoting 100% inspection operations if the inspected lot was rejected (${Z_2}^*$ increased). At the same time, we note the increase of the number of ordered lot (s^* increased) balanced by a decrease of Q^*. In fact, this variation aimed to decrease the total inspection costs. With the lower c_F^B cost, we note an opposite variation of the different optimal parameters.

2.6.2.6 Case 6: Variation of the proportion of non-conforming raw material %p

When the proportion of non-conforming R.M ($\%p$) increases, the acceptance probability Pa decreases, and more received lots are refused. Therefore, the manufacturer had to reduce the frequency of lot returns to the supplier (${Z_2}^*$ increased), increases the number of ordered lots (s^*increases) and increases the F.P threshold level Z^*. In this situation, Q^* decreased to reduce the total inspection costs. In the opposite case ($\%p$ decreases), we have an opposite variation of the parameters.

2.6.2.7 Case 7: Variation of the acceptance number c

When the acceptance number c decreases, the acceptance probability Pa decreases. In this situation, the decision to refuse an inspected lot increases and thus the ordering point s^* and the lot size Q^* increase. At the same time, ${Z_2}^*$ increases to reduce the number of return of the refused lot and Z^* increases to tackle the R.M. stock-out frequency and the demand. In the opposite case (c increases), we have an opposite variation of the optimal parameters.

2.6.2.8 Case 8: Variation of the replenishment delay $\boldsymbol{\delta}$

The increase in the replenishment delay encourages the manufacturer to promote 100% inspection decisions over return decisions (${Z_2}^*$ increases). In this situation, the manufacturer increases the order frequency (s^* increases) and the lot size Q^* to ensure the presence of enough raw materials. In addition Z^* increases to ensure the presence of enough F.P. to meet customer demand. In the opposite case (lead time decreases), we have an opposite variation of the optimal parameters.

In conclusion, the different results obtained in this analysis confirm the robustness of the Hyb policy. This sensitivity analysis was also performed on both 100% and Ret policies to confirm their robustness. During this analysis, we made two main observations. On the one hand, for the different parameters of Table 2.4, $\mathrm{Cost}^*_{\mathrm{Hyb}}$ is always lower than the optimal total cost of both the Ret and 100% policies. On the other hand, contrary to the conclusion of the Table 2.3, the Ret policy could be more preferred than the 100% policy (Table 2.4, case 3: c_{insp}=24$/u and case 8: δ = Expo (0.75)/day). By contrast, the Hyb policy remains superior. Therefore, under which condition is the Ret policy better than the 100% policy and vice-versa? Is the Hyb policy always better than the 100% and Ret policies? To answer these questions, we conduct a detailed comparative study between the three policies in the next section.

2.7 Comparative study of Ret, 100% and Hyb policies

In this section, we compare the Ret, 100% and Hyb policies for a system-wide range of parameters, namely, $\%p, \delta, c_{insp}$ and c. This variation was conducted under similar conditions (simulation parameters, cost variation and inspection plan).

To confirm the different observations presented in Figure 2.9 to Figure 2.16, a Student's t-test was performed. Generally, the confidence interval (CI) of $\bar{C}_1^* - \bar{C}_2^*$ for two distinct policies (1) and (2) is determined by Eq. (2.14) (Banks, 2009).

$$\bar{C}_1^* - \bar{C}_2^* - t_{\frac{\alpha}{2},h-1} s.e(\bar{C}_1^* - \bar{C}_2^*) \leq C_1^* - C_2^* \leq \bar{C}_1^* - \bar{C}_2^* + t_{\frac{\alpha}{2},h-1} s.e(\bar{C}_1^* - \bar{C}_2^*) \quad (2.14)$$

Where: h: Number of replications (h= 20).

$\bar{C}_1^*$ (resp. $\bar{C}_2^*$): Average total cost under the first (resp. second) policy.

$t_{\frac{\alpha}{2},h-1}$: The student coefficient function of parameters h and α, where $(1-\alpha)$ is the confidence level (set at 95%).

$s.e(\bar{C}_1^* - \bar{C}_2^*) = \sqrt{S_D^2/h}$: The Standard error.

To improve the readability of the text, we will use $\mathrm{CI}_{\mathrm{i-j}}$ to designate the confidence interval of $\bar{\mathrm{C}}_\mathrm{i}^* - \bar{\mathrm{C}}_\mathrm{j}^*$, where $\bar{\mathrm{C}}_\mathrm{i}^*$ and $\bar{\mathrm{C}}_\mathrm{j}^*$ are the Average total cost for policy i and j, respectively.

2.7.1 Effect of the proportion of non-conforming %p variation

According to the base case Figure 2.9, we note that:

- For $\%p$ ≤1.5%: The difference between the costs of the three different inspection policies is not significant ($\bar{\mathrm{C}}_{\mathrm{Hyb}}^* \simeq \bar{\mathrm{C}}_{100\%}^* \simeq \bar{\mathrm{C}}_{\mathrm{Ret}}^*$). To confirm this observation, we found that the zero "0" is inside the CI (95%) ($CI_{Ret-100\%}$ =[-6.46, 18.35], $CI_{100\%-Hyb}$ =[-26.99, 6.68], $CI_{Ret-Hyb}$ =[-14.65, 6.23]).

- For $\%p > 1.5\%$: The Hyb policy is the most preferred one given that it offers the least optimal cost. In fact, the determination of the confidence interval for case 2 shows that all the CI(95%)> 0 and that $\bar{C}^*_{\mathrm{Hyb}} < \bar{C}^*_{100\%} < \bar{C}^*_{\mathrm{Ret}}$, ($CI_{Ret-100\%}$ = [279.46, 331.3], $CI_{100\%-Hyb}$=[272.35, 298.95], $CI_{Ret-Hyb}$ =[565.79, 616.27]).

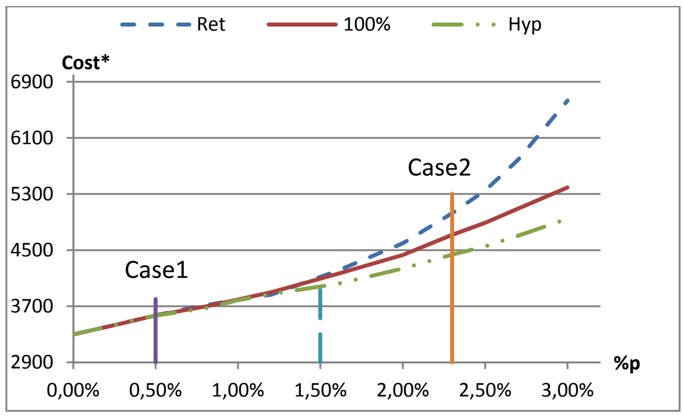


Figure 2.9 Cost* =f (%p), case δ =Expo (2), c =3, c_{insp}=12$/u$.

2.7.2 Effect of the replenishment delay δ variation

Despite the variation of the lead time δ (Figure 2.10 and Figure 2.11), the cost curves present two similar variations as those of Figure 2.9. First, for $\%p$ ≤0.45% (Figure 2.10) and $\%p$ ≤0.6% (Figure 2.11), $\bar{C}^*_{\mathrm{Hyb}} \simeq \bar{C}^*_{100\%} \simeq \bar{C}^*_{\mathrm{Ret}}$; second, for $\%p$ >0.45% (Figure 2.10) and $\%p$ >0.6% (Figure 2.11), the Hyb policy is more preferred than the 100% policy (case 3, $CI_{100\%-Hyb}$ =[158.24, 189.27]> 0 and case 4, $CI_{100\%-Hyb}$ =[573.53, 608.62]). Regarding the comparison between the Hyb and Ret policies, case 4 (Figure 2.10) shows that $\bar{C}^*_{\mathrm{Hyb}} < \bar{C}^*_{\mathrm{Ret}}$. However, in an extreme case where $\delta = 0$ (Figure 2.11), the Hyb policy coincides with the Ret policy ($CI_{Ret-Hyb}$ =[-27.7, 12.36]), which is intuitively predictable.

Unlike Figure 2.9, Figure 2.10 presents different curve positions for the Ret and 100% policies. We note that:

- For $0.45\% < \%p < 2.15\%$: $\bar{C}^*_{\text{Ret}} < \bar{C}^*_{100\%}$ (case 3, $\text{CI}_{\text{Ret}-100\%}$ =[-93.24, -59.24] < 0). In fact, when the lead time and the non-conforming percentage are not too large, it is more appropriate to return the refused lot to the supplier than to perform a 100% inspection in order to avoid additional inspection and rectification costs. This trend holds up to a certain value of $\%p = 2.15\%$, where the Ret policy = the 100% policy.

- For $\%p > 2.15\%$: $\bar{C}^*_{100\%} < \bar{C}^*_{\text{Ret}}$. In response to receiving a lot with a higher percentage of non-conforming items, the frequency of accepting a lot decreases by reducing the acceptance probability P_a. In this situation, it is more preferred to perform a 100% inspection than return the lot, in order to increase the availability of raw materials, which reduces the risk of finished product backlogs.

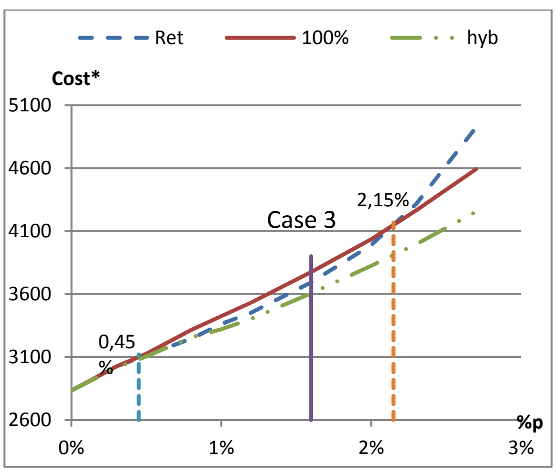


Figure 2.10 Cost* =f (%p), case δ =Expo (**1.5**), c =3, c_{insp}=12$\$/u$

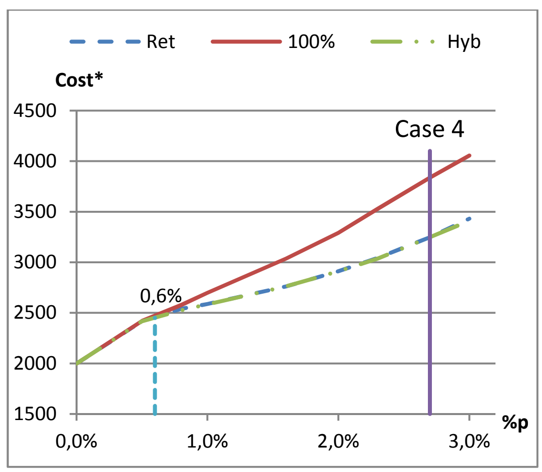


Figure 2.11 Cost*=f (%p), case δ=**0**, c=3, c_{insp}=12$\$/u$

2.7.3 Effect of inspection cost c_{insp} variation

Despite the variation of the inspection cost c_{insp} presented in Figure 2.12, Figure 2.13 and Figure 2.14, the cost curves present two similar variations as those in Figure 2.9. First, for $\%p \leq 0.65\%$ (Figure 2.12), $\%p \leq 0.7\%$ (Figure 2.13) and $\%p \leq 0.84\%$ (Figure 2.14), $\bar{C}^*_{\text{Hyb}} \simeq \bar{C}^*_{100\%} \simeq \bar{C}^*_{\text{Ret}}$. Second, for $\%p > 0.65\%$ (Figure 2.12), $\%p > 0.7\%$ (Figure 2.13) and

$\%p$ >0.84% (Figure 2.14), the Hyb policy is more preferred than the Ret policy. In fact, the determination of the confidence interval for case 5 (Figure 2.12) shows $CI_{Ret-Hyb}$ =[565.79, 616.27]$>$ 0 (same result in cases 6 (Figure 2.13) and 7 (Figure 2.14)). Regarding the comparison between the Hyb and 100% policies, case 5 (Figure 2.12) and case 6 (Figure 2.13) show that the Hyb policy is always better than 100% ($\bar{C}^*_{\mathrm{Hyb}} < \bar{C}^*_{100\%}$). However, in an extreme case where $c_{insp} = 0$ (Figure 2.14), the Hyb policy curve coincides with that of the 100% policy (case 7, $CI_{100\%-Hyb} =$ [-8.59, 10.53]), which is intuitively predictable.

Unlike Figure 2.9, Figure 2.12 and Figure 2.13 present different curve positions of the Ret and 100% policies. We note that:

- For $0.65\% < \%p < 2.42\%$ (Figure 2.12) and $0.7\% < \%p < 2.73\%$ (Figure 2.13): $\bar{C}^*_{\mathrm{Ret}} < \bar{C}^*_{100\%}$. To confirm this observation, we found that $\mathrm{CI}_{\mathrm{Ret}-100\%}$ =[-134.84, -105.59] <0 for case 5 (Figure 2.12) and $\mathrm{CI}_{\mathrm{Ret}-100\%}$ =[-340.56, -295.48]<0 for case 6 (Figure 2.13). In this case, performing a full inspection would lead to higher inspection costs, and returning a refused lot to the supplier becomes a more economical decision. This trend holds up to a certain value of $\%p = 2.42\%$ (Figure 2.12) and $\%p = 2.73\%$ (Figure 2.13) where the Ret policy = the 100% policy. It is preferred to note that when the c_{insp} increases, the range of the %p value for which the Ret policy is superior to the 100% policy increases.

- For $\%p$ >2.42% (Figure 2.12) and $\%p$ >2.73% (Figure 2.13): $\bar{C}^*_{100\%} < \bar{C}^*_{\mathrm{Ret}}$. Even if the inspection cost is high, it would be more preferred to perform a 100% inspection. Such a decision reduces the risk of finished product backlogs by increasing the availability of raw materials when the acceptance probability P_a decreases.

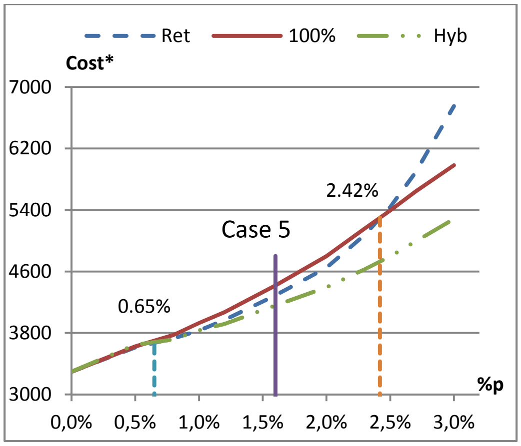


Figure 2.12 Cost*=f (%p), case δ=Expo (2), c =**3**, c_{insp}=**18**$\$/u$

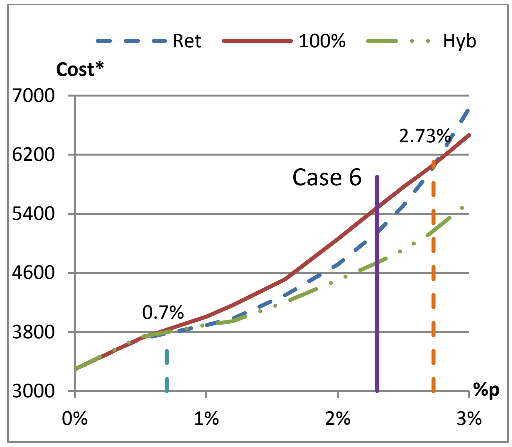


Figure 2.13 Cost*=f (%p), case δ=Expo (2), c =3, c_{insp}=**22**$\$/u$

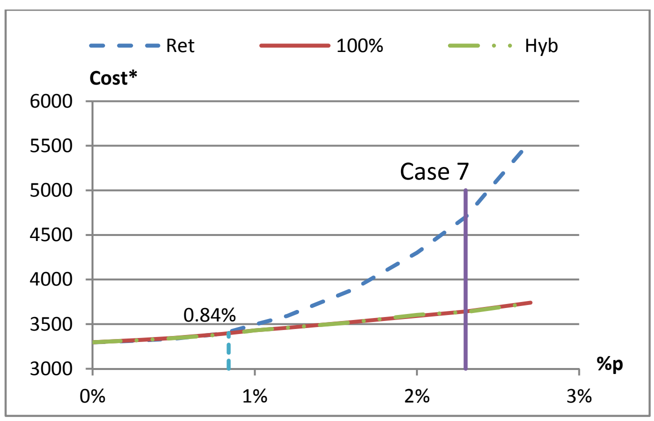


Figure 2.14 Cost*=f (%p), case δ= Expo(2), c =3, c_{insp}=**0**$/u

2.7.4 Effect of the inspection plan severity

Despite the variation of the acceptance number c, Figure 2.15 and Figure 2.16 present the same variation as the curves of Figure 2.12. First, for $\%p$ ≤0.54% (Figure 2.15) and $\%p$ ≤0.1% (Figure 2.16), $\bar{C}^*_{\text{Hyb}} \simeq \bar{C}^*_{100\%} \simeq \bar{C}^*_{\text{Ret}}$. Second, for $\%p$ >0.54% (Figure 2.15) and $\%p$ >0.1% (Figure 2.16), the Hyb policy is the most preferred one. In fact, the determination of the confidence interval for case 8 (Figure 2.15) and case 9 (Figure 2.16) already confirmed that $CI_{Ret-Hyb} > 0$ and $CI_{100\%-Hyb} > 0$. Finally, the Ret and 100% curves show a switching point at $\%p = 1.74\%$ (Figure 2.15) and $\%p$ =1.03% (Figure

2.16) below which $\bar{C}^*_{Ret} < \bar{C}^*_{100\%}$, and above which $\bar{C}^*_{100\%} < \bar{C}^*_{Ret}$. In Figure 2.12, we noted that the switching point is at $\%p = 2.42\%$. However, when the severity of the plan increases (c decreases), the probability of refusing a delivered lot increases, thus causing a decrease in the value of the switching point. That is why the range of the value of $\%p$ for which the Ret policy is better than the 100% policy decreases.

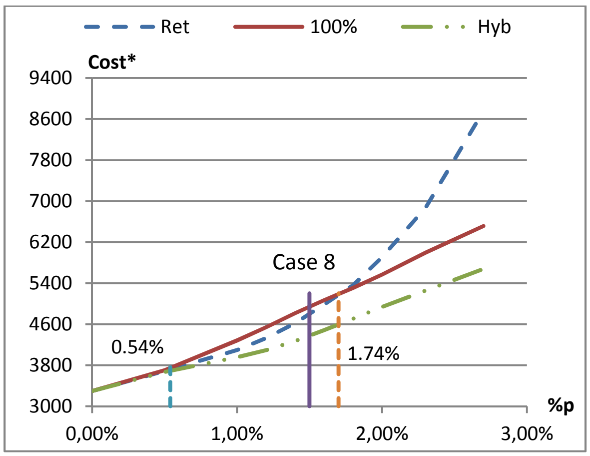


Figure 2.15 Cost*=f (%p), case δ=Expo (2), c =**2**, c_{insp}=**18**$\$/u$

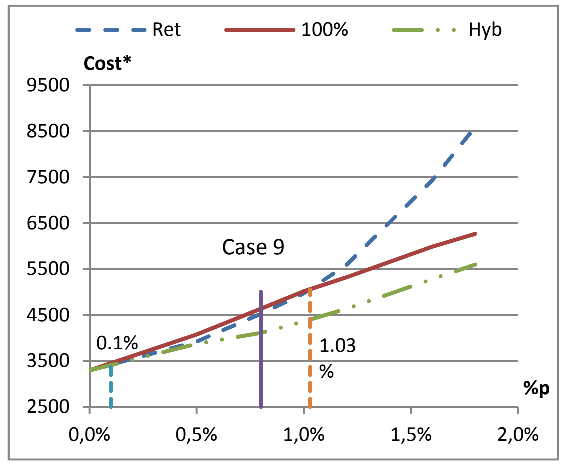


Figure 2.16 Cost*=f (%p), case δ=Expo (2), c=**1**, c_{insp}=**18**$\$/\mathrm{u}$

2.7.5 Summary of the results

The results of section 7 are summarised in Table 2.5. In the previous sections, we noticed two distinguished points corresponding to different percentages of non-conforming raw material, $\%p_A$ and $\%p_B$, where:

- If $\%p \leq \%p_A$, the received lot has a good quality
- If $\%p > \%p_B$: the received lot has a bad quality
- If $\%p_A < \%\mathrm{p} < \%p_B$: the received lot has an intermediate quality

Table 2.5 Summary of quality policies comparison

100% or Ret policy may be avoided	
General case	➢ For $\%p \leq \%p_A$: $\bar{C}^*_{\text{Hyb}} \simeq \bar{C}^*_{100\%} \simeq \bar{C}^*_{\text{Ret}}$ ➢ For $\%p_A < \%p < \%p_B$: $\bar{C}^*_{\text{Hyb}} < \bar{C}^*_{\text{Ret}} < \bar{C}^*_{100\%}$ ➢ For $\%p > \%p_B$: $\bar{C}^*_{\text{Hyb}} < \bar{C}^*_{100\%} < \bar{C}^*_{\text{Ret}}$
Only 100% or Ret must be avoided	
δ =0	➢ For $\%p > \%p_A$: $(\bar{C}^*_{\text{Hyb}} \simeq \bar{C}^*_{\text{Ret}}) < \bar{C}^*_{100\%}$
c_{insp}=0$/u	➢ For $\%p > \%p_A$: $(\bar{C}^*_{\text{Hyb}} \simeq \bar{C}^*_{100\%}) < \bar{C}^*_{\text{Ret}}$

Based on these summarised results, we can confirm that the Hyb policy is always preferred. In fact it gives a lower cost than the classic policies (Ret and 100%) or at least equal to the best of them. However, the preference between 100% and Ret policies depends on the different supply chain parameters.

2.8 Conclusions

In this study, we have developed, in a stochastic dynamic context, an integrated production, replenishment and quality inspection control policy to minimize the total cost of a three-stage supply chain with an unreliable manufacturer and imperfect quality of raw materials. Production, replenishment and inspection decisions are all made at the manufacturer stage. When a lot of raw materials is received, a lot-by-lot acceptance sampling plan is applied, after which the decision taken regarding rejected sampled lot is: 100% screening (100% policy), discarding (Return policy) or a Hybrid policy, where the decision maker can choose either the 100% inspection or return decision, depending on the available information regarding the finished product stock level. Due to the high stochastic level of the considered supply chain and the variability of the inspection decisions, we have used a combined approach based on simulation model and response surface methodology to optimize the control parameters of the three policies.

As a three stage supply chain is considered, the quality decision should not be taken independently of the whole system. In this paper, a comparative study between the three inspection decisions has shown that the new proposed control policy (Hyb policy) is more advantageous than the two other standard quality control policies (100% inspection and return) in terms of total cost. In reality, such a policy allows the decision maker to decrease the total costs, depending on the entire supply chain. Regarding the 100% and Ret policies, the decision maker should study both of them before adopting a final decision. In fact, by considering the supply chain parameters, any one policy could be more preferred than the other. However, when the percentage of non-confirming raw material items is high, performing a 100% inspection on the refused lots ensures fewer costs than the return decision.

The present work might be extended in several directions. One may consider other detailed sample plans such as double and sequential sampling plans. An alternative extension might be to incorporate the presence of several suppliers where we can switch from one supplier to another based on cost, delay, quality and the system state.

CHAPITRE 3

INTEGRATED QUALITY STRATEGY IN PRODUCTION AND RAW MATERIAL REPLENISHMENT IN A MANUFACTURING-ORIENTED SUPPLY CHAIN

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Abstract:

This paper deals with the coordination of production, replenishment and inspection decisions for a manufacturing-oriented supply chain with a failure-prone transformation stage, random lead-time and imperfect delivered lots. Upon reception of the lot, the manufacturer executes an acceptance sampling plan with a zero non-conforming criterion. If the sample does not contain non-conforming items, the lot is accepted; otherwise, it is rejected. In this work, two strategies regarding the refused sampled lot are studied. The first one involves a return of the lot to the supplier, who commits to improving the quality of the lot, while the second assumes that the manufacturer performs a 100% inspection and rectification operation. This work presents two main objectives. The first one is to jointly optimize, in a stochastic and dynamic context, the ordering point of raw material, the lot size of raw material, the final product inventory threshold and the severity of the sampling plan using a simulation-based optimization approach. The second one is to determine the best of the two quality control strategy. The in-depth study has shown that no strategy could be preferred in all the cases.

For this reasons, we present an easy decision-making tool (Indifference curves) to help the manager to select the best quality control strategy when considering the entire supply chain.

Keywords: Stochastic optimal control, Supply chain, Imperfect quality, sampling plan, Manufacturing, Simulation, RSM.

3.1 Introduction

Coordinating mechanisms such as joint ordering and production decisions in a three-stage supply chain subject to uncertainties have received significant attention in recent years (Song *et al.*, 2014). Hajji *et al.* (2009) addressed an integrated production and replenishment control problem in a three-stage supply chain with an unreliable transformation stage and supplier. Song (2009) determined the optimal integrated ordering and production policy in a supply chain with stochastic lead-time, processing time and demand. Sana (2011) presented an integrated production-inventory model for a three-layer supply chain considering perfect and imperfect quality items. He employed an analytical method to optimize the production rate and raw material order size for maximum expected average profit. Berthaut *et al.* (2009) considered a joint supply and remanufacturing activities and proposed a suboptimal control policy. Hajji *et al.* (2011a) proposed a practical approach to the joint production and delayed supply control problem. Hajji *et al.* (2011b) developed a stochastic dynamic programming model to investigate a supplier selection problem, together with optimal controls on inventory replenishment and manufacturing activities. Pal *et al.* (2012) optimized the production rate and raw material order size for a three-layer supply chain containing a supplier, a manufacturer and a retailer, where defective raw materials are sent back to the supplier and imperfect final products are reworked. Sana (2012) developed an integrated economic production quantity and economic order quantity model for a three-layer supply chain subject to defective items in production and transportation, and determined the optimal production rate, order quantity, and number of shipments. Song (2013) studied several stochastic supply chain systems and determined the optimal production and ordering control policies in the case of supply chains with backordering, a multistage serial supply chain, a supply chain with multiple products, and supply chains with assembly operations. Jana *et al.* (2013) proposed to coordinate production and inventory decisions across a three-layer supply chain model under conditionally permissible delay in payments. More recently, Song *et al.* (2014) determined the optimal integrated production-inventory control for a manufacturing supply chain with multiple suppliers in the presence of uncertain material suppliers, stochastic production times and random customer demands, using the stochastic dynamic programming approach. They also studied supplier issues, such as supplier base reduction and supplier differentiation, under the integrated inventory management policy.

From the above literature review, the production-inventory model for a three-stage supply chain adopted two main assumptions concerning the reaction of the manufacturer against the delivered lot: either there is no quality control due to the implicit assumption of perfect delivered raw materials (Hajji *et al.*, 2009; Song, 2013) or there is 100% screening (Pal *et al.*, 2012; Sana, 2012). In reality, a fraction of the received lot may consist of non-conforming parts, known as “items of poor quality” (Papachristos et Konstantaras, 2006). In that case, the inspection policy has to be integrated into the production-inventory model to reduce the impact of raw material non-conformity on ordering and lot sizing decisions (Ben-Daya et Noman, 2008) and on the quality of the finished product (Jiang, 2013). Given that a 100% inspection process may be costly and time consuming, an acceptance sampling plan could be more adequate.

The inspection of the delivered raw material with an acceptance sampling plan has been widely in the industries. However, the research integrating sampling policy with the inventory lot size has received very limited attention (Moussawi-Haidar *et al.*, 2014), and to the best of our knowledge, not in an integrated multi-stage supply chain management decision making context. This paper considers a manufacturer-oriented supply chain system with a failure-prone transformation stage, a random lead-time and an imperfect delivered lot. Upon reception of the lot, the manufacturer performs a lot-by-lot single-sampling plan with a zero acceptance criterion applied. In fact, this kind of sampling plan is widely adopted in the aerospace manufacturing (Squeglia, 2008) and food industries, among pharmaceutical companies, fisheries (Schilling et Neubauer, 2009) and electronic manufacturing processes (Chattinnawat, 2013). If the sample does not contain non-conforming items, the lot is accepted; otherwise, the lot is rejected.

When the lot is rejected, some authors have examined the involvement of the supplier in their studies. Starbird (2001) examined the effect of the buyer's rewards, penalties, and inspection policies on the behaviour of an expected cost minimizing supplier. Wan *et al.* (2013) determined the acceptance sampling plan of the firm and the quality effort level of the supplier either in the simultaneous game or in the Stackelberg leadership game where both buyer and supplier share the inspection cost and the recall loss. However, to the best of our knowledge, in the case of the supplier-buyer relationship, authors have not considered that the returned lot may be inspected by the supplier, leading to an improvement of its quality. Other authors have assumed a 100% inspection on the refused lot. Ben-Daya et Noman (2008) studied an integrated inventory inspection models with and without replacement of non-confirming items. Moussawi-Haidar *et al.* (2013) presented an analytical method to optimize the lot size, sample size and acceptance number in an EOQ-type model that achieves a certain average outgoing quality limit.

In this work, as a stochastic lead-time and a backlog cost of the final product are considered, the manufacturer may prefer to go with the 100% option, but with some corrective action, such as reworking the non-conforming items of the rejected lot, rather than returning it to the supplier. 100% option may ensure the presence of raw material and the continuity of the transformation process. However, if the supplier offers a certain degree of improvement of the lot whenever it is returned, the manufacturer could be attracted by this option. In fact, the return option may allow the manufacturer to deliver better quality and avoid additional inspection and rectification costs, but at the same time, it may lead to an increase in the delivery delay, which may in turn lead to the production system being starved of the raw material. In this case, the production process is stopped, causing an increase in the backlog costs of the final product due to the presence of customer demand. For these reasons, it is important to study the different strategies regarding the refused lots.

We formulate, in a stochastic and dynamic context, the integrated production, replenishment and quality control decision making problem. In the second part of this work, we propose integrated decision strategies capable of dealing with coordination within the considered supply chain. A simulation model and a response surface methodology are then applied to find the optimal parameters governing the proposed decision strategies. An in-depth study is also conducted regarding the two proposed policies (return and 100% inspection) following the lot rejection.

The rest of this paper is organized as follows. Section 2 presents the notation and the problem statement. Section 3 reports the control policy. Section 4 illustrates the resolution approach. The simulation model is presented in section 5. A numerical example is delivered in section 6 to outline the usefulness of the proposed control policy. Sensitivity analyses are discussed is section 7. The decision making choice regarding the rejected lot and the effects of the supplier's involvements are studied in section 8. Finally, the paper is concluded in section 9.

3.2 Notation and problem statement

3.2.1.1 Notation

The notations used in the paper are defined as follows.

dem	:	Finished product demand rate (units/time)
u^{max}	:	Maximum manufacturing production rate (units/time)
Q	:	Raw material lot size
s	:	Raw material ordering point
n	:	Sample size
c	:	Acceptance number
p	:	Proportion of non-conforming items in the received lot
P_a	:	Acceptance probability of a lot

δ	:	Replenishment delay
τ_{insp}	:	Inspection delay per unit (time/unit)
τ_{rect}	:	Raw material rectification time (time/unit)
ω	:	the degree of involvement of the supplier in improving the quality of a rejected lot
γ		the number of times that the lot is rejected by the manufacturer
c_R^H	:	Raw material holding cost (\$/time/unit)
c_F^H	:	Finished product holding cost (\$/time/unit)
c_F^B	:	Finished product backlog cost (\$/time/unit)
c_{insp}	:	Raw material inspection cost (\$/unit)
c_{rect}^R	:	Raw material rectification cost (\$/unit)
c_{remp}^F	:	Non-conforming finished product replacement cost (\$/unit)

3.2.1.2 Problem statement

We consider a three-stage supply chain with one supplier, one manufacturer and one customer. The manufacturer could be unavailable due to failures and repair operations. The supplier takes an order of raw materials with quantity Q and supplies it to the manufacturer after a random shipment delay δ. It is assumed that each delivered lot contains a percentage, denoted p, of non-conforming items.

Upon reception, the manufacturer applies a lot-by-lot single acceptance sampling plan with attributes to control the quality of the received lot. This plan is characterised by a sample of size n and a zero acceptance number ($c = 0$). After inspecting a random sample n, the manufacturer decides to accept this lot, if the number of non-conforming $d = 0$, or to refuse it, if $d > 0$. In this situation, the manufacturer's decision could be expressed by the probability of acceptance P_a (Schilling et Neubauer, 2009), which is given as follows:

$$P_a = (1-p)^n \tag{3.1}$$

In this paper, we consider that the accepted lot is immediately placed in the raw materials stock. In this situation, some unsafe product may pass inspection, be transformed into a finished product, and then sold to the final customer. It is assumed that the customer can detect and return it to be replaced with a c_{remp}^{F} per unit cost.

Concerning the rejected lot, the manufacturer will face two options:

- Option1 (RET (ω) policy): the supplier proposes to improve the quality of each rejected lot by applying an additional control operation (Figure 3.1- Option 1). Let us denote by ω ($0 \leq \omega \leq 1$) the degree of involvement of the supplier in improving the quality of this lot, and γ the number of times that the lot is rejected by the manufacturer. In other words, if $\omega = 1$, the supplier undertakes to perform a 100% inspection of each refused lot. And, if $\omega = 0$, no inspection operation is undertaken by the supplier. After an additional shipment delay δ, this lot will be delivered with a new percentage of non-conforming items $p_{(\gamma=1)} = p.(1-\omega)$. At the reception, the lot will be inspected and the manufacturer decides to accept or to refuse it. If the lot is rejected again, the supplier will improve its quality and the new percentage of non-conforming items will be $p_{(\gamma=2)} = p.(1-\omega)^2$. Then, the percentage of p_γ varies according to the following relationship:

$$p_\gamma = \begin{cases} p.(1-\omega)^\gamma \text{ , if the supplier performs an inspection of the refused lot.} \\ p \text{ Otherwise } (\gamma = 0). \end{cases} \tag{3.2}$$

- Option 2 (100% policy): the rejected lot is submitted to 100% inspection. We consider that all non-conforming items in lot Q are rectified with a τ_{rect} delay per unit and c_{rect}^{R} cost per unit (Figure 3.1- Option 2).

The raw material (RM) held in the manufacturer's warehouse incurs a holding cost c_R^H per item per unit time. The manufacturer produces a single type of finished product to respond to the continuous and constant demand rate "dem". The holding cost of the final product (FP) for the manufacturer is c_F^H per item per unit time. However, if the manufacturer could not respond to the customer demand, a backlog cost c_F^B per item per unit time is considered. Given that a sampling plan is adopted, some unsafe product may pass inspection, be transformed into a finished product, and then sold to the final customer. In this case, it is assumed that the customer can detect and return it to be replaced with a c_{remp}^F per unit cost.

The whole state of the considered supply chain at time t is described by a hybrid state combining a discrete component, $\alpha\ (t)$, and two continuous components $y(t)$ and $x(t)$. The discrete component represents the state of the transformation stage, and can be classified as "manufacturing system is available", denoted by $\alpha(t) = 1$, or "manufacturing system is unavailable", denoted by $\alpha(t) = 2$. The first continuous element $y(t)$ represents the stock level of the finished product. It can be positive, for an inventory, or negative, for a backlog. Further, the second one, $x(t)$, represents the stock level of the raw material ($x(t) \geq 0$).

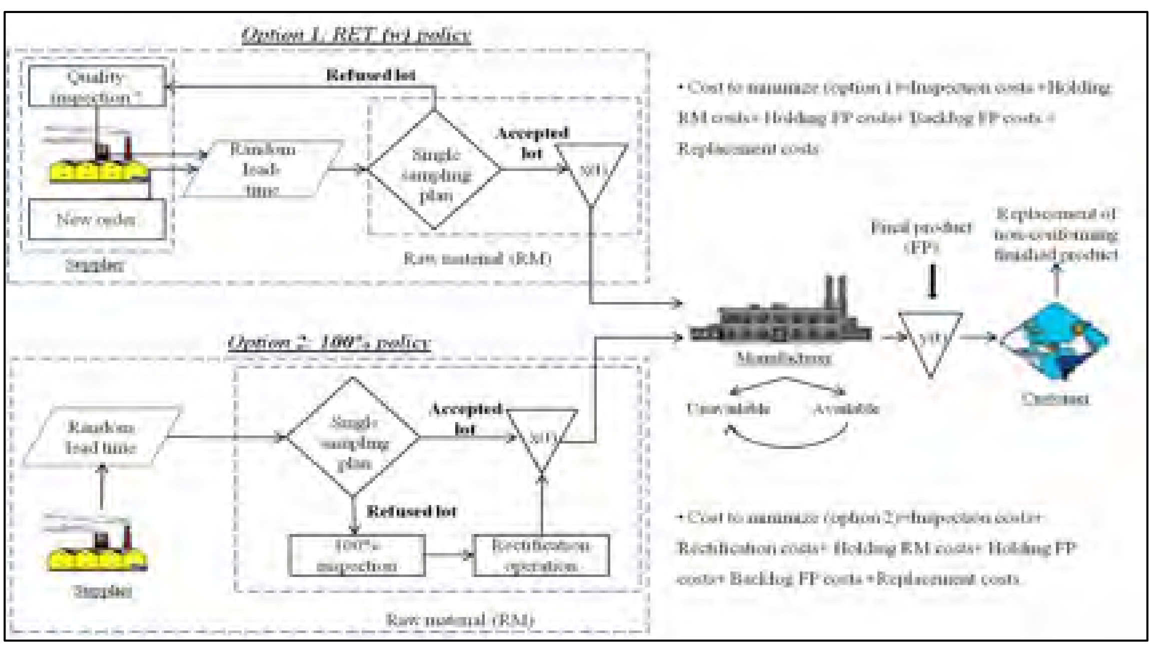


Figure 3.1 Supply chain under study

Assuming that the production process produces only good quality items, we consider that the quality levels of our raw material and of the finished product are equivalent. In this case, the dynamics of the stock level is given by the following differential equations:

$$\dot{y}(t) = u(t,\alpha) - \frac{dem}{1 - AOQ}, y(0) = y_0 \ \ \forall t \geq 0$$

$$\dot{x}(t) = -u(t,\alpha), x(0) = x_0 \ \ \forall t \in \left]\xi_i, \xi_{i+1}\right[\tag{3.3}$$

$$x(\xi_i^+) = x(\xi_i^-) + Q_i \ \forall\ i = 1 \dots N \tag{3.4}$$

where y_0, x_0 represents the initial stock levels, $u(t,\alpha)$ denotes the manufacturing system production rate in mode α, dem denotes the demand rate, AOQ represents the average outgoing quality of the raw material, and ξ_i^-, ξ_i^+ represent the negative and positive boundaries of the N receipt instants after an inspection operation, respectively.

According to the inspection policy, the average outgoing quality of the raw material AOQ can be measured as follows (Schilling et Neubauer, 2009) :

$$AOQ = \begin{cases} AOQ_{100\%} = P_a . p . \left(\frac{Q-n}{Q}\right) \\ AOQ_{RET(\omega)} = p_{\Upsilon} \end{cases} \tag{3.5}$$

In a dynamic stochastic context, Hajji *et al.* (2011a) analysed this class of model, but without including an imperfect delivered raw material. Given the complex structure of the optimization equations, they first adopted a numerical approach to illustrate the structure of the integrated production and delayed replenishment control policy, and secondly, a simulation-based experimental approach to cover more complex situations. They showed that the optimal production strategy is defined by a Hedging Point Policy (HPP) and that the optimal replenishment strategy belongs to the class of (s, Q) policies. The HPP policy consists in maintaining a surplus of products to be able to meet demand (dem) when the manufacturing system is unavailable due to machine failures. The (s, Q) policy consists in ordering an economic lot Q of raw materials when the upstream inventory level reaches s.

3.3 Control policy

The main objective of this work is to determine the production policy $u(.)$, the supply policy Ω and the best quality control policy (RET (ω) and 100%). According to the findings of Hajji *et al.* (2011a), production and supply policies are defined by the Hedging Point Policy (HPP) and the (s, Q) policy, respectively. However, by considering the effect of average total quality of the raw material $AOQ(t)$ on the real demand rate, a modified HPP may be more appropriate to illustrate our production policy.

The following structures of the production and supply policies, as well as the two quality control policies, are proposed as follows, where u^{max} represents the maximum production rate, s the ordering point, Q the lot size, and Z the final product hedging level.

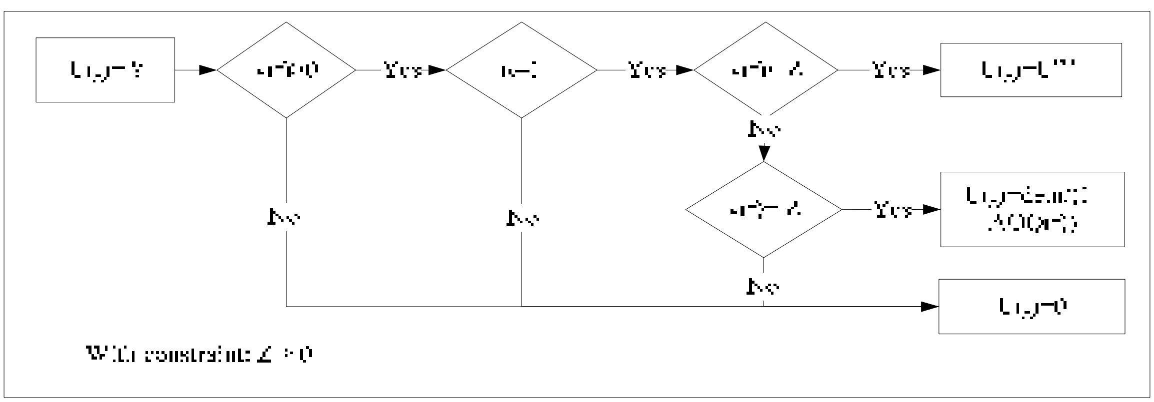


Figure 3.2 Production policy (Modified Hedging Point Policy (MHPP))

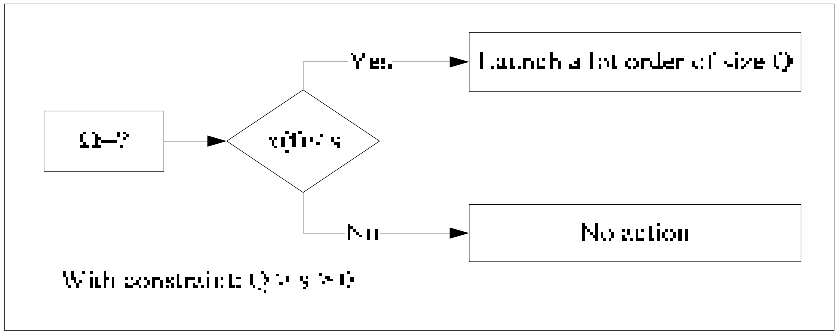


Figure 3.3 Supply policy (s, Q)

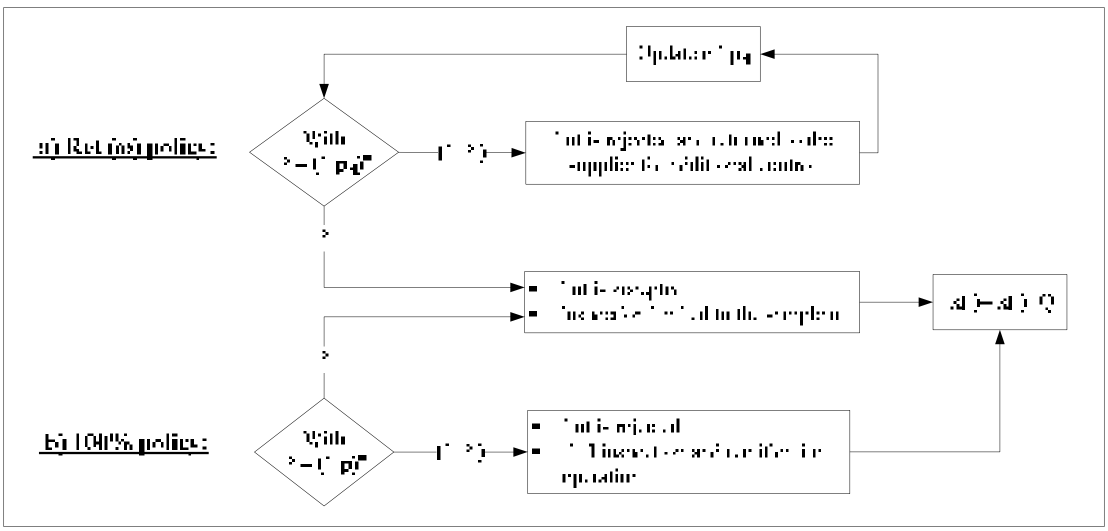


Figure 3.4 Quality strategy

To illustrate the interaction of production, supply and inspection activities, Figure 3.5 presents graphically the evolution of the stock level of the raw material $x(t)$ and final product $y(t)$ when the manufacturer's inspection decision is to return the refused lot.

1. When the $x(t)$ level crosses the ordering point (Arrow), the manufacturer orders a new lot. Once the lot is delivered after δ delay, a sample size n is inspected with delay. In this situation, if the lot is accepted, it is added to the final stock of RM (Arrow). Otherwise, the supplier picks it up and the manufacturer has to wait for an additional lead-time δ (Arrow).

2. At the same time, when the production system and RM are available, the RM is transformed to FP at the maximal rate (Arrow) whenever $y(t)$ is below Z, and at an adjusted demand (Arrow) rate whenever $y(t)$ is equal to Z.

3. The production process is stopped for two reasons. The first one (Arrow) is the unavailability of the manufacturer stage. The second one (Arrow) is the out-of- stock RM state ($x(t) = 0$). Since the manufacturer faces a continuous demand, a backlog of FP may arise (Arrow) depending on the state of the entire chain and quality decisions.

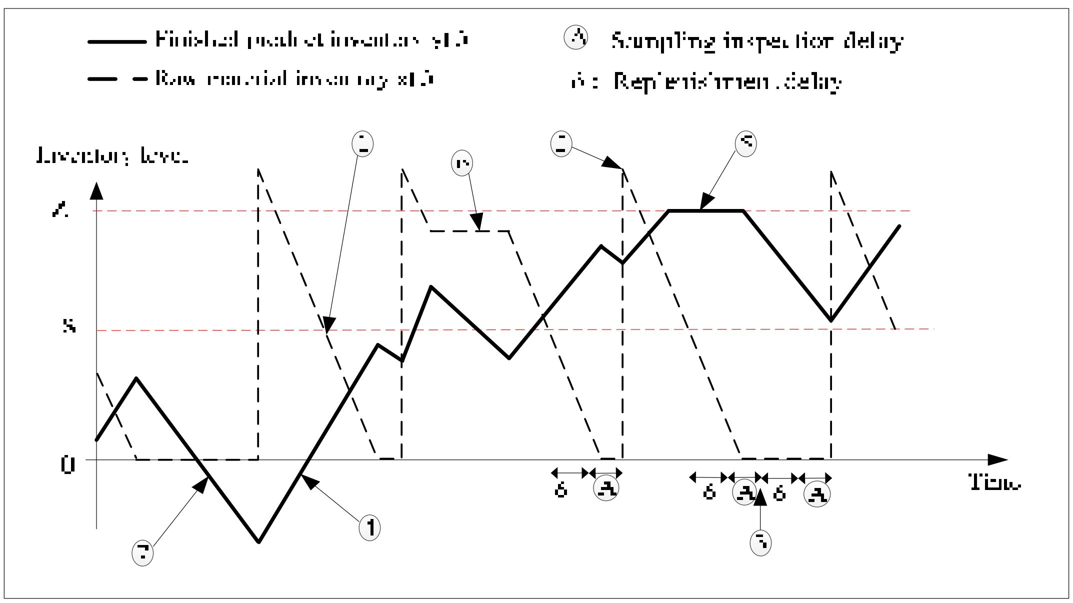


Figure 3.5 Evolution of raw material and finished product inventory under the joint production, supply and Ret inspection policies

In this study, our decision variables are the sample size n, the final product hedging level Z and the supply policy (s, Q). Given the complex structure of the considered system, we propose to determine experimentally the optimum control parameters (s, Q, Z, n) that give the best approximation of the long-term expected total cost consisting of the raw material holding cost, the finished product holding/backlog costs, the sampling costs, the costs of 100% inspection and rectification (Case 100% policy), and the cost of replacing non-confirming finished products.

3.4 Resolution approach

A simulation-based optimization method is adopted. This approach combines simulation modelling, experimental design and Response Surface Methodology. This approach was applied in different field such as production control problem (Sajadi *et al.*, 2011), an integrated production, maintenance and emission control problem (Ben-Salem *et al.*, 2014b) and an integrated production, overhaul and preventive maintenance problem (Rivera-Gomez *et al.*, 2013). The structure of the proposed control approach is as follows:

1. Based on the developed control policy presented previously, a simulation model is developed to describe the dynamics of each integrated production, replenishment and quality problem. Therefore, the total incurred cost is obtained for the given value of the control policy (Figure 3.2 - Figure 3.4).

2. An appropriate experimental design approach defines how control factors can be varied in order to identify the effects of the main factors and their interactions on the response (the incurred cost).

3. The Response Surface Methodology (RSM) is used to determine the relationship between the incurred cost and the significant main factors and/or interactions. From this estimated relation, the optimal values of the control policy parameters, called (s^*, Q^*, Z^*, n^*) and the optimal cost value are determined.

3.5 Simulation model

To represent the dynamic behaviour of the considered supply chain, two simulation models were developed using the SIMAN simulation language (ARENA simulation software) with C++ subroutines, where a combined discrete/continuous model is adopted according to the considered quality policy. Indeed, using such a combined approach allows us to reduce the execution time and secure more flexibility than with a purely discrete model (Assid *et al.*, 2014). The first model reproduces the integrated production-replenishment- raw material quality control policy when the RET (ω) is adopted. The second model reproduces the integrated policies when the 100% is selected. Figure 3.6 presents the overall model structure used in each of the two model.

1. The INITIALIZATION block initializes the values of the joint production replenishment and quality control policy (s, Q, Z, n) and the problem variables, such as the initial states (x_0, y_0), production rates, inspection parameters, the replenishment lead-time, and the number of rejections of the same lot γ^i. We also assign the simulation time T_∞ at this step such that the steady-state is reached.

2. The PRODUCTION CONTROL POLICY block sets the production rates according to Figure 3.2. This block relates to the "Update finished product inventory level" block in charge of raising a FLAG whenever the FP inventory level crosses the threshold (Z).

3. The SUPPLY CONTROL POLICY block sets the order quantities according to Figure 3.3. This block relates to the "Update raw material inventory" block in charge of raising a FLAG whenever the raw material inventory level crosses the threshold s.

4. The QUALITY CONTROL POLICY block sets the inspection policy according to Figure 3.4 (a or b). When the lot is delivered after a lead-time, a sample size is inspected. The decision of the inspector is modelled by a probabilistic BRANCH block of SIMAN, which represents the probability of acceptance P_a (Eq. 3.1). Indeed, P_a lots are accepted and $(1 - P_a)$ lots are rejected. If the lot is accepted, the average outgoing quantity $AOQ(.)$ is updated according to Eq. 3.5. If the lot is refused, and depending on the adopted quality policy, the proportion of non-conforming items p in a lot is updated according to Eq. 3.2 (case of RET policy) or the lot is 100% inspected and all non-

conforming items are rectified (case of 100% policy). Once the quality control is completed, the lot is added to the raw materials stock and then the stock level is updated (Eq. 3.4).

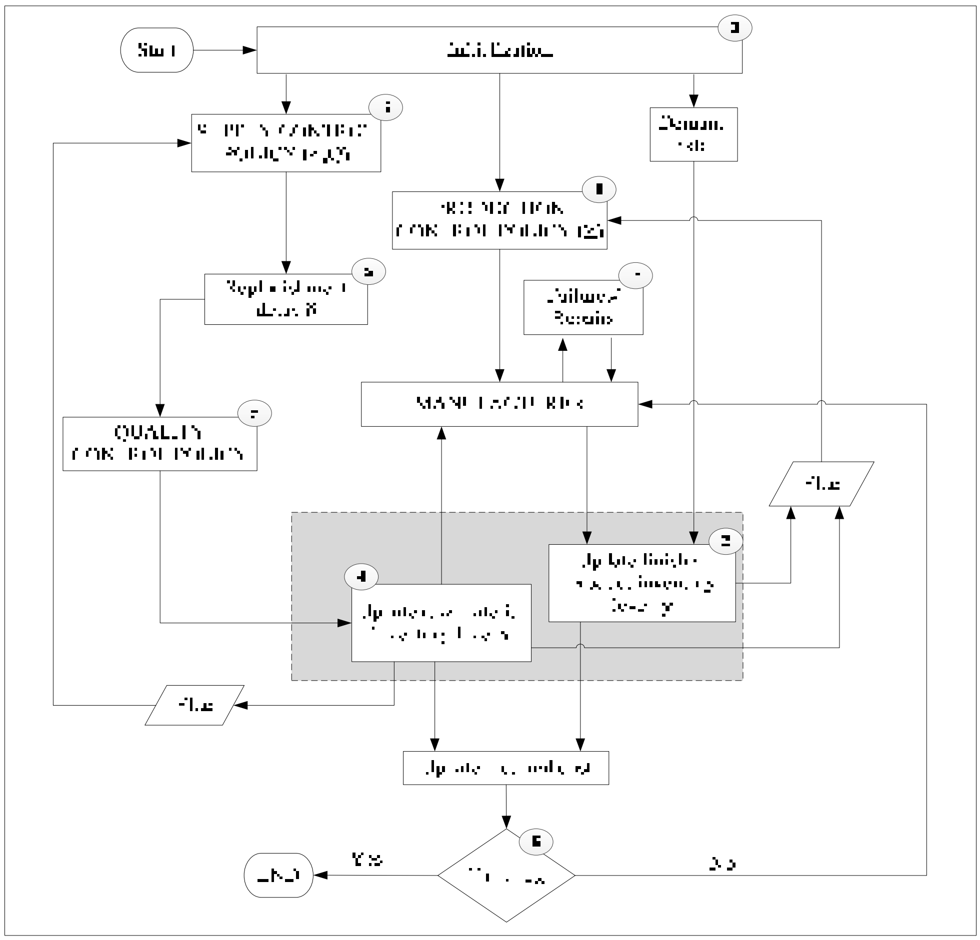


Figure 3.6 Simulation block diagram

5. The FAILURES AND REPAIRS block models the manufacturing system failure and repair events as a closed loop following the time to failure (*TTF*) and the time to repair (*TTR*) distributions, respectively. The operational states of the manufacturing system are incorporated in the state equations (Eq. 3.3) (defined as a C language insert) through binary variables, which multiplies the production rates.

6. Finally, when the current time of the simulation T_{Sim} reaches T_{∞}, the simulation is stopped.

3.6 Experimental results

In this section, we apply the procedure outlined in the previous section. The purpose is firstly, to find out whether the input parameters (s, Q, Z,n) affect the response (the cost), and then develop a regression equation. Secondly, the optimal parameter values of the two proposed policies (RET (ω) and 100%) and the optimal expected cost are determined. Finally, a sensitivity analysis is conducted to show the robustness of the policies and highlight important features.

The values of the operational and cost parameters, characterising the supply chain and inspection operations, are given in Table 3.1 and Table 3.2:

Table 3.1 Cost and production parameters

Parameter	u^{max}	dem	TTF	TTR	c_R^H	c_{insp}	c_F^H	c_F^B	c_{remp}^F	c_{rect}^R
Values	300	180	Expo(15)	Expo(1.65)	5	18	5	150	1300	350

Table 3.2 Inspection and delay (per day) parameters

Parameter	c	p	ω	δ	τ_{insp}	τ_{rect}	T_{∞}
Values	0	2.5%	1	Expo (1.5)	0.00025	0.012	10^6

3.6.1 Experimental design

Since we have four dependent parameters (s, Q, Z, n), a Face-Centered Central Composite design FCCCD is used for the design of experiments. This experimental design is built by 2^4 factorial design with 8 star points and 4 center points. In fact, a 2-level factorial design augmented with center and axis points presents a desirable plan (Lavoie *et al.*, 2010) thanks to its two main characteristics: orthogonality and rotatability. For more details, we refer the reader to (Montgomery, 2013). Five replications were conducted for each combination of factors, and therefore, 140 (28*5) simulation runs were conducted. In addition, we used the “common random number” technique (Law, 2007) to reduce the variability in the response.

3.6.2 Statistical analysis and response surface methodology

The statistical analysis of the simulated data consists of the multi-factor analysis of the variance (ANOVA). Indeed, it provides the effects of the independent variables (s, Q, Z, n) on the dependent variable (the cost). Using a statistical software application such as STAGRAPHICS, we note that all the R^2_{adj} values (Table 3.3 and Table 3.4) are greater than 95%; over 95% of the total variability is thus explained by the models (Montgomery, 2013). Furthermore, we can see from Table 3.3 and Table 3.4 that all “P-values” are below the 0.05 level. This observation leads us to conclude that the main factors (s, Q $, Z$ and n) of the different policies, their quadratic effects (s^2, Q^2, Z^2 and n^2), as well as their interactions ($s.Q$, $s.Z$, $s.n$, $Q.Z$, $Q.n$ and $Z.n$), are significant at a 95% confidence level.

A residual analysis was conducted to verify the adequacy of the models. In fact, a residual versus predicted value plot and normal probability plot were analysed to confirm the homogeneity of residuals and normality assumption, respectively.

Table 3.3 ANOVA Table case of 100% policy

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
s	[illegible]	1	[illegible]	230.81	0.0000
Q	[illegible]	1	[illegible]	141.07	0.0000
Z	[illegible]	1	[illegible]	117.46	0.0000
n	[illegible]	1	[illegible]	[illegible]	0.0000
s^2	[illegible]	1	[illegible]	[illegible]	0.0000
$s.Q$	[illegible]	1	[illegible]	[illegible]	0.0000
$s.Z$	[illegible]	1	[illegible]	[illegible]	0.0000
$s.n$	152844.	1	152844.	23.08	0.0000
Q^2	280647.	1	280647.	43.15	0.0000
$Q.Z$	614300.	1	614300.	92.55	0.0000
$Q.n$	[illegible]	1	[illegible]	[illegible]	[illegible]
Z^2	[illegible]	1	[illegible]	40.11	0.0000
$Z.n$	[illegible]	1	[illegible]	8.95	0.0032
n^2	[illegible]	1	[illegible]	72.48	0.0000
Blocks	[illegible]	2	[illegible]	[illegible]	0.0000
Total error	[illegible]	149	[illegible]		
Total (corr.)	[illegible]	[illegible]			

$R^2_{ajs} = 95.6\%$

Table 3.4 ANOVA Table case of RET (1) policy

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
s	[illegible]	1	[illegible]	[illegible]	0.0000
Q	[illegible]	1	[illegible]	[illegible]	0.0000
Z	[illegible]	1	[illegible]	[illegible]	0.0000
n	[illegible]	1	[illegible]	[illegible]	0.0000
s^2	[illegible]	1	[illegible]	[illegible]	[illegible]
$s.Q$	[illegible]	1	[illegible]	[illegible]	0.0000
$s.Z$	[illegible]	1	[illegible]	[illegible]	0.0000
$s.n$	[illegible]	1	[illegible]	11.22	0.0010
Q^2	[illegible]	1	[illegible]	[illegible]	0.0000
$Q.Z$	[illegible]	1	[illegible]	[illegible]	0.0000
$Q.n$	[illegible]	1	[illegible]	[illegible]	0.0000
Z^2	[illegible]	1	[illegible]	[illegible]	0.0000
$Z.n$	[illegible]	1	[illegible]	[illegible]	[illegible]
n^2	[illegible]	1	[illegible]	[illegible]	0.0000
Blocks	[illegible]	2	[illegible]	[illegible]	0.0000
Total error	[illegible]	[illegible]	[illegible]		
Total (corr.)	[illegible]	[illegible]			

$R^2_{ajs} = 95.9\%$

From STATSGRAPHICS, the response surface of each policy is given by:

$$Cost_{100\%}\ (s, Q, Z, n) = 36085.4 - 25.2423.\ s - 6.29228.Q - 19.0234.\ Z - 3.34413.n + 0.010034.\ s^2 + 0.00316484.\ s.Q + 0.00869226.\ s.Z - 0.00425615.\ s.n + 0.00111096.\ Q^2 + 0.00152369.\ Q.Z - 0.00110553.\ Q.n + 0.00583735.\ Z^2 - 0.0022115.Z.n + 0.0312996.\ n^2. \tag{3.6}$$

$$\mathrm{Cost}_{\mathrm{RET(1)}}\ (\mathrm{s, Q, Z, n}) = 38050.8 - 24.5475.\mathrm{s} - 7.34538.\mathrm{Q} - 17.7012.\mathrm{Z} - 4.03131.\mathrm{n} + 0.00745007.\mathrm{s}^2 + 0.0032186.\ \mathrm{s.Q} + 0.00655328.\mathrm{s.Z} - 0.00730539.\mathrm{s.n} + 0.000999941.\mathrm{Q}^2 + 0.00156783.\mathrm{Q.Z} - 0.00463165.\mathrm{Q.n} + 0.00470823.\mathrm{Z}^2 - 0.00364351.\mathrm{Z.n} + 0.0802871.\mathrm{n}^2. \tag{3.7}$$

Furthermore, to ensure the validity of our models, we determined the confidence interval at 95% (Eq. (3.8)). In fact, $m = 20$ extra replications were conducted using optimal supply chain parameters (Table 3.5). From Table 3.5, it can be seen that the optimal cost of each quality policy falls within the confidence interval:

$$\bar{C}^*(m) \pm t_{\frac{\alpha}{2},m-1} \cdot \sqrt{S^2(m)/_m} \tag{3.8}$$

where $\bar{C}^*$ is the average optimal cost, S the sample standard deviation, and $(1-\alpha)$ the confidence level.

Table 3.5 Optimal parameters, cost and confidence interval results

Policy	Optimal Parameters				Optimal Cost	CI (95%)
	s^*	Q^*	Z^*	n*		
100%	651.84	1292	1005.12	156	13972.9	[13933.49, 13980.74]
RET (1)	882.27	1773	1024.61	140	11359.9	[11299.85, 11365.52]

In this section, we determined the optimal parameter value and the optimal expected cost for the 100% policy and RET (1) policies. In this case study, Table 3.5 shows that the decision maker has to choose the RET (1) policy rather than the 100% policy. By choosing the RET (1) policy, we note up to 18.7% cost savings $\%\Delta C^* = 18.7\%$, where $\%\Delta C^* = [(C^*_{100\%}$-$C^*_{RET(\omega)})/ C^*_{100\%}]$. These savings express the percentage of the relative gain that the manufacturer can enjoy if the RET (1) policy is selected.

3.7 Sensitivity analysis

To properly understand the effect of a given parameter variation on the integrated production, supply and quality control policy, and to make sense of all these effects, a set of numerical examples were considered to measure the sensitivity of the obtained control policy. The following variations (Table 3.6) are explored and compared to the basic case of the RET (1) policy.

3.7.1 Case 1: Variation of the raw material holding cost $\mathbf{c_R^H}$

When the c_R^H cost increases (respectively decreases), the optimal ordering point s^* and lot size Q^* decreases (respectively increases) to reduce (respectively increase) the stock level of RM. In this case, the manufacturer promotes (respectively demotes) first the transformation of RM to FP, where the optimal hedging level Z^* increases (respectively decreases) and second the acceptance decision of a delivered lot, where the sample size n^* decreases (respectively increases).

3.7.2 Case 2: Variation of the finished product holding cost $\mathbf{c_F^H}$

When the c_F^H cost increases, the level Z^* decreases to reduce the FP inventory costs. By reducing the transformation of the RM, the system will make creates more RM stocks (s^* and Q^* increase), and with better quality (n^* increases), to be used when required. When the c_F^H cost decreases, we note an opposite variation of the optimal parameters.

3.7.3 Case 3: Variation of the finished product backlog cost $\mathbf{c_F^B}$

When increasing the c_F^B cost, the values of all the decisions variable s^*, Q^*, Z^* and n^* increase. In fact, the manufacturer must keep a significant stock level (Z^* increases) with better quality (n^* increases) to limit the risk of shortage. The increase in the supply parameters aims to reduce the stock-out RM frequency due to the presence of the lead-time and inspection decision. In the opposite case (c_F^B decreases), we have an opposite effect on the different optimal parameters.

Table 3.6 Sensitivity analysis data and results of Ret (ω) policy

Case	Parameter	Variation	Optimal Parameters s^*	Q^*	Z^*	n^*	Cost^*	Impact on
Base	-	-	882.27	1773	1024.61	140	11359.9	-
1	c_R^H	2.5	1049.55	2152	961.46	157	9572.7	s*↑ Q*↑ Z*↓ n*↑ Cost*↓
		7.5	794.12	1715	1290.83	135	13986.9	s*↓ Q*↓ Z*↑ n*↓ Cost*↑
2	c_F^H	**2.5**	763.02	1643	1620.84	137	9054.7	s*↓ Q*↓ Z*↑ n*↓ Cost*↓
		7.5	954.38	1927	901.63	164	13992.4	s*↑ Q*↑ Z*↓ n*↑ Cost*↑
3	c_F^B	**100**	870.04	1726	894.79	134	10557.5	s*↓ Q*↓ Z*↓ n*↓ Cost*↓
		200	918.13	1814	1121.63	147	11905	s*↑ Q*↑ Z*↑ n*↑ Cost*↑
4	c_{insp}	**15**	890.13	1743	1025.66	143	11273.9	s*↑ Q*↓ Z*↑ n*↑ Cost*↓
		20	877.50	1791	1024.06	138	11415.2	s*↓ Q*↑ Z*↓ n*↓ Cost*↑
5	δ	**Expo(1)**	567.78	1413	932.73	138	9594	s*↓ Q*↓ Z*↓ n*↓ Cost*↓
		Expo(2)	1279.34	2080	1125.38	154	13493.5	s*↑ Q*↑ Z*↑ n*↑ Cost*↑
6	ω	**0.8**	1033.18	1893	1104.23	87	13426.2	s*↑ Q*↑ Z*↑ n*↓ Cost*↑
		0.6	1177.39	2031	1064.78	71	14893.2	
		0.2	619.55	1360	951.365	1	15098	

3.7.4 Case 4: Variation of the inspection cost c_{insp}

When the inspection cost c_{insp} increases, the system tends to reduce the total inspection cost by decreasing the optimal sample size n^*. This variation leads to an increase in the P_a probability, and then to an increase in the acceptance frequency for the supplied lot. As result, the FP level Z^* decreases due to the decrease in the RM stock-out frequency. Regarding the supply parameters, s^* decreases and Q^* increases to avoid a high level of RM stock. The decrease in inspection cost produces the opposite effects.

3.7.5 Case 5: Variation of the lead-time δ

When the δ increases (respectively decreases), s^* and Q^* increase (respectively decrease) to ensure a higher (respectively lower) RM stock level. Facing an increased (respectively decreased) supplied lot size, the system decreases (respectively increases) the P_a probability by increasing (respectively reducing) the sample size n^*. At the same time, the Z^* level increases (respectively decreases) to face the RM stock-out frequency (respectively availability).

3.7.6 Case 6: Variation of the degree of supplier's involvement ω

When the degree of supplier involvement ω decreases, the system promotes an acceptance decision by increasing the acceptance probability P_a (n^*decreases). This effect must be balanced by higher supply parameters (s^* and Q^* increase) to maintain an appropriate RM availability. In this situation, the level Z^* increases to face the stock-out and the reduction of the product quality.

It is interesting to note that when the degree of the supplier involvement ω is very low (ω=0.2), the system determines that the supplier involvement is not enough to offset the effect of additional delivery delay. The system will then prefer to omit the return policy of a rejected inspected lot by maximizing the acceptance probability P_a. This trend is illustrated by the optimal sample size n^*=1.

Through this analysis, we can conclude the following: Firstly, we have confirmed that varying the control parameters evolves as expected with respect to parameter variations. Secondly, given the economic challenges at play, it is important to coordinate quality control for the delivered lot with production and replenishment activities. By choosing the RET policy, gains obtained can be up to 19% compared to the 100% policy. Finally, it is important to consider the sample size as a control parameter for the integrated production-supply-raw material quality control problem. In fact, the determination of the optimal sample size parameter provides the decision maker with the possibility of varying the severity of the inspection plan. This parameter can be set to n^{*}=1 where there is maximum acceptance of delivered batches.

From Table 3.6 (case 6), we observe that when the degree of involvement ω of the supplier decreases, the optimal expected cost increases. This variation causes a decrease in the cost saving $\%\Delta C^{*}$ (Table 3.7), which influences the decision maker in his choice of the 100% or the RET (ω) policy. In fact, when $\%\Delta C^{*} > 0$, the decision maker has to select the return policy. However, if $\%\Delta C^{*} < 0$, the 100% policy must be selected. In the next section, a detailed comparative study between these two policies is conducted to highlight the main aspects differentiating them.

Table 3.7 $\%\Delta C^{*}$ variation

ω	1	0.8	0.6	0.2
$\%\Delta C^{*}$	18.7%	3.9%	−6.6%	−8.1%

3.8 Comparative study between 100% and RET (ω) strategies

The objective of this section is to conduct an in-depth comparative study in order to determine the best quality policy in terms of cost. Even if the preference of the decision maker depends essentially on the degree of involvement of the supplier ω, other parameters (such as the proportion of non-conforming items p and the lead-time δ) may have a significant influence on the manufacturer choice.

Figure 3.7 and Figure 3.8 illustrate the variation of cost saving $\%\Delta C^{*}$ depending on the quality of the delivered lot p and the lead-time δ, respectively. The different steps performed to establish Figure 3.7 (respectively, Figure 3.8) are as follows: For each percentage of non-conforming items p (respectively, lead-time δ), we first determined the optimal parameter value and the optimal expected cost for the 100% policy. Secondly, we determined the optimal parameter value and the optimal expected cost for the RET (ω) policy, for different degrees of involvement ω. The cost saving $\%\Delta C^*$ was then calculated as in the previous sections.

3.8.1 Effect of p

From Figure 3.7, we note that the decision maker may have more than one decision to make, depending on p values:

- p =1%: RET (ω) and 100% policies should be avoided. We notice that $\%\Delta C^* = 0\%, \forall\, \omega \in [0,1]$. In fact, this observation is illustrated through the optimization of the different control parameters, where the optimal sample size n^* is equal to 1. When it encounters a good quality lot, the system tries to maximize the probability of acceptance P_a and then encourages the decision maker to omit the inspection operation and its involvement to avoid additional delays and costs caused either by a return decision or a 100% inspection and rectification operation.

- p =1.5%: The RET (ω) policy is more advantageous than the 100% policy only for a certain value of ω. The system still considers that quality of the delivered lot is good. As a result, the system tries to maximize the probability of acceptance P_a and then encourages the decision maker to omit additional inspection costs caused by a 100% inspection and rectification operation. This decision is in keeping with the policy to return the inspected lot when the degree of involvement of the supplier ω is low. However, from a certain degree of ω ($\omega > 0.75$), the systems prefers the return policy to ensure better performance of the supply chain.

- $p \geq 2.5\%$: The RET (ω) or 100% policy may be selected. The $\%\Delta C^*$ curve shows a switching point ω_s of decision for which $\%\Delta C^* = 0\%$ (no preference for a specific quality policy). Figure 3.7 shows also that when the percentage of non-conforming items p increases, the ω_s value decreases (for $p = 2.5\%, \omega_s = 0.73$; for $p = 3.5\%$, $\omega_s = 0.69$). This is explained by the need to avoid incurring additional significant rectification costs due to the presence of more non-conforming items in the lot. For the remaining values of ω, the decision maker has to select the RET (ω) policy, if $\%\Delta C^* > 0\%$, and the 100% policy, if $\%\Delta C^* < 0\%$.

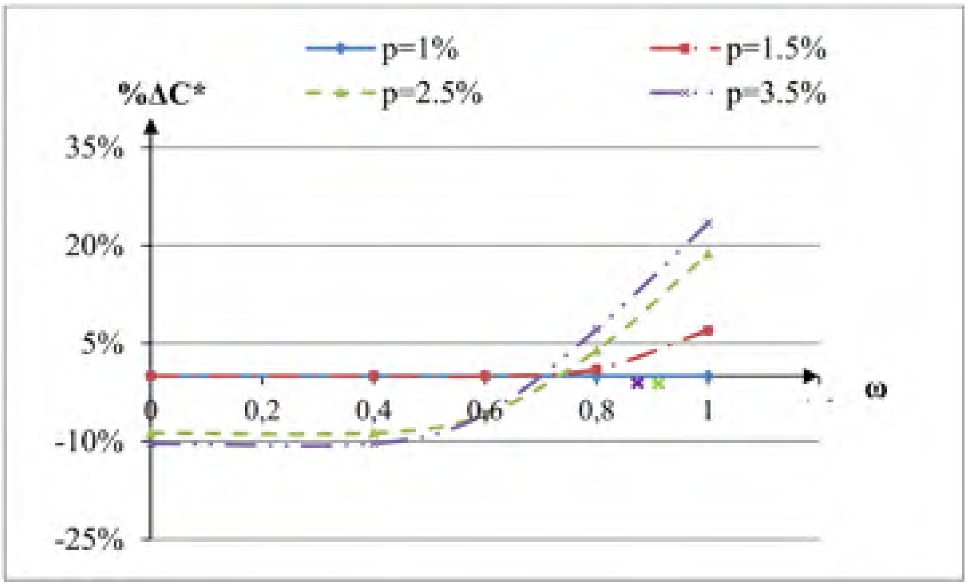


Figure 3.7 $\%\Delta C^*= f(\omega)$ with different values of p, c_{insp}=18$/u, δ= Expo (1.5)

3.8.2 Effect of δ

From Figure 3.8, we note that, depending on the δ value, the decision maker may decide as follows:

- δ= Expo (3.5): Only one inspection policy may be selected, and the return policy should not be taken ($\%\Delta C^* < 0\%, \forall\, \omega \in [0,1]$). To avoid an increase in the RM stock-out frequency, an increase in the risk of stoppage of the production process and then, an increase in the final product backlog cost, the decision maker must choose the 100% inspection and rectification operation policy.

- δ <Expo (2.5): RET (ω) or 100% policies may be selected. The ΔC^* curves show a switching point ω_s of decision for which $\%\Delta C^* = 0\%$. It can be seen that when the lead-

time δ decreases, the ω_s value decreases. Indeed, when δ is low, the decision maker will accept a lower level of involvement of the supplier. For the remaining values of ω, the decision maker must select the return policy, if $\%\Delta C^* > 0\%$ and the 100% policy, if $\Delta C^* < 0\%$.

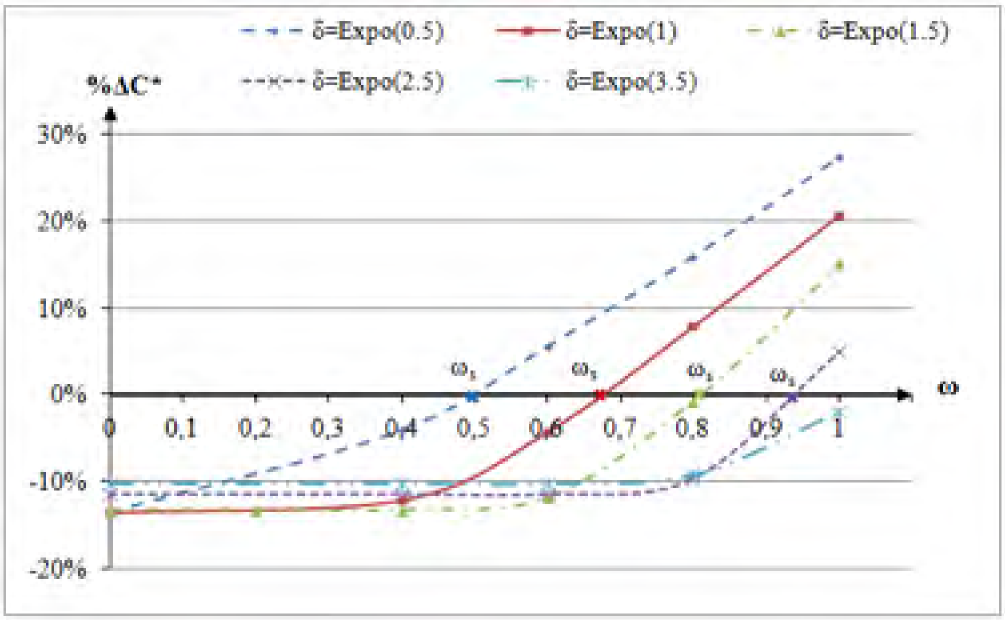


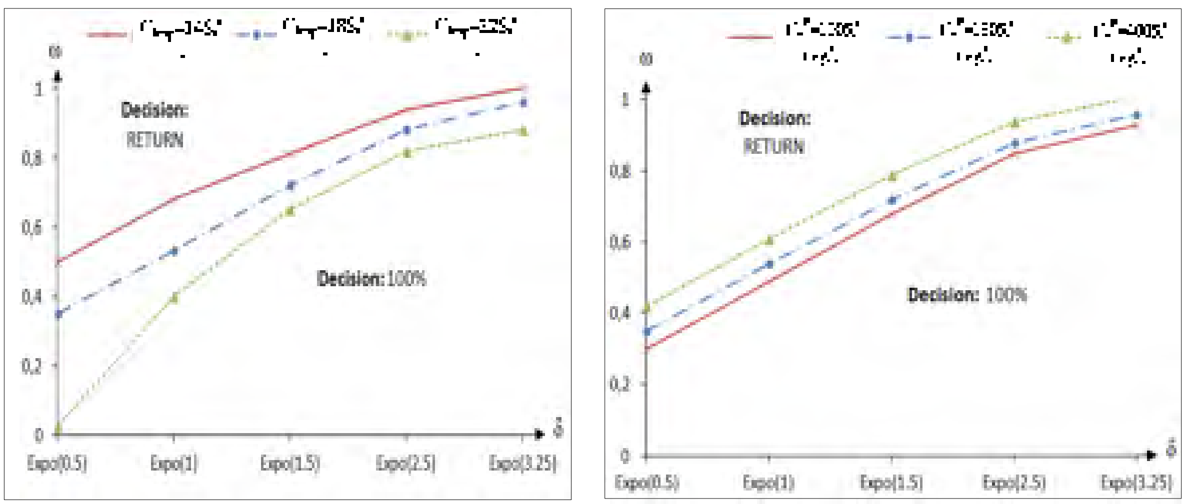
Figure 3.8 $\%\Delta C^* = f(\omega)$ with different value of lead-time δ, case c_{insp}=14\$/u, p=2.5%

3.8.3 Effect of c_{insp} and c_F^B

Figure 3.7 and Figure 3.8 showed that ω_s values vary depending on the supply chain parameters. In fact, the latter represents the minimum implication degree that the supplier must provide so that the return policy ensures better results. To select the most economic policy, we present in Figure 3.9 the indifference curves for lead-time δ and degree of involvement of the supplier ω.This curve devises the area in two zones which present whether or not to choose the 100% policy as the best quality control policy.

Figure 3.9.a shows the effect of the inspection cost c_{insp}variation on the indifference curve. It can be seen that when c_{insp} increases from 14\$/u to 22\$/u, the area in which a return policy

is more advantageous increases. Indeed, this variation is explained by the tendency of the system to avoid greater total inspection costs. The decrease in the c_{insp} cost produces the opposite effect. Figure 3.9.b shows the effect of the finished product backlog cost c_F^B variation on the indifference curve. It can be seen that when c_F^B increases from 100$/day/u to 400$/day/u, the area where the 100% inspection and rectification operation policy is more advantageous increases. Indeed, this variation is explained by the tendency of the system to avoid the risk of stoppage of the production process due to RM stock-out caused by delivery times. The decrease in c_F^B cost produces the opposite effect.



(a): For different value of c_{insp} (b): For different value of c_F^B

Figure 3.9 Indifference curve for lead-time δ and degree of involvement of the supplier ω, p=2.5%

3.9 Conclusion

In this work, the simulatneous production, replenishement and raw material quality control problem was addressed for the case of a manufacturing-oriented supply chain with a failure-prone transformation stage, random lead-time and imperfect delivered lot. Upon reception of the lot, the manufacturer performs an acceptance sampling plan with a zero non-conforming criterion applied. The problem was formulated in a stochastic dynamic context, where the production rate, the order quantity, the reorder point and the sample size are considered as decision variables. We focused first on the determination of the optimal control parameters, and secondly on the best quality control issues concerning the rejected sampled lot. Two quality policies were considered, with the first involving a return of the lot to the supplier who is committed to improve its quality, while the second assumed that the manufacturer executes a 100% inspection and rectification operation. An experimental approach based on simulation modelling, design of experiment and response surface methodology was applied to determine the parameters of the control policy involving the two quality policies.

This paper highlighted two interesting results. First, we observed that it is important to consider the sample size of the acceptance sampling plan as a control variable. In fact, depending on the entire supply chain parameters, this parameter varies the severity degree of the quality control at the reception to ensure the minimum total cost. Secondly, in the supply chain management context, the manufacturer must investigate both the 100% and return policies. Indeed, we showed that the different parameters of the supply chain and the degree of involvement of the supplier have a significant influence on the decision to be made following inspection.

In conclusion, the findings of this work set the stage for further studies, including other sampling policies, such as double sampling plans and selection between multiple suppliers. The evaluation and optimization of such a supply chain remains a challenging area.

CHAPITRE 4

AN INTEGRATED PRODUCTION, REPLENISHMENT AND RAW MATERIAL QUALITY CONTROL STRATEGIES WITH IMPERFECT SUPPLIED ITEMS THAT MAY CAUSE FAILURES

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Not yet submitted

Abstract:

In this paper, we develop, in a stochastic and dynamic context, integrated production, replenishment and raw material quality control policy for a manufacturing-oriented supply chain. After a random lead time, the supplier delivers to the manufacturer the raw materials in batches each of which contains perfect and imperfect items. At the reception four quality policies are studied including no inspection, 100% inspection, sampling inspection with 100% inspection decision of the rejected lot and sampling inspection with decision to return the rejected lot to the supplier. The manufacturing system may be stopped due to operational failure and the consumption of an admitted non-conforming raw material. We propose integrated decisions strategies capable of dealing with the coordination issue in the context of presence of poor quality raw material that can affect the production process. A simulation model and a response surface methodology are applied to determine the optimal production, replenishment and quality inspection parameters in order to minimize the total cost represented by purchasing costs, quality costs, as well as inventory/backlog costs. Sensitivity analysis is presented to illustrate the usefulness of the model and the effect of system parameters on the optimal decision parameters. The result shows the importance of adopting

a sampling inspection policy at the reception. The obtained result also shows that involving the supplier in the joint production-replenishment-raw material quality control policy may offers cost savings that can reach 52% as compared to results obtained with a no inspection policy.

Keywords: Stochastic optimal control, Supply chain, Imperfect quality, Experimental design, Inspection, Simulation.

4.1 Introduction

The least literature reveals that more and more studies are interested in supply chain management. In fact, more than 4090 scientific publications related to this term was published between 2009 and 2012 (Ullrich, 2014). As supply chain system are getting more complex due to random fluctuation (breakdowns of the production system, lead time, quality of product…), co-ordination of the decisions of the whole supply chain becomes crucial.

In the control theory and stochastic context, joint ordering and production decisions in a three-stage supply chain has been achieved where the material flow and finished product are studied as continuous variables or discrete variables. In the continuous materiel flow model, Hajji *et al.* (2009) proposed a single supplier, manufacturer, customer and item supply chain model for determining the optimal production and supply control policy that minimize the total expected costs of this system. They showed that the optimal production is a « modified state dependent multi-level base stock policy » (MBSP) and the optimal replenishment policy is a « State dependant economic order quantity » (SD-EOQ). Berthaut *et al.* (2009) studied a control policy for both the supply and remanufacturing activities composed of a multi-hedging point policy (MHPP) and an (s, Q) policy. In order to better approach the real context of supply chains, Hajji *et al.* (2009) work's has been extended to an integrated production and delayed supply control problem (Hajji *et al.*, 2011a) and multiple supplier context (Hajji *et al.*, 2011b).

In the discrete materiel flow model, Song (2009) considered a supply chain with supplier, manufacturer and customer and determined the optimal integrated production and control policy that minimise the expected total cost subject to finite capacitated warehouses. Song (2013) has determined the optimal production control policies and the optimal ordering policies for a different stochastic supply chain systems such as multistage serial supply chain supply chain with multiple products and supply chains with assembly operations…More recently, Song *et al.* (2014) presented a integrated inventory management and supplier base reduction model for a manufacturing supply chain with multiple suppliers.

Although the control theory problem has received considerable attention, a common unrealistic assumption in the integrated production-supply model is that all received raw material are of good quality. In the literature, recent studies have considered the imperfect quality assumption of delivered raw material and a 100% inspection as a quality control policy. Sana (2011) proposed an analytical method for a three layer supply chain involving one supplier, one manufacturer and one retailer, considering perfect and imperfect quality items. Pal *et al.* (2012) considered the problem of an integrated production-inventory model with a single supplier, manufacturer and retailer where perfect and imperfect quality items, production reliability and reworking of defective items are taken in consideration. Pal *et al.* (2013) determined the optimal production rate and raw material order size under three levels of trade credit policy for supplier-manufacturer-retailer supply chain. Sana *et al.* (2014) studied a replenishment size and production lot size problem for multiple suppliers, manufacturers, retails and items supply chain. However, by considering a 100% inspection process at the reception, the research assumed to avoid the effect of accepting non-conforming raw material items into their production system, such as the blockage of the transformation process (Groover, 1980) or the failure of the machine (Akbarov *et al.*, 2008). To the best of our Knowledge, none of the previous research considered the blockage of the transformation process due to the acceptance of non-conforming raw material in an integrated decision making of multi-stage supply chain.

In this paper, we consider a manufacturing-oriented supply chain with failure-prone transformation stage producing one part-type in continuous mode. Apart from the unreliable manufacturer, the system is also subject to random lead-time and imperfect delivered lots. At the reception, the manufacturer may use some types of quality policy which are no inspection, sampling inspection or 100% inspection. The production process may be stopped due the consumption of an admitted non-conforming raw material or a mechanical/electrical failure. The problem is to find the optimal manufacturer's production, replenishment and the best quality control decision in order to minimize the costs associated with ordering, inventory, backlog and quality.

Hajji *et al.* (2011a) have shown that it is difficult to analytically obtain the control policy in an integrated production-replenishment problem. For this reason, they resorted to a numerical solution to determine the control policy. Then, a simulation based approach to validate the policy configurations for more complex configuration. During recent years, more and more researchers have opted for a simulation and response surface methodology to optimise the parameters of their heuristic approach such as in Bouslah *et al.* (2013a), Ben-Salem *et al.* (2014a) and Assid *et al.* (2015). Following these research studies, we firstly formulate, in a stochastic and dynamic context, the integrated production, replenishment and quality control decision making problem. Secondly, we propose integrated decision strategies capable of dealing with coordination within the considered supply chain. Finally, a simulation model and a response surface methodology are then applied to find the optimal parameters governing the proposed decision strategies.

The rest of this paper is built as follows. In section 2, the problem statement is presented. Section 3 introduces the policy control. Section 4 and section 5 provide the experimental resolution approach and the developed simulation model, respectively. A numerical example is delivered in section 6. Sensitivity analysis is presented in section 7 to illustrate important aspects of the model. In section 8, the decision making choice regarding the best quality control policy is studied. Finally, some conclusions and perspectives are presented in section 9.

4.2 Problem formulation

4.2.1 Notations

The notations used in developing the model are as follows:

dem	:	Finished product demand rate (units/day)
u^{max}	:	Maximum manufacturing production rate (units/ day)
Q	:	Raw material lot size
s	:	Raw material ordering point
n	:	Sample size
p	:	Proportion of non-conforming items in the received lot
P_a	:	Acceptance probability of a lot
δ	:	Replenishment delay
τ_{insp}	:	Inspection delay per unit (day /unit)
W	:	Ordering cost
c_R^H	:	Raw material holding cost ($/day /unit)
c_F^H	:	Finished product holding cost ($/day /unit)
c_F^B	:	Finished product backlog cost ($/day /unit)
c_{insp}	:	Raw material inspection cost ($/unit)
c_{rej}^R	:	Raw material rejection cost ($/unit)
c_{Acc}	:	Non-conforming accepted raw material cost ($/unit)
π	:	Consumed non-conforming item that causes "Type 2" failure probability
ω	:	Supplier involvement

4.2.2 Problem statement

We study a three-stage supply chain including one supplier, one manufacturer and one customer with the manufacturer having failure-prone machine producing one product type to meet a constant demand rate (Figure 4.1).

The manufacturer places orders of size Q from a supplier who will deliver it after a replenishment delay δ. Each lot contains a percentage, denoted p, of non-conforming items. The production process may be stopped due to two types of machine failure: the first one "Type 1" is caused by a mechanical or electrical problem. The second "Type 2" is caused by the consummation of a non-conforming raw material. We consider that when a non-conforming is consumed, there is a probability π that this item stops the production process. In this case, the item will be removed. Regarding the remaining non-conforming items that pass the production process, we assumed that the customer can detect and return them to be replaced.

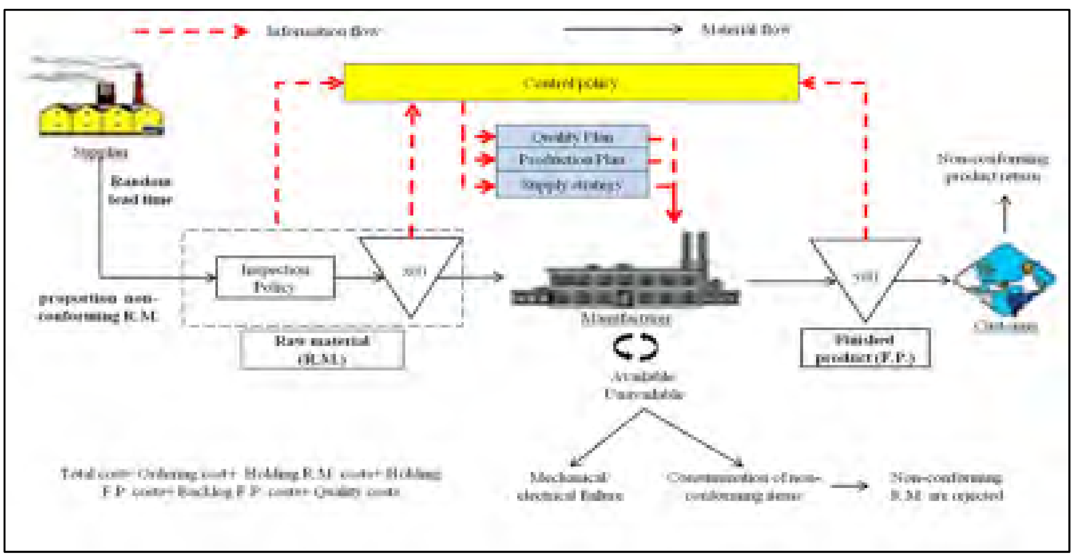


Figure 4.1 Three-stage supply chain with quality control

At the reception, the manufacturer may use some type of inspection policy. These policies are:

- No inspection "No policy": A proportion of non-conforming items $p.Q$ is accepted with each lot delivered with c_{Acc} per unit cost.

- 100% inspection "100% policy": The lot is full inspected and all non-conforming items are rejected with a cost. This operation will involve additional delay $Q.\tau_{insp}$, where τ_{insp} is the inspection delay per unit and additional costs $Q.c_{insp} + p.Q.c_{rej}^{R}$, where c_{insp} and c_{rej}^{R} are unit inspection cost and unit rejection cost, respectively.

- Sampling inspection "Samp policy": At the reception, the manufacturer applied a lot-by-lot acceptance simple plan characterised by a random sample of size n and a zero acceptance criteria ($c = 0$). According to Schilling et Neubauer (2009), the decision of acceptance or rejection of a lot can be determined by the probability of acceptance P_a (Eq. 4.1).

$$P_a = (1 - p)^n \tag{4.1}$$

If the sample n contains no non-conforming items, the whole lot is accepted and $p.(Q - n)$ non-conforming items may be accepted with c_{Acc} per unit cost. Otherwise, the lot will be rejected. There are two scenarios here:

i. Samp100% policy: The rejected lot will be subjected to 100% inspection with inspection delay $\tau_{insp}(Q - n)$. All non-conforming items are then rejected with c_{rej}^{R} per unit cost.

ii. SampRet(ω) policy: the rejected lot is returned to the supplier who offers a certain degree of improvement of the lot. Let's denote by ω ($0 \leq \omega \leq 1$) the degree of involvement of the supplier to improve the quality of this lot. After an additional replenishment delay δ, the lot is delivered with a new proportion of non-conforming items equal to $p.(1-\omega)$. In this situation, we assume that this lot will be accepted with no additional inspection operation.

In order to model this system at time t, we have introduced three variables. More specifically:

- A discrete component $\alpha\ (t)$ which describe the mode of the manufacturing system. A manufacturer is available when it is operational ($\alpha\ (t) = 1$), unavailable when machine breakdown because of “Type 1” failure ($\alpha\ (t) = 2$) or “Type 2” failure ($\alpha\ (t) = 3$).

- A continuous variable $x(t)$ which represents the stock level of the raw material. It can be only positive for an inventory.

- A continuous variable $y(t)$ which represents the stock level of the finished product. It can be positive for an inventory or negative for a backlog.

Assuming a perfect production process, we consider that the quality of our raw material and finished product are equivalent. In this case, the dynamics of the stock level is given by the following differential equations.

$$\dot{y}(t) = u(t,\alpha) - \frac{dem}{1-AOQ}, y(0) = y_0 \ \ \forall t \geq 0$$

$$\dot{x}(t) = -u(t,\alpha), x(0) = x_0 \ \ \forall t \in]\xi_i, \xi_{i+1}[\tag{4.2}$$

$$x(\xi_i^+) = x(\xi_i^-) + Q_i \ \forall\ i = 1 \dots N \tag{4.3}$$

where y_0, x_0 denote the initial stock levels, dem denotes the demand rate, $u(t,\alpha)$ denotes the manufacturing system production rate in mode α, $AOQ(t)$ denotes the average total quality of the raw material, and ξ_i^-, ξ_i^+ denote the negative and positive boundaries of the N receipt instants after an inspection operation, respectively.

Depending on the adopted inspection policy, the average outgoing quality of the raw material AOQ can be measured as follow:

$$AOQ(t) = \begin{cases} AOQ_{No}\,(\mathrm{t}) = p \\ AOQ_{100\%}(\mathrm{t}) = 0 \\ AOQ_{Samp100\%}(t) = \dfrac{\sum_{i=1}^{N(t)} \mathrm{P_a}.p.(Q-n)}{\sum_{i=1}^{N(t)} \mathrm{P_a}.Q + \sum_{i=1}^{N(t)} (1-\mathrm{P_a}).(Q-p.Q)} \\ AOQ_{SampRet(\omega)}(t) = \dfrac{\sum_{i=1}^{N(t)} \mathrm{P_a}.p.(Q-n) + \sum_{i=1}^{N(t)} (1-\mathrm{P_a}).p.(1-\omega).\mathrm{Q}}{\sum_{i=1}^{N(t)}.\mathrm{Q}} \end{cases} \tag{4.4}$$

4.3 Control policy

In a dynamic stochastic context and without quality consideration, Hajji *et al.* (2011a) showed that the optimal production strategy is defined by a Hedging Point Policy (HPP) and that the optimal replenishment strategy belongs to the class of (s, Q) policies. The HPP policy consists in maintaining a surplus of products to be able to meet demand (dem) when the manufacturing system is unavailable due to machine failures. The supply policy Ω consists in ordering an economic lot Q of raw materials when the upstream inventory level reaches s. However, by considering the effect of average total quality of the raw material $AOQ(t)$ on the real demand rate, a modified HPP may be more appropriate to illustrate our production policy. The following structures of the production and supply policies, as well as the four quality control strategies, are proposed as follows, where u^{max} represents the maximum production rate, s the ordering point, Q the lot size, and Z the final product hedging level.

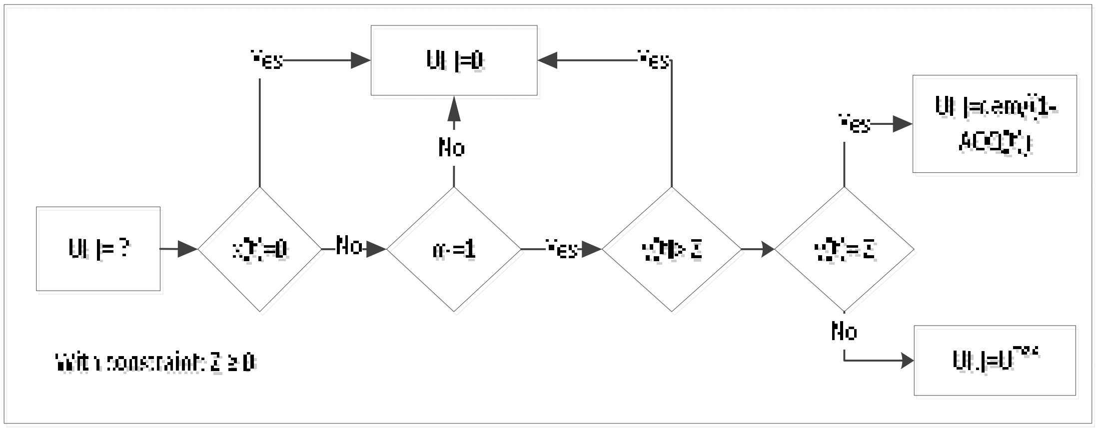


Figure 4.2 Production policy (Modified Hedging Point Policy (MHPP))

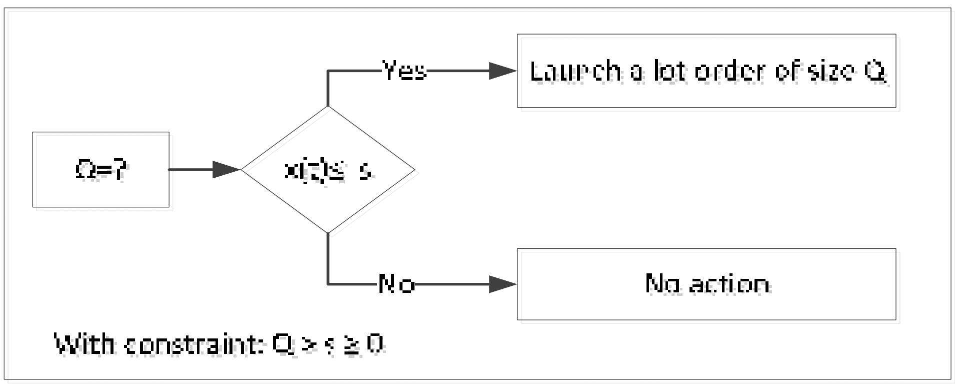


Figure 4.3 Supply policy

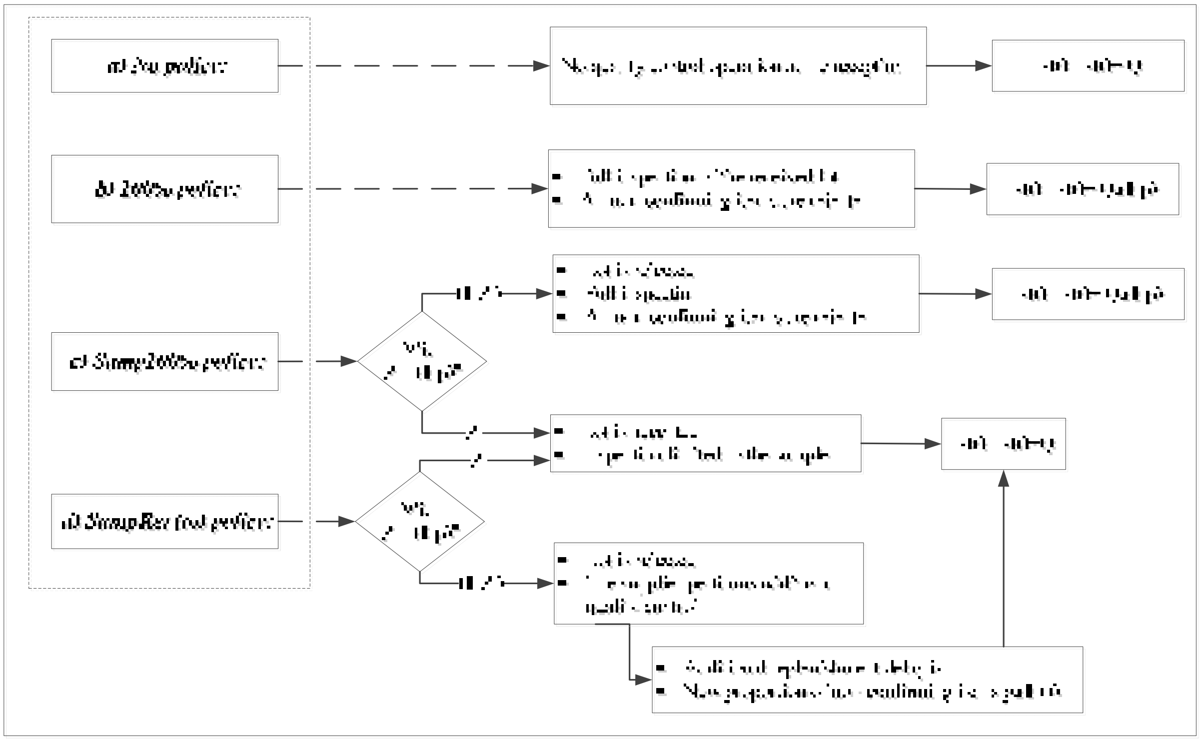


Figure 4.4 Four quality policies

Figure 4.5 illustrates the variation of the raw material $x(t)$ and finished product $y(t)$ stock over the time where the Samp100% policy is adopted. Following this dynamic, the joint production, supply and quality control policies are thus well presented.

1. Replenishment activity: when the raw material $x(t)$ level is under the ordering point s ①, the manufacturer orders a batch of products from the supplier which is derived after a lead time δ.

2. Quality control activity: At reception, a sample size n is inspected with ② delay and an inspection decision is taken. If the lot is accepted, it is transferred directly to the storage level of raw material and then we note an impulsive increase of $x(t)$ level with Q items ③. In this situation, $\pi.p.(Q-n)$ "Type 2" failure have to be considered. Otherwise, the lot is 100% inspected with ④ delay and all non-confirming items are rejected. After this operation, we note an impulsive increase of $x(t)$ level with $(Q-p.Q)$ items ⑤.

3. Production activity: The production activity is stopped for three reasons. The first one is the unavailability of the manufacturer stage due to “Type 1” failure. The second one is the unavailability of the manufacturer stage due to “Type 2” failure. The third one is the out-of- stock RM state ($x(t) = 0$).When the production system is available (after repair delay or) and the $x(t) > 0$, the raw material is transformed to finished product. Then, if $y(t)$ is under the hedging level Z, the manufacturer produces at the maximal rate and at an adjusted demand rate whenever $y(t)$ is equal to Z. Since the manufacturer faces a continuous demand, a backlog of FP may arise depending on the state of the entire chain and quality decisions.

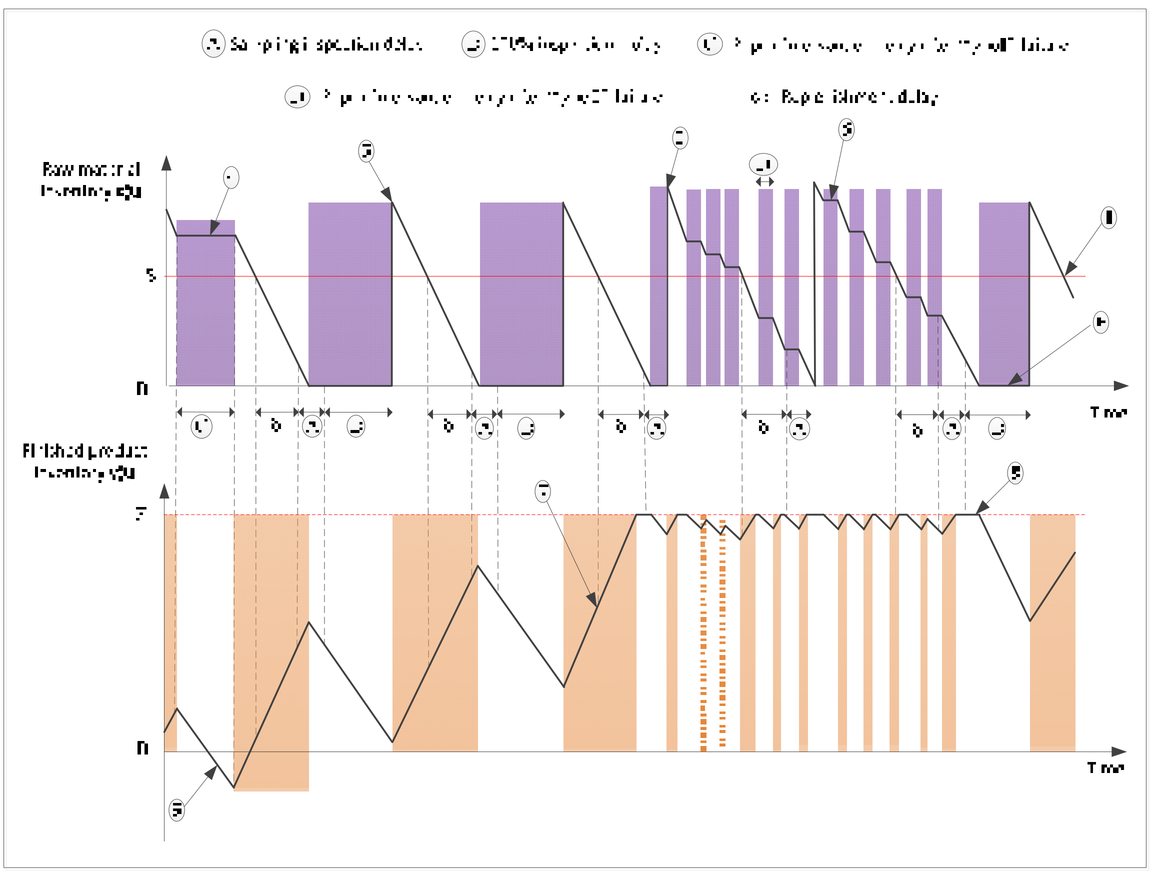


Figure 4.5 Dynamic behaviour of the stock of the raw material $x(t)$ and finished product $y(t)$ in the case of Samp100% policy

In this study, we propose to determine experimentally the optimum control parameter which are the optimal ordering point s, the optimal lot size Q, the optimal hedging level of final product Z and the optimal simple size n (case of Sampl100% and SampRet(ω) policies) that minimize the long-term expected total cost consisting of the ordering cost, the raw material holding cost, the finished product holding/backlog costs, the sampling costs, the costs of 100% inspection and rejection (Case 100% and Samp100% policies), and the cost of accepting non-confirming raw materials.

4.4 Resolution approach

The proposed approach (Figure 4.6) combines simulation modeling, experimental design and response surface methodology. The reader is referred to (Bouslah *et al.*, 2013a) for more details. This approach can be summarised by the following steps:

Step 1: Description of the control problem: this step presents the integrated production, replenishment and quality control problem described in previous section. The objective here is to find the optimal supply chain control variables: the optimal hedging level of final product Z, the optimal supply control s and Q, and the optimal sample size n (case of Sampl100% and SamplRet(ω) policies).

Step 2: Simulation model: The simulation model describes the dynamic behavior of the integrated control problem. The control parameters (s, Q, Z) or (s, Q, Z, n) are used as an input to conduct several experiments and to evaluate the system performance. Hence, for a set of input parameters, the long term average cost (output parameter) is obtained from the simulation model.

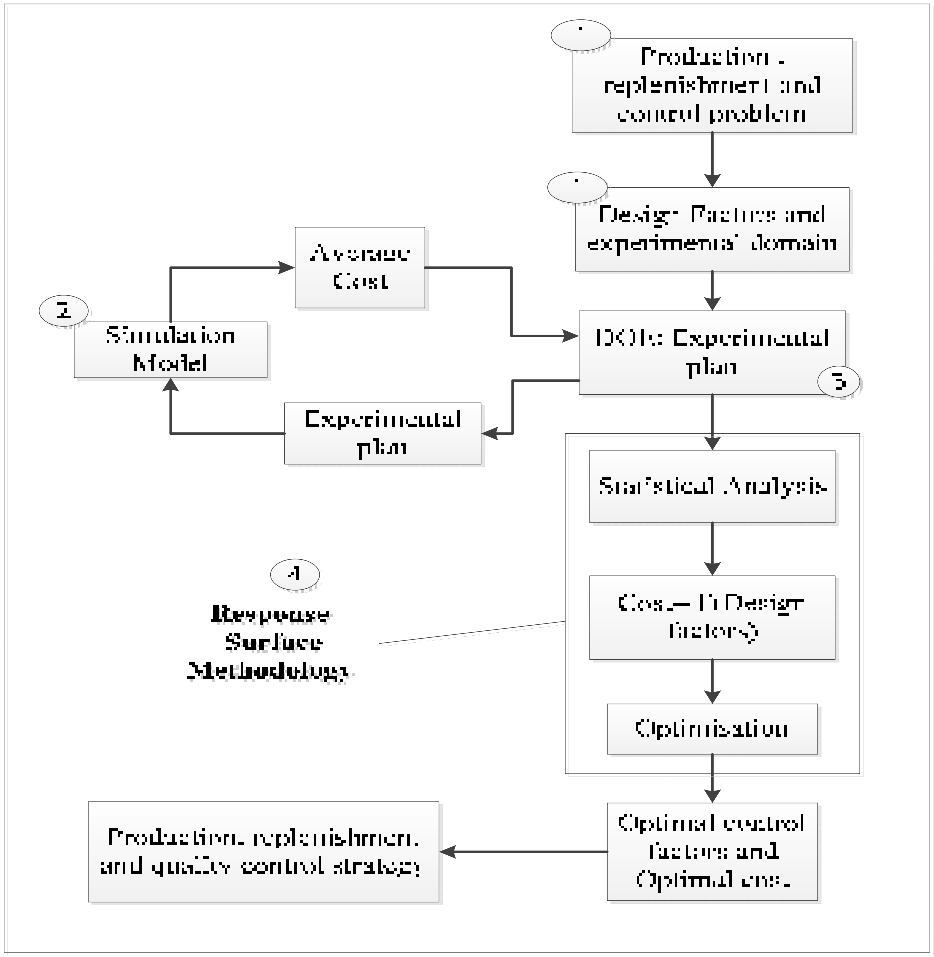


Figure 4.6 Experimental approach

Step 3: Experimental design (DOE): This step consists on the application of an experimental plan to define how the control factors (s, Q, Z) or (s, Q, Z, n) should be varied in order to identify the effect of the main factors and their interactions on the output parameter (the cost).

Step 4: Response surface methodology (RSM): RSM aims to fit the relationship between the incurred cost and the significant main factors and/or interactions. From this estimated relation, the optimal value of control policy parameters (s^*, Q^*, Z^*) or (s^*, Q^*, Z^*, n^*) and the optimal cost value are determined.

4.5 Simulation model

The simulation model is composed of several networks describing specific tasks in the system such as random events, production activity, replenishment activity and quality control. This model was developed using the SIMAN simulation language (ARENA simulation software) with C++ subroutines where a combined discrete/continuous model is adopted. Indeed, using such a combined approach allows us to reduce the executing time and secure more flexibility than a purely discrete model (Lavoie *et al.*, 2010). Figure 4.7 presents the simulation model diagram of the simulation model when a Sampling policy is selected.

1. The INITIALIZATION block initializes the value of the parameters of the system, the decision variables (s, Q, Z, n), the initial states (x_0, y_0) and the simulation time.

2. The PRODUCTION CONTROL POLICY block sets the production rates according to Figure 4.2.

3. The SUPPLY CONTROL POLICY sets the order quantities according to Figure 4.3 and allows supplying a new order whenever the raw material inventory level crosses the threshold s.

4. QUALITY CONTROL POLICY sets the inspection policy according to Figure 4.4 (c or d). After a random lead lime, the lot is received and a sample seize is inspected. To model the quality inspection decision, we used a probabilistic BRANCH block of SIMAN where the probability of acceptance P_a is determined by (Eq. 4.1). Indeed, P_a lots are accepted and $(1 - P_a)$ lots are rejected. If the lot is rejected and depending on the adopted sampling quality policy, the lot is submitted to 100% inspection and all non-confirming items are rejected (Figure 4.4.c) or returned to the supplier (Figure 4.4.d). If the lot is accepted, the average outgoing quantity $AOQ(.)$ is updated according to Eq. 4.4 ($\mathrm{AOQ}_{\mathrm{Samp100\%}}$or $\mathrm{AOQ}_{\mathrm{SamplRet(\omega)}}$) and $\pi.p.(Q - n)$ random position of non-conforming raw material are generated as the instance of beginning of “Type 2” failure. Once the

quality control is completed, the lot is added to the raw materials stock and then the stock level is updated (Eq. 4.3).

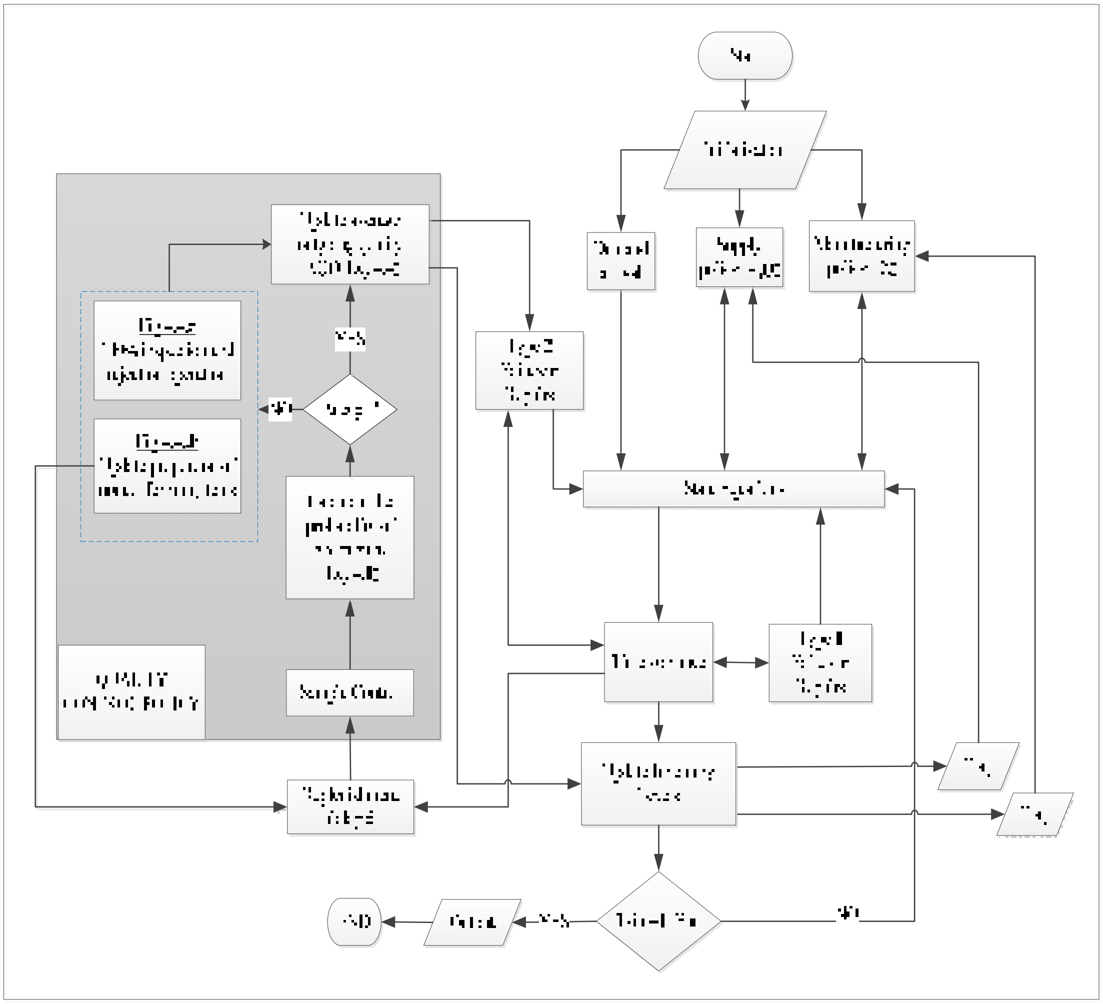


Figure 4.7 Simulation diagram

5. The “Type 1” FAILURES AND REPAIRS block models the failure and repair events of the mechanical or electrical problem as a closed loop following the time to failure (TTF) and the time to repair (TTR_1) distributions, respectively. The operational states of the manufacturing are incorporated in the state equations through binary variables, which multiplies the production rates.

6. The “Type 2” FAILURES AND REPAIRS block models the failure and repair events of the consummation of a non-conforming raw material as a closed loop following the time to repair (TTR_2) distributions. The operational states of the manufacturing are incorporated in the state equations through binary variables, which multiplies the production rates.

7. The STATE EQUATIONS are defined as C languages insert. They describe the variation of inventory level $x(t)$ and $y(t)$ defined by (Eq. 4.2).

8. At the end of the simulation run, the simulation is stopped and the total cost is calculated.

4.6 Numerical example

The parameters used in this section are as follow: u^{max}=731, dem= 463, p =2%, δ=Expo(1.2), W=3000, c_R^H=c_F^H=0.2, c_{insp}=1.1, c_F^B= 15, c_{Acc}= 200, c_{rej}^R=25, τ_{insp}= 0.00005, TTF= Log-Normal (50,6), TTR_1=Log-Normal (5, 0.6), TTR_2=Log-Normal (0.006, 0.0008), π= 50% and ω= 0.8. Due to the lack of sufficient data for the failure distribution caused by the non-conforming raw material product admitted after a screening process, we assume that these items are uniformly distributed in the whole accepted lot. In order to ensure that the steady-state is reached, the duration of each simulation run is set to T_∞=200 000 units of time.

To identify the main factors and their interactions on the output parameter (the cost), an appropriate experimental design should be selected taking into account the number of independent factors (Montgomery, 2013). Since we have three independent factors (s, Q, Z) for the No and 100% policies respectively, a 3^3-response surface design is selected. In the case of Samp100% and SampRet(ω) policies, we selected a Face-Centered Central Composite design FCCCD (2^4 + 8 star points + 4 center points), since that the control policy have four independent factors. Five replications were conducted for each combination of level of the independent factor, and therefore, $135(3^3 * 5))$ simulation runs were completed for the No and 100% policies, respectively and 140 (28*5) simulation runs were completed for Samp100% and SampRet(ω) policies. Moreover, to reduce the model variability, we used the common random number technique (Law, 2007).

We used the statistical software STATGRAPHICS in order to perform a multi-factorial analysis of variance (ANOVA) and determine the regression model fitting the dependent variable (total expected cost) for each inspection policy. The optimal parameters and cost are summarised in Table 4.1.

From Table 4.1, we note that all R_{adj}^2 of the proposed regression models are greater than 95%. Over 95% of the total variability is thus explained by the models (Montgomery, 2013). Furthermore, a residual analysis was carried out to verify the adequacy of the models. In fact, a residual versus predicted value plot and normal probability plot were analysed to confirm the homogeneity of residuals and normality assumption, respectively.

Table 4.1 Optimal parameters, cost and confidence interval Results ($p = 2\%$)

Policy	Optimal Parameters				Optimal Cost	R_{adj}^2	CI (95%)
	s^*	Q^*	Z^*	n*			
No	705.27	4779	2834.77	-	2143.51	97.79%	[2122.11,2149.51]
100%	964.269	4701	2550.22	-	2128.52	95.42%	[2116.36,2138.44]
Samp100%	802.301	5037	2915.73	274	2036.78	95.28%	[2023.69,2038.53]
SampRet(0.8)	1779.66	5414	2558.12	245	1626.62	95.5%	[1623.7,1631.86]

From STATSGRAPHICS, the second-order models of the total cost for each quality policy are given by:

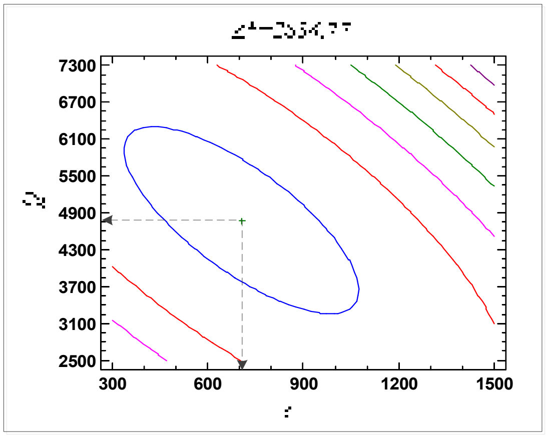
$$\begin{aligned}\mathrm{Cost_{No}}\,(\mathrm{s,Q,Z}) &= 13245.7 - 5.29444.\mathrm{s} - 1.17465.\mathrm{Q} - 4.53553.\mathrm{Z} \\ &+0.000958245.\mathrm{s}^2 + 0.000350975.\mathrm{s.Q} + 0.000799229.\mathrm{s.Z} \\ &+0.0000565164.\mathrm{Q}^2 + 0.000136502.\mathrm{Q.Z} + 0.000585513.\mathrm{Z}^2\end{aligned} \tag{4.5}$$

$$\begin{aligned}\mathrm{Cost_{100\%}}\,(\mathrm{s,Q,Z}) &= 7028.38 - 1.1596.s - 1.34304.Q - 0.770652.Z \\ &+0.000157126.\mathrm{s}^2 + 0.0000939166.\mathrm{s.Q} + 0.000151715.\mathrm{s.Z} \\ &+0.000112775.\mathrm{Q}^2 + 0.0000488475.\mathrm{Q.Z} + 0.0000745144.\mathrm{Z}^2\end{aligned} \tag{4.6}$$

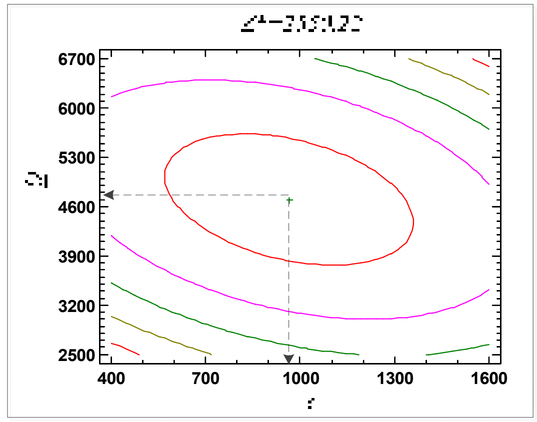
$$\begin{aligned}LOG(Cost_{Samp100\%}\,(s,Q,Z,n)) &= 10.3709 - 0.00100374.s \\ &-0.000267785.Q - 0.00109631.Z - 0.000556627.n \\ &+1.2515.10^{-7}.s^2 + 5.94864.10^{-8}.s.Q + 1.72611.10^{-7}.s.Z \\ &+1.27463.10^{-8}.Q^2 + 3.14334.10^{-8}.Q.Z + 1.37091.10^{-7}.Z^2 \\ &+0.00000101496.n^2\end{aligned} \tag{4.7}$$

$$\begin{aligned}\mathrm{Cost_{SampRet(0.8)}}\,(\mathrm{s,Q,Z,n}) &= 11040.7 - 2.46954.s - 0.723674.Q \\ &-4.01638.Z - 1.07643.n + 0.000243654.\mathrm{s}^2 + 0.000127377.\mathrm{s.Q} \\ &+0.000377156.\mathrm{s.Z} - 0.000313854.\mathrm{s.n} + 0.0000270889.\mathrm{Q}^2 \\ &+0.0008113.\mathrm{Q.Z} + 0.000579347.\mathrm{Z}^2 - 0.00486963.\mathrm{Z.n} \\ &+0.00332621.\mathrm{n}^2\end{aligned} \tag{4.8}$$

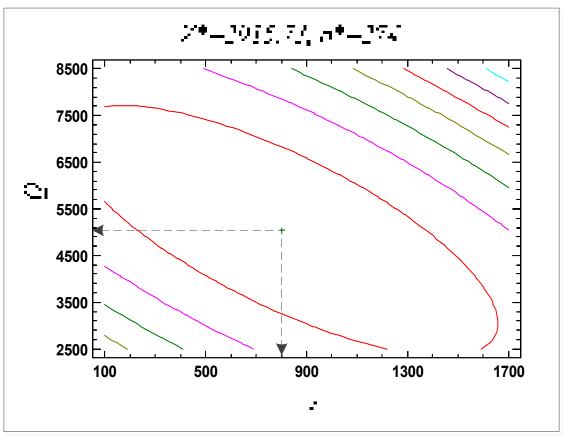
Figure 4.8 presents the cost response surfaces of the four quality control policies:



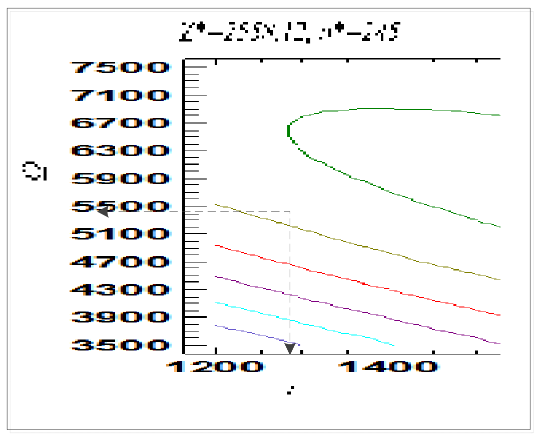
(a) No policy



(b) 100% policy



(c) Samp100% policy



(d) SampRet(0.8) policy

Figure 4.8 Response surface contour plot for the total cost

To crosscheck the robustness of the proposed approach, we have established the confidence interval at 95%. By running $m = 20$ extra replications using the optimal supply chain parameters (s^*, Q^*, Z^* and n^*), we notice that the minimum cost of each quality policy is within its confidence interval Table 4.1.

In this section, we determined the optimal parameter value and the optimal expected cost for the four quality policies. As shown in Table 4.1, the decision maker has to choose the

SampRet(0.8) policy rather than the other one. For example, SampRet(0.8) policy ensure cost up to 23% less than No policy.

4.7 Sensitivity analysis

Sensitivity analysis of the proposed joint optimal production, supply and quality policy are performed to demonstrate the robustness of the control policy when a SampRet(ω) policy is considered. Table 4.2 presents the behavior of the optimal design factors and incurred cost when varying some operational parameters judged the most appropriate. As expected, the results obtained make sense.

- Variation of the ordering cost W (case 1): When the ordering cost increases, the ordering point s^* decreases and the lot size Q^* increases, which is intuitively predictable. By reducing the number of ordering lot, the decision maker had to conserve more finished product with better quality (Z^* and n^* increases). When the W cost decreases, we have an opposite variation of the optimal parameters.

- Variation of the raw material holding cost c_R^H (case 2): When the c_R^H cost increases, the decision maker had to lower the stock level of raw material (R.M.). As a result, s^* and Q^* decrease. At the same time, the system has to avoid returning a rejected inspected lot to the supplier by decreasing the sample size n^* in order to reduce the effect of the stock-out frequency of R.M on the whole supply chain. In this situation, the manufacturer had to increase the stock level of finished product Z^* to face the presence of demand. When the c_R^H cost decreases, we have an opposite variation of the optimal parameters.

- Variation of the finished product holding cost c_F^H (case 3): When the holding cost decreases, the hedging points level Z^* increases, which is intuitively predictable. At the same time, we note the decrease of s^* and the increase of Q^* and n^*. In fact, the manager had to reduce the presence of R.M. by ordering less frequent orders and promoting return decision. When the c_F^H cost increases, we have an opposite variation of the optimal parameters.

- Variation of the finished product backlog cost c_F^B (case 4): When the backlog cost increases, the system reacts by increasing Z^* value to ensure better protection against the shortage effect. In this situation, the manufacturer had to increase the stock level of R.M. by increasing the ordering point s^* balanced by the fall of Q^*. Furthermore, the manufacturer had to promote return decision by increasing the simple size n^* in order to ensure better delivered lot and then increase the availability of the transformation stage. When the c_F^B cost decreases, we have an opposite variation of the optimal parameters.

- Variation of the non-conforming raw material acceptance cost c_{Acc} (case 5): When the c_{Acc} cost increases, the system needs the supplier involvement to improve the quality of delivered lot in order to reduce the effect of accepting non-conforming product. Therefore, n^* increases in order to increase the probability of refusing the delivered lot. At the same time, the system increases the ordering point s^* and Q^* to reduce the effect of the stock-out frequency of R.M on the whole supply chain. Concerning the finished product level, Z^* decreases. Indeed, given that less non-conforming items are accepted, the system can reduce the optimal threshold level Z^* because of the increase of the availability of the production process. When the c_{Acc} cost decreases, we have an opposite variation of the optimal parameters.

- Variation of the replenishment delay δ (case 6): When the lead time δ increases, the manufacturer had to increase the frequency of ordering a lot by increasing the ordering point s^* and the lot size Q^*, to ensure enough R.M. By increasing the lot size, the proportion of non-conforming items delivered increases. Therefore, the system increases the sample size n^* to ensure better quality of the stock of R.M. Concerning the finished product level, the manufacturer increases Z^* to meet the customer demand. When the δ value decreases, we have an opposite variation of the optimal parameters.

Table 4.2 Sensitivity analysis data and results (SampRet(ω) policy)

Case	Parameter	Variation	Optimal parameters				Cost*	Impact on
			s*	Q*	Z*	n*		
Base	-	-	1779.66	5414	2558.12	245	1626.62	-
1	W	3500	1668.05	5791	2565.34	246	1668.05	s*↓ Q*↑ Z*↑ n*↑ Cost*↑
		2500	1912.64	4931	2548.33	243	1581.76	s*↑ Q*↓ Z*↓ n*↓ Cost*↓
2	c_R^H	0.3	1621.24	4926	2863.08	233	1895.49	s*↓ Q*↓ Z*↑ n*↓ Cost*↑
		0.1	1832.34	6597	2527.83	254	1271.69	s*↑ Q*↑ Z*↓ n*↑ Cost*↓
3	c_F^H	0.3	1845.04	5364	2455.99	243	1838.97	s*↑ Q*↓ Z*↓ n*↓ Cost*↑
		0.1	1722.03	5457	2659.1	247	1405.05	s*↓ Q*↑ Z*↑ n*↑ Cost*↓
4	c_F^B	22	1997.46	5036	2640.45	265	1682.03	s*↑ Q*↓ Z*↑ n*↑ Cost*↑
		8	1425.82	5579	2429.21	226	1513.46	s*↓ Q*↑ Z*↓ n*↑ Cost*↓
5	c_{Acc}	250	1779.73	5421	2555.06	250	1669.76	s*↑ Q*↑ Z*↓ n*↑ Cost*↑
		150	1779.04	5405	2561.29	239	1583.27	s*↓ Q*↓ Z*↑ n*↓ Cost*↓
6	δ	Expo(1.7)	3138.81	5928	2778.46	292	1804.96	s*↑ Q*↑ Z*↑ n*↑ Cost*↑
		Expo(0.7)	559.44	4853	2593.31	228	1425.31	s*↓ Q*↓ Z*↓ n*↓ Cost*↓
7	π	0.9	1959.29	5179	2529.3	300	1479.58	s*↑ Q*↓ Z*↓ n*↑ Cost*↓
		0.1	1846.16	5101	2575.44	222	1761.75	s*↑ Q*↓ Z*↑ n*↓ Cost*↑
8	ω	1	1550.68	5780	2758.51	266	1464.67	s*↓ Q*↑ Z*↑ n*↑ Cost*↓
		0.5	1985.88	5193	2662.67	189	1976.59	s*↑ Q*↓ Z*↑ n*↓ Cost*↑

- Variation of the probability that a non-conforming items causes failure π (case 7): When π probability increases, the system decreases the probability of acceptance P_a (n^* increases). Such a variation aims to improve the quality of the lot thanks to the supplier involvement. In this situation, the system accepts less non-conforming items and then, increases the total availability of the manufacturing system. At the same time, the system tends to reduce the effect of the stock-out frequency of R.M on the whole supply chain by increasing s^* and decreasing Q^*. As result, the system decreases the Z^* value due to the increase in the availability of the production process and the raw material. When π probability decreases, the effect of the non-conforming raw material on the transformation stage decreases. Then, the system increases the probability of acceptance P_a (n^* decreases) to avoid important additional replenishment delay. However, as more non-conforming items will be accepted, more final product will be returned by the customer. For these reasons, the system has to ensure the availability of the R.M. by increasing the ordering point s^* and decreasing the lot size Q^* to ensure the transformation of RM to FP, and the availability of final product to respond to the demand by increases the Z^* value.

- Variation of the degree of supplier's involvement ω (case 8): when the degree of supplier involvement ω increases, the system promotes the return of the rejected inspected lot to ensure better quality results (n^* increases). Therefore, the decision maker has to supply less number of order (s^* decreases) but with important lot size (Q^* increases) in order to take advantage of the important level of supplier implication. Concerning the finished product level, the system increases the Z^* level to face the effect of the stock-out frequency of R.M. When ω decreases, we have an opposite variation of all optimal parameters except Z^*. In fact, when the degree of involvement of the supplier to improve the quality of the lot decreases, the system decreases the probability of acceptance P_a (n^* decreases) to avoid important additional replenishment delay. As a consequence, the decision maker has to supply more (s^* increases) but with lower lot size (Q^* decreases). In this situation, the decision maker has to increase the Z^* level to face the effect of non-conforming items on the availability of the manufacturing system and the returned final product.

From Table 4.2, we note that when the degree of involvement ω of the supplier decreases (ω =0.5), the optimal expected cost increases. This variation causes a decrease in the cost saving. However, the preference of the decision maker has not changed compared to the results of Table 4.1. In the next section, a comparative study will be presented to highlight the best quality policy.

4.8 Comparative study analysis

In this section, we conduct a comparative study in order to determine the best quality policy in terms of cost. Figure 4.9 illustrates the variation of the optimal total cost depending on the quality of the delivered lot. It include No policy, 100% policy, Sampl100% policy and SampRet(ω) policy with different degree of supplier implication.

From Figure 4.9, we note that:

- For $p \leq p_A$: 100% policy should be avoided. In fact, for lower proportion of p, performing a full inspection will considerably increase on one hand the total inspection costs, and on the other hand the total inspection delays that increase the stock-out frequency of the raw material. Therefore, No and Sampling policies may be more preferred to avoid such a situation.

- For $p > p_A$: No policy should be avoided. In fact, for higher proportion of p, accepting a significant amount of low-quality product will increase the unavailability of the production process due to the consumed non-conforming item, the final product stock-out frequency and the total cost of accepting non-conforming items. Therefore, it will be more preferred to perform quality control operation at the reception.

Concerning the decision maker preference between Sampl100%, No and 100% policies, the Sampl100% policy is the most interesting one. In fact, depending on the p value, Figure 4.9 shows that:

- For $p \leq p_B$, the Sampl100% policy $\simeq$ the No policy. In fact, this observation is illustrated through the optimization of the different control parameters, where the optimal sample size n^* is equal to 1. When it encounters a good quality lot, the system tries to maximize the probability of acceptance P_a to avoid additional delays and costs.

- For $p_B \leq\ p < p_C$, the Samp100% policy is the most advantageous.

- For $p > p_{\mathrm{C}}$, the Sampl100% policy $\simeq$ the 100% policy. In this situation, the system increases the optimal sample size n^* to minimise the probability of acceptance P_a and then encourages more 100% inspection to avoid the effect of accepting an important proportion of non-conforming items and to increase the availability of the transformation stage.

Concerning the decision maker preference between SampRet(ω) and the different other quality policy, the choice depends on the degree of the implication of the supplier ω and the percentage of non-confirming p . Form Figure 4.9, we note that for low value of p ($p \leq p_{\mathrm{D}}$), $(\overline{\mathrm{C}}^*_{\mathrm{SampRet}(\omega)} \simeq \overline{\mathrm{C}}^*_{\mathrm{Samp100\%}} \simeq \overline{\mathrm{C}}^*_{\mathrm{No}}) < \overline{\mathrm{C}}^*_{\mathrm{S100\%}}$. We also note that when $p > p_{\mathrm{D}}$:

- For higher ω value, SampRet(ω) policy should be selected. In fact, by choosing the SampRet(1) policy, gains obtained can be up to 52% higher than that of No policy and 36% higher than with the 100% or Sampl100% policy (case $p = 4\%$).

- For lower ω value ($\omega = 0.3$), SampRet (ω) policy may be selected for certain p value ($p\ \leq p_E$). However, when $p\ > p_E$, SampRet (ω) is less advantageous. Indeed, when the p value increase, the system tends to encourage the return of the lot to the supplier to reduce the effect of non-conforming items. Nevertheless, when the degree ω is low, the system could not offset the effect of additional delivery delay and then, the 100% and Samp100% policies become more preferred.

- For $\omega = 0$, the SampRet (ω) policy should be avoided. In this situation, the system will prefer to omit the return option of a rejected inspected lot by maximizing the acceptance probability P_a. This trend is illustrated by the optimal sample size $n^* = 1$. As all delivered lot are accepted, the SampRet (ω) policy $\simeq$ the No policy.

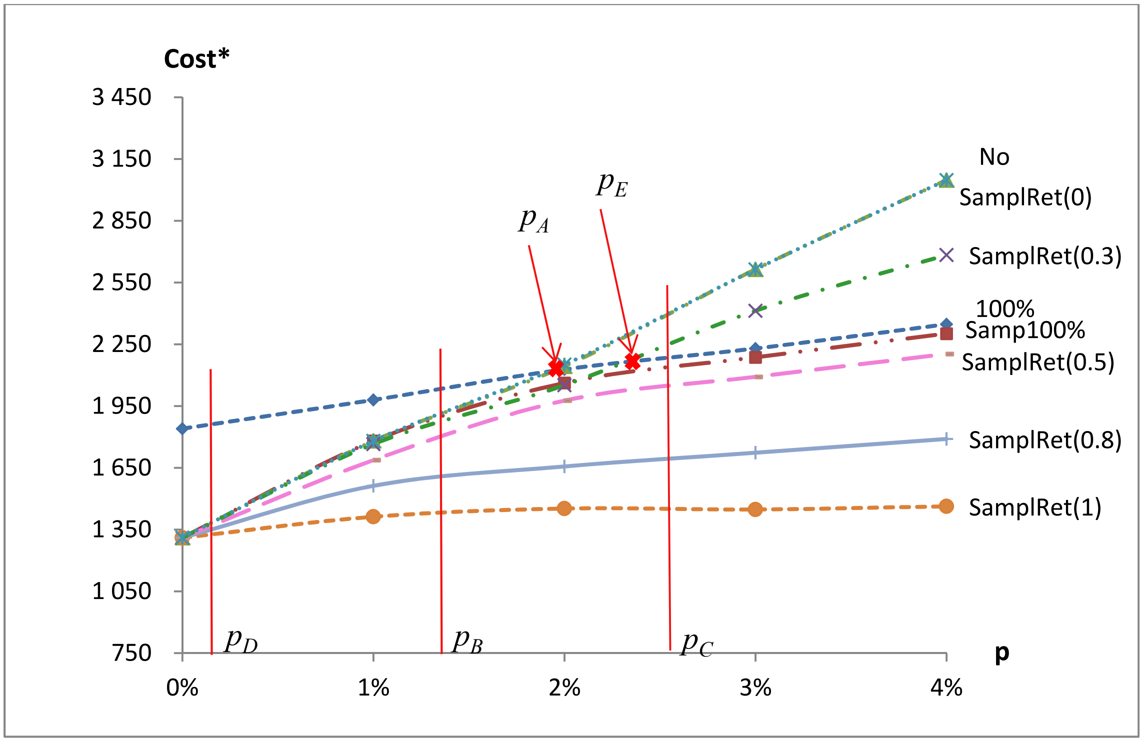


Figure 4.9 $\mathrm{Cost}^* = \mathrm{f}(\mathrm{p})$

To conclude, the results obtained from Figure 4.9 shows that the decision maker has to select the sampling policy as the quality control policy at the reception. In fact, this policy is always better than 100% policy or No policy, especially, when the parameters of the plan are optimised.

4.9 Conclusion

In this paper, we have determined, in a dynamic stochastic context, an integrated production, replenishment and quality inspection control policy to minimize the total cost of a three-stage supply chain with an unreliable manufacturer and imperfect-quality of raw materials. At the reception four inspection policies are studied including no inspection, 100% inspection, sampling inspection with 100% inspection decision of the rejected lot and sampling inspection with return to the supplier decision of the rejected lot. This work distinguish itself from the literature by taking into account the effect of non-conforming accepted raw material on the production process which may generate additional failures. We have used a combined approach based on simulation and response surface methodology to determine control parameters. The obtained result shows that the Sampl100% policy is more preferred than No and 100% policies. The result also shows that when the degree of the implication of the supplier is important, the SampRet(ω) policy should be selected. In fact, this policy may offers cost savings of over 52% as compared to results obtained with a No inspection decision. Future research may be developed by considering a multi-supplier, multi-manufacturing and multi-product case.

CONCLUSION

Dans ce travail, nous avons étudié un problème de coordination des décisions de contrôle de qualité de la matière première avec celle de la production et de l'approvisionnement dans un contexte d'une chaîne d'approvisionnement composée par un fournisseur qui peut livrer des lots de matière première imparfaits, un processus de production non fiable qui peut tomber en panne et un client final. À la réception de la matière première, un contrôle de qualité par plan d'échantillonnage est appliqué. Ce travail a permis de répondre à deux objectifs principaux. Le premier est de développer une politique de commande intégrant les décisions de production, d'approvisionnement et de contrôle de qualité. Le deuxième est d'aider le décideur à choisir la meilleure politique de contrôle de qualité à la réception.

Pour résoudre les différentes problématiques présentées dans ce travail, une approche de résolution expérimentale a été adoptée. Elle est une combinaison de simulations et des techniques d'optimisation statistiques (plan d'expérience, analyse de la variance et méthodologie de surface de réponse), permettant d'optimiser les paramètres de contrôle de la politique de commande. Les modèles de simulation ont été modélisés par une combinaison d'événements discrets et continus pour réduire le temps de calcul par rapport à une modélisation par événements purement discrets (Lavoie *et al.*, 2010). Ces derniers ont été développés avec le logiciel ARENA de Rockwell Automation avec des routines C++. L'utilisation d'un tel outil nous a permis de mieux présenter, dans le contexte stochastique, la dynamique des chaînes d'approvisionnements. Pour les techniques d'optimisation statistiques, nous avons utilisé le logiciel STATGRAPHICS. Pour valider la robustesse et l'efficacité de cette approche, des analyses de sensibilité ont été réalisées.

Dans le premier chapitre, nous avons présenté et critiqué une série de revues scientifiques sur les politiques de commande optimale des systèmes manufacturiers et des chaînes d'approvisionnement, l'intégration des décisions de production et d'approvisionnement et les stratégies de contrôle de la qualité de la matière première. Cette revue de littérature a permis de montrer l'originalité de notre travail par rapport à l'ensemble des anciens travaux.

Dans le deuxième chapitre, une politique de commande de la production, de l'approvisionnement et de contrôle de la qualité a été proposée. Nous avons effectué une étude comparative entre trois politiques de contrôle. Les deux premières sont deux politiques largement utilisées par les industriels suite au rejet d'un lot de matière première qui sont un contrôle à 100 % du lot ou un retour au fournisseur. Nous avons proposé une nouvelle politique, dite hybride qui est une combinaison de décision de contrôle à 100 % et du retour au fournisseur. Les résultats obtenus ont montré l'avantage de l'application de la nouvelle politique dans un contexte de gestion d'une chaîne d'approvisionnement.

Le troisième chapitre a traité l'avantage de l'optimisation d'un plan d'échantillonnage et l'effet de l'intégration du fournisseur dans l'amélioration de la qualité de la matière première. La chaîne d'approvisionnement était constituée d'un fournisseur, d'un manufacturier et d'un client final. À la réception, un plan d'échantillonnage simple caractérisé par un critère d'acceptation nul a été considéré. Dans ce travail, nous avons étudié deux décisions vis-à-vis du lot rejeté suite à une inspection, la première est que le lot est inspecté à 100 %. Le deuxième est que le lot est retourné au fournisseur qui s'engage à l'amélioration de la qualité du lot retourné. Pour facilité le choix du décideur, un outil de prise de décision a été développé afin d'assurer la sélection de la politique de contrôle de la qualité la plus efficace en termes de coût.

Au chapitre 4, nous avons considéré qu'il est possible qu'une pièce non-conforme de matière première affecte le processus de production en causant des pannes additionnelles. Dans ce chapitre, nous avons proposé une politique de commande intégrant les décisions de production, d'approvisionnement et de contrôle de qualité. À travers une analyse de sensibilité, nous avons montré l'effet de l'intégration de telles pannes dans une chaîne d'approvisionnement sur les différents paramètres de la politique de contrôle. De plus, nous avons effectué une étude comparative de plusieurs politiques de contrôle de qualité, soit aucune inspection, une inspection à 100 %, un plan d'échantillonnage simple avec une décision d'inspection à 100 % du lot rejeté et un plan d'échantillonnage simple avec une décision de retourner le lot rejeté au fournisseur qui assura l'amélioration de sa qualité. Le critère de comparaison était le coût minimum total de lancement de commande, de stockage (matière première et produit fini), de rupture de stock du produit fini et de qualité. La comparaison nous a montré l'avantage de l'application d'un plan d'échantillonnage à la réception. Elle a aussi confirmé que lorsque l'implication du fournisseur est très importante, le décideur doit choisir cette politique.

En conclusion, dans le cadre de ce mémoire, nous avons rédigé trois articles de journal. Le premier article (chapitre 2) est soumis à « International Journal of Production Economics ». Le deuxième article (chapitre 3) est soumis à « International Journal of Advanced Manufacturing Technology ». Le troisième (chapitre 4) est dans une phase de révision avancée avant la soumission. Comme extensions de nos modèles, plusieurs axes de recherche peuvent se présenter tels que : une chaîne d'approvisionnement composée par plusieurs fournisseurs produisant plusieurs types de produits, la détérioration de la machine suite à la consommation de la matière première non-conforme et l'intégration d'autre plan d'inspection tel qu'un plan d'échantillonnage double ou multiples.

ANNEXE I

MODÈLE DE SIMULATION D'UNE CHAÎNE D'APPROVISIONNEMENT À TROIS ÉCHELONS AVEC UNE POLITIQUE HYBRIDE DE CONTRÔLE DE QUALITÉ

Domaine expérimental (*Experiment Frame*)

```
PROJECT, "Supply chain-Hybrid","Rached Hlioui",,,Yes,Yes,Yes,Yes,No,No,Yes,No,Yes,No;

CONTINUOUS, 2,,.000001,1,,RKF(.0001,.0001,Warning),Warning;

FILES: File 1, "C:\Users\rhlioui\Desktop\Chapitre_2\Hybrid\F_M1P1_Q_Hybrid.xlsx", MSExcel2007,,Dispose,,Hold,RECORDSET(Recordset 1,"Inputs",2),RECORDSET(Recordset 2,"Outputs",2);

VARIABLES:
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n,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
Beginning,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
UnitSamplingT,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),0.0005:
TotalRectificationT,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
RectificationUnitT,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),0.001:
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Duration,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):

SEEDS: 1,,Yes: 2,,Yes: 3,,Yes: 4,,Yes: 5,,Yes: 6,,Yes: 7,,Yes: 8,,Yes: 9,,Yes: 10,,Yes;

CSTATS:
StMP,Total Stock MP,,DATABASE(,"Continuous","User Specified","Total stock MP"):
```

SnPf,Negative Stock PF,,DATABASE(,"Continuous","User Specified","Negative Stock PF"):
AOQ,Average Ordering Quantity,,DATABASE(,"Continuous","User Specified","Average Ordering Quantity"):
StPf,Total stock Profuit fini,,DATABASE(,"Continuous","User Specified","Total stock Profuit fini"):
SpMP,Positive Stock MP,,DATABASE(,"Continuous","User Specified","Positive stock MP"):
BLOC,Disponibilite machine,,DATABASE(,"Continuous","User Specified","Disponibilite machine"):
SpPf,Positive Stock PF,,DATABASE(,"Continuous","User Specified","Positive stock PF"):
TauxP1,Production rate,,DATABASE(,"Continuous","User Specified","Production rate"):
SnMP,Negative Stock MP,,DATABASE(,"Continuous","User Specified","Negative Stock MP");

COUNTERS:
order Number,,,,DATABASE(,"Count","User Specified","order Number"):
Supplier Return,,,,DATABASE(,"Count","User Specified","Supplier Return"):
Number of Accepted lot,,,,DATABASE(,"Count","User Specified","Number of Accepted lot"):
100% inspection,,,,DATABASE(,"Count","User Specified","100% inspection");

REPLICATE, 112,,DaysToBaseTime(950000),Yes,Yes,,,,24,Days,No,No,,,No,No;

LEVELS:1,StPf: 2,StMP: 3,SpPf: 4,SnPf:
5,SpMP: 6,SnMP: 7,BLOC: 8,Dem1,215:
9,TauxP1: 10,Order: 11,Um1,: 12,Zx:
13,Zy,: 14,Q,: 15,AOQ,: 16,%p:
17,CSatisfaction: 18,AcceptOrRefuse: 19,Return:
20,Zy2: 21,SFF;

RATES: 1,DStockPF: 2,DStockMP;

Modèle de simulation

; Model statements for module: BasicProcess.Create 1 (Create 1)
34$ CREATE, 1,DaysToBaseTime(0.0),Entity 1:DaysToBaseTime(1),1:NEXT(35$);

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35$        ASSIGN:      Create 1.NumberOut=Create 1.NumberOut + 1:NEXT(15$);

;    Model statements for module:  BasicProcess.Separate 1 (Separate 1)
15$        DUPLICATE,    100 - 50:
                  1,40$,50:NEXT(39$);

;    Model statements for module:  AdvancedProcess.ReadWrite 4 (ReadWrite 1)
2$         READ,        File 1,RECORDSET(Recordset 1):
                  X10,
                  X20,
                  Um1,
                  Zx,
                  Q,
                  Zy,
                  Zy2,
                  NumStream,
                  %p,
                  c,
                  n,
                  Pa:NEXT(12$);

12$        VBA:         1,vba:NEXT(0$);
;    Model statements for module:  BasicProcess.Process 1 (Time of simulation)
42$        DELAY:       TFIN,,NVA:NEXT(51$);
13$        VBA:         2,vba:NEXT(31$);
;    Model statements for module:  BasicProcess.Assign 37 (Assign 37)
31$        ASSIGN:      Return=CAVG(Client Satisfaction) * Dem1 *AOQ:NEXT(14$);
;    Model statements for module:  AdvancedProcess.ReadWrite 7 (ReadWrite 2)
14$        WRITE,       File 1,RECORDSET(Recordset 2):
                  X10,
                  Zx,
                  X20,
                  Zy,
                  CAVG(Total Stock MP),
                  CAVG(Positive Stock MP),
                  CAVG(Negative Stock MP),
                  CAVG(Total stock Profuit fini),
                  CAVG(Positive Stock PF),
                  CAVG(Negative Stock PF),
```

```
                    CAVG(Production rate),
                    Return,
                    NC(order Number),
                    NC(Number of Accepted lot),
                    NC(100% inspection),
                    NC(Supplier Return),
                    CAVG(Disponibilite machine),
                    TFIN,
                    Duration:NEXT(1$);

;   Model statements for module:  BasicProcess.Dispose 3 (Dispose 1)
1$       ASSIGN:     Dispose 1.NumberOut=Dispose 1.NumberOut + 1;
92$      DISPOSE:    Yes;
;   Model statements for module:  BasicProcess.Assign 25 (Assign 1)
7$       ASSIGN:     StPf=X20:
                    StMP=X10:
                    Order=0:NEXT(3$);
;   Model statements for module:  BasicProcess.Assign 19 (Machine dispo)
3$       ASSIGN:     BLOC=1:NEXT(4$);
;   Model statements for module:  BasicProcess.Process 5 (MTTF machine)
94$      DELAY:      EXPO(15,NumStream),,VA:NEXT(103$);
;   Model statements for module:  BasicProcess.Assign 20 (Machine en panne)
5$       ASSIGN:     BLOC=0:NEXT(6$);
;   Model statements for module:  BasicProcess.Process 6 (MTTR mahine)
145$     DELAY:      EXPO(1.65,NumStream),,VA:NEXT(154$);
8$       DETECT:     StPf,Positive,Zy,0.001:NEXT(9$);
;   Model statements for module:  BasicProcess.Dispose 16 (Dispose 2)
9$       ASSIGN:     Dispose 2.NumberOut=Dispose 2.NumberOut + 1;
195$     DISPOSE:    Yes;
10$      DETECT:     StPf,Either,0,0.001:NEXT(11$);
;   Model statements for module:  BasicProcess.Dispose 17 (Dispose 3)
11$      ASSIGN:     Dispose 3.NumberOut=Dispose 3.NumberOut + 1;
196$     DISPOSE:    Yes;
16$      DETECT:     StMP,Negative,0,0.001:NEXT(17$);
;   Model statements for module:  BasicProcess.Dispose 19 (Dispose 19)
17$      ASSIGN:     Dispose 19.NumberOut=Dispose 19.NumberOut + 1;
197$     DISPOSE:    Yes;
19$      DETECT:     StMP,Negative,Zx,0.01:NEXT(21$);
;   Model statements for module:  BasicProcess.Process 16 (Replenishment Delay)
```

```
199$        DELAY:        EXPO(2,NumStream),,VA:NEXT(208$);
;    Model statements for module:  BasicProcess.Record 3 (order Number)
26$         COUNT:        order Number,1:NEXT(25$);
;    Model statements for module:  BasicProcess.Process 17 (Simpling Process)
250$        DELAY:        n * UnitSamplingT,,VA:NEXT(259$);
22$         BRANCH,       1:
                          With,Pa,30$,Yes:
                          With,1-Pa,33$,Yes;
;    Model statements for module:  BasicProcess.Assign 36 (Accpeted lot)
30$         ASSIGN:       AcceptOrRefuse=1:
                          vreturn=vreturn+(SFF*%p*(Q-n))+((1-SFF)*%p*Q):NEXT(23$);
;    Model statements for module:  BasicProcess.Record 1 (Number of Accepted lot)
23$         COUNT:        Number of Accepted lot,1:NEXT(18$);
;    Model statements for module:  BasicProcess.Assign 34 (R.M Update)
18$       ASSIGN:       StMP=StMP + Q:
          AOQ=vreturn /  (  ( NC(Number of Accepted lot) +NC(100% inspection))  *Q):
           SPMP=SpMP+Q:NEXT(20$);
;    Model statements for module:  BasicProcess.Dispose 21 (Dispose 21)
20$         ASSIGN:       Dispose 21.NumberOut=Dispose 21.NumberOut + 1;
300$        DISPOSE:      Yes;
33$         BRANCH,       1:
                          If,SFF == 1,29$,Yes:
                          Else,32$,Yes;
;    Model statements for module:  BasicProcess.Assign 35 (Assign 35)
29$         ASSIGN:       AcceptOrRefuse=0:NEXT(24$);
;    Model statements for module:  BasicProcess.Record 2 (to 100% inspection)
24$         COUNT:        100% inspection,1:NEXT(27$);
;    Model statements for module:  BasicProcess.Process 18 (100% inspection)
302$        DELAY:        (Q-n) * UnitSamplingT,,VA:NEXT(311$);
;    Model statements for module:  BasicProcess.Process 19 (Rectification process)
353$        DELAY:        Q*%p*RectificationUnitT,,VA:NEXT(362$);
;    Model statements for module:  BasicProcess.Record 4 (Supplier Return)
32$         COUNT:        Supplier Return,1:NEXT(21$);
```

Routine C++

```
extern "C" void cdecl cstate  ()
{
SMREAL      DStockPF;
SMREAL      DStockMP;
```

```
SMREAL      dStPF;
SMREAL      dStMP;
SMREAL      valuePF;
SMREAL      valueMP;
SMREAL      dBLOC;
SMREAL      dDem1;
SMREAL      dTauxP1;
SMREAL      dOrder;
SMREAL      dUm1;
SMREAL       dZx;
SMREAL       dZy;
SMREAL       dQ;
SMREAL       dAOQ;
SMREAL      dp;
SMREAL      dCSatisfaction;
SMREAL      dAcceptOrRefuse;
SMREAL      dZy2;
SMREAL      dSFF;

static SMINT  StPF    =1;
static SMINT  StMP    =2;
static SMINT  SpPF     =3;
static SMINT  SnPF     =4;
static SMINT  SpMP     =5;
static SMINT  SnMP     =6;
static SMINT  BLOC    =7;
static SMINT  Dem1       =8;
static SMINT  TauxP1   =9;
static SMINT  Order    =10;
static SMINT  Um1      =11;
static SMINT  Zx       =12;
static SMINT  Zy       =13;
static SMINT  Q         =14;
static SMINT  AOQ     =15;
static SMINT  p         =16;
static SMINT  CSatisfaction   =17;
static SMINT  AcceptOrRefuse  =18;
static SMINT  Zy2       =20;
static SMINT  SFF       =21;
```

```
  dBLOC = getss(&BLOC);
  dDem1 = getss(&Dem1);
  dTauxP1 = getss(&TauxP1);
  dOrder = getss(&Order);
  dUm1 = getss(&Um1);
  dZx= getss(&Zx);
  dZy= getss(&Zy);
  dQ= getss(&Q);
  dAOQ= getss(&AOQ);
  dp=getss(&p);
  dCSatisfaction=getss(&CSatisfaction);
  dAcceptOrRefuse=getss(&AcceptOrRefuse);
  dStPF = getss(&StPF );
  dStMP = getss(&StMP );
  dZy2= getss(&Zy2);
  dSFF= getss(&SFF);

if (dStMP < 0)
		{dTauxP1 = 0;}

if (dStMP == 0)
		{dTauxP1 =  0;}

if (dStPF > dZy)
		{dTauxP1 = 0;}
else if (dStPF == dZy)
		{if (dStMP > 0)
			{dTauxP1 = dDem1/(1-dAOQ);}
		else
			{dTauxP1 = 0;}
		}
else
		{if (dStMP > 0)
			{dTauxP1 = dUm1;}
		else
			{dTauxP1 = 0;}
		}
```

```
if      (dStMP > dZx)
        {dOrder=0; setss(&Order, &dOrder);}
 else
        {dOrder=1; setss(&Order, &dOrder);}

if (dStPF > dZy2)
        {dSFF=0; setss(&SFF, &dSFF);}
else
        {dSFF=1; setss(&SFF, &dSFF);}

if (dBLOC==0)
{dTauxP1=0;}

DStockPF = dTauxP1 * dBLOC - (dDem1/(1-dAOQ));
DStockMP = -dTauxP1 * dBLOC;
setd(&StPF , &DStockPF);
setss(&TauxP1, &dTauxP1);
setd(&StMP , &DStockMP);

if (dStPF >= 0)
        {valuePF = dStPF ; setss(&SpPF , &valuePF);}
else
        {valuePF = 0; setss(&SpPF , &valuePF);}

if (dStPF  < 0)
        {valuePF = -dStPF ; setss(&SnPF , &valuePF);}
else
        {valuePF = 0; setss(&SnPF , &valuePF);}

if (dStPF > 0)
        {dCSatisfaction = 1 ; setss(&CSatisfaction , &dCSatisfaction);}
else
        {dCSatisfaction = 0 ; setss(&CSatisfaction , &dCSatisfaction);}

if (dStMP >= 0)
        { valueMP = dStMP ; setss(&SpMP , &valueMP);}
else
        { valueMP = 0; setss(&SpMP , &valueMP);}
```

```
 if (dStMP < 0)
        {valueMP = -dStMP ; setss(&SnMP , &valueMP);}
 else
        {valueMP = 0; setss(&SnMP , &valueMP);}
return;
}
```

ANNEXE II

MODÈLE DE SIMULATION D'UNE CHAÎNE D'APPROVISIONNEMENT À TROIS ÉCHELONS AVEC POLITIQUE D'IMPLICATION DU FOURNISSEUR DANS L'AMÉLIORATION DE LA QUALITÉ DU LOT REFUSÉ

Domaine expérimental (*Experiment Frame*)

```
PROJECT, "Supply chain-Ret-Improv","Rached Hlioui",,,Yes,Yes,Yes,Yes,No,No,Yes,No,Yes,No;

CONTINUOUS,   2,,.00000000001,1,,RKF(.0001,.0001,Warning),Warning;

ATTRIBUTES:   num_lot_coma,DATATYPE(Real);

FILES: File 1,"C:\Users\rhlioui\Desktop\Chapitre 3\Model Ret _w\F_M1P1_Qu_Chap3_Supp_Ret.xlsx",MSExcel2007,,Dispose,,Hold,
          RECORDSET(Recordset 1,"Inputs",2),RECORDSET(Recordset 2,"Outputs",2);

VARIABLES:
c,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
n,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
UnitSamplingT,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),0.00025:
RectificationUnitT,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),0:
X10,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
p1,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
NumStream,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
X20,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
n_passa_f,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
Duration,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
 coef_red,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
```

SEEDS: 1,,Yes: 2,,Yes: 3,,Yes: 4,,Yes: 5,,Yes: 6,,Yes: 7,,Yes: 8,,Yes: 9,,Yes: 10,,Yes;

CSTATS:
StMP,Total Stock MP,,DATABASE(,"Continuous","User Specified","Total stock MP"):
SnPf,Negative Stock PF,,DATABASE(,"Continuous","User Specified","Negative Stock PF"):
AOQ,Average Ordering Quantity,,DATABASE(,"Continuous","User Specified","Average Ordering Quantity"):
StPf,Total stock Profuit fini,,DATABASE(,"Continuous","User Specified","Total stock Profuit fini"):
SpMP,Positive Stock MP,,DATABASE(,"Continuous","User Specified","Positive stock MP"):
BLOC,Disponibilite machine,,DATABASE(,"Continuous","User Specified","Disponibilite machine"):
SpPf,Positive Stock PF,,DATABASE(,"Continuous","User Specified","Positive stock PF"):
TauxP1,Production rate,,DATABASE(,"Continuous","User Specified","Production rate"):
SnMP,Negative Stock MP,,DATABASE(,"Continuous","User Specified","Negative Stock MP");

COUNTERS:
Refused lot,,,,DATABASE(,"Count","User Specified","Refused lot"):
N_inspected_lot,,,,DATABASE(,"Count","User Specified","N_inspected_lot"):
order Number,,,,DATABASE(,"Count","User Specified","order Number"):
Number of Accepted lot,,,,DATABASE(,"Count","User Specified","Number of Accepted lot");

REPLICATE, 140,,DaysToBaseTime(1000000),Yes,Yes,,,,24,Days,No,No,,,No,No;

LEVELS:
1,StPf: 2,StMP: 3,SpPf: 4,SnPf:
5,SpMP: 6,SnMP: 7,BLOC: 8,Dem1,180:
9,TauxP1: 10,Order: 11,Um1,: 12,Zx:
13,Zy,: 14,Q,: 16,AOQ,: 17,DecisionReturnorC:
18,%p: 19,CSatisfaction: 20,AcceptOrRefuse:
21,Return;

RATES: 1,DStockPF: 2,DStockMP;

Modèle de simulation

```
;     Model statements for module:  BasicProcess.Create 1 (Create 1)
34$                                CREATE,                          1,DaysToBaseTime(0.0),Entity
1:DaysToBaseTime(1),1:NEXT(35$);
35$          ASSIGN:       Create 1.NumberOut=Create 1.NumberOut + 1:NEXT(15$);
;     Model statements for module:  BasicProcess.Separate 1 (Separate 1)
15$          DUPLICATE,     100 - 50:
                      1,40$,50:NEXT(39$);
39$              ASSIGN:           Separate 1.NumberOut Orig=Separate 1.NumberOut Orig +
1:NEXT(2$);
40$              ASSIGN:           Separate 1.NumberOut Dup=Separate 1.NumberOut Dup +
1:NEXT(7$);
;     Model statements for module:  AdvancedProcess.ReadWrite 4 (ReadWrite 1)
2$           READ,         File 1,RECORDSET(Recordset 1):
                      X10,
                      X20,
                      Um1,
                      Zx,
                      Q,
                      Zy,
                      NumStream,
                      coef_red,
                      %p,
                      c,
                      n,
                      Pa:NEXT(12$);

12$          VBA:          1,vba:NEXT(0$);
;     Model statements for module:  BasicProcess.Process 1 (Time of simulation)
0$           ASSIGN:       Time of simulation.NumberIn=Time of simulation.NumberIn + 1:
                      Time of simulation.WIP=Time of simulation.WIP+1;
70$          STACK,        1:Save:NEXT(42$);
42$          DELAY:        TFIN,,NVA:NEXT(51$);
13$          VBA:          2,vba:NEXT(28$);
;     Model statements for module:  BasicProcess.Assign 37 (Assign 37)
28$          ASSIGN:       Return=CAVG(Client Satisfaction) * Dem1 *AOQ:NEXT(14$);
;     Model statements for module:  AdvancedProcess.ReadWrite 7 (ReadWrite 2)
14$          WRITE,        File 1,RECORDSET(Recordset 2):
```

```
                        X10,
                        Zx,
                        X20,
                        Zy,
                        CAVG(Total Stock MP),
                        CAVG(Positive Stock MP),
                        CAVG(Negative Stock MP),
                        CAVG(Total stock Profuit fini),
                        CAVG(Positive Stock PF),
                        CAVG(Negative Stock PF),
                        CAVG(Production rate),
                        Return,
                        NC(order Number),
                        NC(N_inspected_lot),
                        NC(Number of Accepted lot),
                        NC(Refused lot),
                        CAVG(Disponibilite machine),
                        TFIN,
                        Duration:NEXT(1$);

;     Model statements for module:  BasicProcess.Dispose 3 (Dispose 1)
1$          ASSIGN:       Dispose 1.NumberOut=Dispose 1.NumberOut + 1;
92$         DISPOSE:      Yes;
;     Model statements for module:  BasicProcess.Assign 25 (Assign 1)
7$          ASSIGN:       StPf=X20:
                        StMP=X10:
                        Order=0:NEXT(3$);
;     Model statements for module:  BasicProcess.Assign 19 (Machine dispo)
3$          ASSIGN:       BLOC=1:NEXT(4$);
;     Model statements for module:  BasicProcess.Process 5 (MTTF machine)
94$         DELAY:        EXPO(15,NumStream),,VA:NEXT(103$);
;     Model statements for module:  BasicProcess.Assign 20 (Machine en panne)
5$          ASSIGN:       BLOC=0:NEXT(6$);
;     Model statements for module:  BasicProcess.Process 6 (MTTR mahine)
145$        DELAY:        EXPO(1.65,NumStream),,VA:NEXT(154$);
8$          DETECT:       StPf,Positive,Zy,0.00001:NEXT(9$);
;     Model statements for module:  BasicProcess.Dispose 16 (Dispose 2)
9$          ASSIGN:       Dispose 2.NumberOut=Dispose 2.NumberOut + 1;
195$        DISPOSE:      Yes;
```

```
10$        DETECT:     StPf,Either,0,0.001:NEXT(11$);
;   Model statements for module:  BasicProcess.Dispose 17 (Dispose 3)
11$        ASSIGN:     Dispose 3.NumberOut=Dispose 3.NumberOut + 1;
196$       DISPOSE:    Yes;
16$        DETECT:     StMP,Negative,0,0.001:NEXT(17$);
19$        DETECT:     StMP,Negative,Zx,0.01:MARK(num_lot_coma):NEXT(26$);
;   Model statements for module:  BasicProcess.Record 3 (order Number)
26$        COUNT:      order Number,1:NEXT(29$);
;   Model statements for module:  BasicProcess.Assign 38 (Assign 38)
29$        ASSIGN:     Pa1=Pa:
                  p1=%p:
                  lot_cree=num_lot_coma:
                  n_passa_f=0:NEXT(21$);
;   Model statements for module:  BasicProcess.Process 16 (Replenishment Delay)
199$       DELAY:      EXPO(1.5,NumStream),,VA:NEXT(208$);
;   Model statements for module:  BasicProcess.Record 4 (N_inspected_lot)
32$        COUNT:      N_inspected_lot,1:NEXT(25$);
250$       DELAY:      n * UnitSamplingT,,VA:NEXT(259$);
22$        BRANCH,     1:
                  With,Pa1,27$,Yes:
                  With,1-Pa1,24$,Yes;
;   Model statements for module:  BasicProcess.Assign 36 (Accpeted lot)
27$        ASSIGN:     AcceptOrRefuse=1:
                  vreturn=vreturn+p1*Q:NEXT(23$);
;   Model statements for module:  BasicProcess.Record 1 (Number of Accepted lot)
23$        COUNT:      Number of Accepted lot,1:NEXT(18$);
;   Model statements for module:  BasicProcess.Assign 34 (R.M Update)
18$        ASSIGN: StMP=StMP + Q:
                   SpMP=SpMP+Q:
                   AOQ=vreturn / ( NC(Number of Accepted lot) *Q):NEXT(20$);
;   Model statements for module:  BasicProcess.Record 2 (Refused lot)
24$        COUNT:      Refused lot,1:NEXT(31$);
;   Model statements for module:  BasicProcess.Assign 40 (Assign 40)
31$        ASSIGN:     n_passa_f=n_passa_f+1:NEXT(33$);
;   Model statements for module:  BasicProcess.Assign 41 (Assign 41)
33$        ASSIGN:     p1=%p *(( 1-coef_red ) **n_passa_f ):NEXT(30$);
;   Model statements for module:  BasicProcess.Assign 39 (Assign 39)
30$        ASSIGN:     Pa1=EP( - n * p1):
                  DecisionReturnorC=1:
```

```
AcceptOrRefuse=0:NEXT(21$);
```

Routine C++

```
extern "C" void cdecl cstate  ()
{
  SMREAL      DStockPF;
  SMREAL      DStockMP;
  SMREAL      dStPF;
  SMREAL      dStMP;
  SMREAL      valuePF;
  SMREAL      valueMP;
  SMREAL      dBLOC;
  SMREAL      dDem1;
  SMREAL      dTauxP1;
  SMREAL      dOrder;
  SMREAL      dUm1;
  SMREAL       dZx;
  SMREAL       dZy;
  SMREAL       dQ;
  SMREAL       dAOQ;
  SMREAL      dDecisionReturnorC;
  SMREAL      dp;
  SMREAL      dCSatisfaction;
  SMREAL      dAcceptOrRefuse;

  static SMINT  StPF     =1;
  static SMINT  StMP     =2;
  static SMINT  SpPF     =3;
  static SMINT  SnPF     =4;
  static SMINT  SpMP     =5;
  static SMINT  SnMP     =6;
  static SMINT  BLOC     =7;
  static SMINT  Dem1     =8;
  static SMINT  TauxP1  =9;
  static SMINT  Order    =10;
  static SMINT  Um1      =11;
  static SMINT  Zx       =12;
  static SMINT  Zy       =13;
  static SMINT  Q        =14;
```

```
   static SMINT  AOQ      =16;
   static SMINT  DecisionReturnorC =17;
   static SMINT  p=18;
   static SMINT  CSatisfaction=19;
   static SMINT  AcceptOrRefuse=20;


   dBLOC = getss(&BLOC);
   dDem1 = getss(&Dem1);
   dTauxP1 = getss(&TauxP1);
   dOrder = getss(&Order);
   dUm1 = getss(&Um1);
   dZx= getss(&Zx);
   dZy= getss(&Zy);
   dQ= getss(&Q);
   dAOQ= getss(&AOQ);
   dDecisionReturnorC=getss(&DecisionReturnorC);
   dp=getss(&p);
   dCSatisfaction=getss(&CSatisfaction);
   dAcceptOrRefuse=getss(&AcceptOrRefuse);
   dStPF  = getss(&StPF );
   dStMP  = getss(&StMP );

if (dStMP  < 0)
         {dTauxP1 =  0;}

if (dStMP == 0)
          {dTauxP1 =  0; }

if(dStPF  > dZy)
{ dTauxP1 = 0;}
else if (dStPF == dZy)
         {if (dStMP>0)
                  {dTauxP1 = dDem1/(1-dAOQ);}
         else
                  {dTauxP1 = 0;}
                  }
else
         {if (dStMP>0)
```

```
                {dTauxP1 = dUm1;}
        else
                {dTauxP1 = 0;}
        }

if      (dStMP  > dZx)
        {dOrder=0; setss(&Order, &dOrder);}
else
        {dOrder=1;setss(&Order, &dOrder);}

if (dBLOC==0)
        {dTauxP1=0;}

DStockPF = dTauxP1 * dBLOC - (dDem1/(1-dAOQ));
DStockMP = -dTauxP1 * dBLOC;
setd(&StPF , &DStockPF);
setss(&TauxP1, &dTauxP1);
setd(&StMP , &DStockMP);

if (dStPF  >= 0)
        {valuePF = dStPF ;setss(&SpPF , &valuePF);}
else
        {valuePF = 0; setss(&SpPF , &valuePF);}

if (dStPF  < 0)
        {valuePF = -dStPF ; setss(&SnPF , &valuePF);}
else
        {valuePF = 0;  setss(&SnPF , &valuePF);}


if (dStPF  > 0)
        {dCSatisfaction = 1 ;  setss(&CSatisfaction , &dCSatisfaction);}
else
        {dCSatisfaction = 0 ;  setss(&CSatisfaction , &dCSatisfaction);}

 if (dStMP  >= 0)
        {valueMP = dStMP ; setss(&SpMP , &valueMP);}
  else
        { valueMP = 0; setss(&SpMP , &valueMP); }
```

```
if (dStMP  < 0)
        { valueMP = -dStMP ; setss(&SnMP , &valueMP);}
else
        {valueMP = 0; setss(&SnMP , &valueMP);}

return;
}
```

ANNEXE III

MODÈLE SE SIMULATION D'UNE CHAÎNE D'APPROVISIONNEMENT À TROIS ÉCHELONS AVEC DEUX TYPES DE PANNE OÙ LA POLITIQUE DE CONTRÔLE EST UN PLAN D'ÉCHANTILLONNAGE AVEC DÉCISION DE CONTÔLE À 100% DU LOT REJETÉ

Domaine expérimental (*Experiment Frame*)

PROJECT, "Sampl100%","Rached Hlioui ",,,Yes,Yes,Yes,Yes,No,No,Yes,No,Yes,No;

CONTINUOUS, 3,,.000000000001,1,,RKF(.0001,.0001,Warning),Warning;

ATTRIBUTES: Numerolot,DATATYPE(Real);

FILES: File 1,"C:\Users\rhlioui\Desktop\Chapitre 4\Model Arena Samp100%\Chap4_Samp100%_p2%.xlsx",MSExcel2007,,Dispose,,
Hold,RECORDSET(Recordset 1,"Inputs",2),RECORDSET(Recordset 2,"Outputs",2);

VARIABLES:
vreturn,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
tablverifirepetition(400),CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
%wQua,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
c,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
n,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
Nbralea,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
decisionlot22(40000),CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
Taillelotsansdefau,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
addp,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
tompon,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):

OrderArr,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
UnitSamplingT,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),0.00005:
addp11,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
X10,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
Nbralea01,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
Pa,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
NumStream,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
X20,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
sauvgb1(12),CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
Propordelot11(40000),CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
Increment1,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),1:
Increment2,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),1:
Increment3,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),1:
Itemdefect,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
passagelot,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
NCPINCONFO1,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
NbrPiecNConRepla,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
NblotconsometSSP,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):
Nbrlotconsomer,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),0:
Nbrpanneaddi,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),1:
listeNombrealeat(400),CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real):

SEEDS: 1,,Yes: 2,,Yes: 3,,Yes: 4,,Yes: 5,,Yes: 6,,Yes: 7,,Yes: 8,,Yes: 9,,Yes: 10,,Yes;

CSTATS:
StMP,Total Stock MP,,DATABASE(,"Continuous","User Specified","Total stock MP"):
VerifdisPn2,Disponibilite machine Pan2,,DATABASE(,"Continuous","User Specified","Disponibilite machinePan2"):
SnPf,Negative Stock PF,,DATABASE(,"Continuous","User Specified","Negative Stock PF"):
AOQ,Average Ordering Quantity,,DATABASE(,"Continuous","User Specified","Average Ordering Quantity Rest"):
StPf,Total stock Profuit fini,,DATABASE(,"Continuous","User Specified","Total stock Profuit fini"):
SpMP,Positive Stock MP,,DATABASE(,"Continuous","User Specified","Positive stock MP"):
AOQProd,Average panne event,,DATABASE(,"Continuous","User Specified","Average panne event "):
BLOC,Disponibilite machine,,DATABASE(,"Continuous","User Specified","Disponibilite machine Pan1"):
SpPf,Positive Stock PF,,DATABASE(,"Continuous","User Specified","Positive stock PF"):
TauxP1,Production rate,,DATABASE(,"Continuous","User Specified","Production rate"):
SnMP,Negative Stock MP,,DATABASE(,"Continuous","User Specified","Negative Stock MP");

COUNTERS:
Confideconsom,,,,DATABASE(,"Count","User Specified","Confideconsom"):
Refused lot,,,,DATABASE(,"Count","User Specified","Refused lot"):
Panne1,,,,DATABASE(,"Count","User Specified","Panne1"):
Panne2,,,,DATABASE(,"Count","User Specified","Panne2"):
order Number,,,,DATABASE(,"Count","User Specified","order Number"):
Number of Accepted lot,,,,DATABASE(,"Count","User Specified","Number of Accepted lot"):

REPLICATE, 112,,HoursToBaseTime(200000),Yes,Yes,,,,24,Hours,No,No,,,No,No;

LEVELS:
1,StPf: 2,StMP: 3,consomlotentier: 4,SpPf:
5,SnPf: 6,SpMP: 7,SnMP: 8,BLOC:

```
        9,Dem1,463:    10,TauxP1:        11,Order:              12,Um1,:
        13,Zx:            14,Zy,:            15,Q,:                  16,AOQ,:
        17,DecisionReturnorC:        18,%p:              19,CSatisfaction:
        20,AcceptOrRefuse:            21,Return:          22,BLOC_Q,1:
        23,Zp:               24,debutcommande,0:            25,VerifdisPn2:
        26,AOQProd,0;

RATES:  1,DStockPF:            2,DStockMP:            3,Dconsomlotentier;
```

Modèle de simulation

```
;     Model statements for module:  BasicProcess.Create 1 (Create 1)
99$                    CREATE,                    1,HoursToBaseTime(0.0),Entity
1:HoursToBaseTime(1),1:NEXT(100$);
100$        ASSIGN:       Create 1.NumberOut=Create 1.NumberOut + 1:NEXT(13$);
;     Model statements for module:  BasicProcess.Separate 1 (Separate 1)
13$         DUPLICATE,     100 - 50:
                     1,105$,50:NEXT(104$);
104$           ASSIGN:          Separate 1.NumberOut Orig=Separate 1.NumberOut Orig +
1:NEXT(2$);
105$           ASSIGN:          Separate 1.NumberOut Dup=Separate 1.NumberOut Dup +
1:NEXT(7$);
;     Model statements for module:  AdvancedProcess.ReadWrite 4 (ReadWrite 1)
2$          READ,          File 1,RECORDSET(Recordset 1):
                     X10,
                     X20,
                     Um1,
                     Zx,
                     Q,
                     Zy,
                     NumStream,
                     %wQua,
                     c,
                     n:NEXT(10$);

10$         VBA:          1,vba:NEXT(0$);
;     Model statements for module:  BasicProcess.Process 1 (Time of simulation)
0$          ASSIGN:       Time of simulation.NumberIn=Time of simulation.NumberIn + 1:
                     Time of simulation.WIP=Time of simulation.WIP+1;
```

```
135$        STACK,        1:Save:NEXT(107$);
107$        DELAY:        TFIN,,NVA:NEXT(116$);
                          Time of simulation.WIP=Time of simulation.WIP-1:NEXT(11$);
11$         VBA:          2,vba:NEXT(16$);
;     Model statements for module:  BasicProcess.Assign 37 (Assign 37)
16$         ASSIGN:       Return=CAVG(Client Satisfaction) * Dem1 *AOQ:NEXT(12$);
;     Model statements for module:  AdvancedProcess.ReadWrite 7 (ReadWrite 2)
12$         WRITE,        File 1,RECORDSET(Recordset 2):
                          X10,
                          Zx,
                          X20,
                          Zy,
                          CAVG(Total Stock MP),
                          CAVG(Positive Stock MP),
                          CAVG(Negative Stock MP),
                          CAVG(Total stock Profuit fini),
                          CAVG(Positive Stock PF),
                          CAVG(Negative Stock PF),
                          CAVG(Production rate),
                          Return,
                          NC(Panne1),
                          NC(Panne2),
                          NC(order Number),
                          NC(Number of Accepted lot),
                          NC(Refused lot),
                          CAVG(Disponibilite machine Pan1),
                          CAVG(Disponibilite machine Pan2),
                          vreturn,
                          CAVG(Average panne event),
                          TFIN,
                          Duration:NEXT(1$);

;     Model statements for module:  BasicProcess.Dispose 3 (Dispose 1)
1$          ASSIGN:       Dispose 1.NumberOut=Dispose 1.NumberOut + 1;
157$        DISPOSE:      Yes;
;     Model statements for module:  BasicProcess.Assign 25 (Assign 1)
7$          ASSIGN:       StPf=X20:
                          StMP=X10:
                          Order=0:
```

```
                    NblotconsometSSP=1:
                    Taillelotsansdefau=Q - Itemdefect:
                    VerifdisPn2=1:NEXT(22$);
;    Model statements for module:  BasicProcess.Separate 2 (Separate 2)
22$         DUPLICATE,     100 - 50:
                    1,160$,50:NEXT(159$);
;    Model statements for module:  BasicProcess.Assign 19 (Machine dispo)
3$          ASSIGN:        BLOC=1:NEXT(4$);
;    Model statements for module:  BasicProcess.Process 5 (MTTF machine)
162$        DELAY:         LOGN( 50,6 ,NumStream),,VA:NEXT(171$);
;    Model statements for module:  BasicProcess.Assign 20 (Machine en panne)
5$          ASSIGN:        BLOC=0:NEXT(20$);
;    Model statements for module:  BasicProcess.Record 4 (Panne1)
20$         COUNT:         Panne1,1:NEXT(6$);
;    Model statements for module:  BasicProcess.Process 6 (MTTR mahine)
213$        DELAY:         LOGN( 5, 0.6 ,NumStream),,VA:NEXT(222$);
;    Model statements for module:  BasicProcess.Assign 52 (Assign 52)
44$         ASSIGN:        passagelot=passagelot+1:
                    Itemdefect=NCPINCONFO2:NEXT(36$);
;    Model statements for module:  BasicProcess.Assign 46 (creer un nombre aleatoire)
36$         ASSIGN:        Nbralea01=UNIF(0,1,NumStream):
                    Nbralea=ANINT(Nbralea01*(Q- (Q*%p))):NEXT(81$);
81$         BRANCH,        1:
                    If,Nbralea == 0,36$,Yes:
                    Else,70$,Yes;
70$         ASSIGN:        Nbralea=ANINT(Nbralea01*(Q- (Q*%p))):
                    listeNombrealeat ( Increment1 )=Nbralea:
                    tablverifirepetition ( Increment1 )=listeNombrealeat ( Increment1 );
50$         BRANCH,        1:
                    If,Increment1<= Itemdefect,79$,Yes:
                    Else,72$,Yes;
;    Model statements for module:  BasicProcess.Assign 75 (Assign 75)
79$         ASSIGN:        Increment3=1:NEXT(76$);
76$         BRANCH,        1:
                    If,(Increment3<> Itemdefect) &&  ( Increment1  > 1),80$,Yes:
                    Else,63$,Yes;
80$         BRANCH,        1:
                    If,Increment3 <= (Increment1-1),77$,Yes:
                    Else,63$,Yes;
```

```
77$        BRANCH,      1:
              If,listeNombrealeat ( Increment1 ) == tablverifirepetition(Increment3),36$,Yes:
                    Else,78$,Yes;
;    Model statements for module:  BasicProcess.Assign 74 (Assign 74)
78$        ASSIGN:      Increment3=Increment3+1:NEXT(80$);
;     Model statements for module:  BasicProcess.Assign 62 (Incrementation pour remblir les variables aleatoire)
63$        ASSIGN:      Increment1=Increment1+1:NEXT(36$);
;    Model statements for module:  BasicProcess.Assign 69 (Assign 69)
72$        ASSIGN:      Increment1=1:NEXT(64$);
64$        BRANCH,      1:
                    If,Increment1<Itemdefect,74$,Yes:
                    Else,75$,Yes;
;    Model statements for module:  BasicProcess.Assign 72 (Assign 72)
74$        ASSIGN:      Increment2=Increment1+1:NEXT(66$);
66$        BRANCH,      1:
                    If,Increment2 <= Itemdefect,67$,Yes:
                    Else,65$,Yes;
67$        BRANCH,      1:
              If,listeNombrealeat ( Increment1 )  > listeNombrealeat (Increment2 ),71$,Yes:
                    Else,73$,Yes;
71$        ASSIGN:      tompon=listeNombrealeat ( Increment1 ):
                    listeNombrealeat ( Increment1 )=listeNombrealeat ( Increment2 ):
                    listeNombrealeat ( Increment2 )=tompon:NEXT(73$);
;    Model statements for module:  BasicProcess.Assign 70 (Assign 70)
73$        ASSIGN:      Increment2=Increment2+1:NEXT(66$);
;     Model statements for module:  BasicProcess.Assign 63 (Incrementation pour le premier boucle)
65$        ASSIGN:      Increment1=Increment1+1:NEXT(64$);
;    Model statements for module:  BasicProcess.Assign 73 (Assign 73)
75$        ASSIGN:      Increment1=1:NEXT(68$);
68$        BRANCH,      1:
                    If,Increment1<= Itemdefect,53$,Yes:
                    Else,37$,Yes;
;    Model statements for module:  BasicProcess.Assign 54 (Assign 54)
53$        ASSIGN:      Zp=listeNombrealeat( Increment1 ):NEXT(51$);
; Model statements for module:  BasicProcess.Assign 68 (Incrementation pour choix de panne)
69$        ASSIGN:      Increment1=Increment1+1:NEXT(68$);
```

```
;	Model statements for module:  BasicProcess.Assign 49 (Assign 49)
37$	ASSIGN:	Increment1=1:
		Increment2=1:
		Increment3=1:
		Zp=0:
		VerifdisPn2=1:NEXT(47$);
8$	DETECT:	StPf,Positive,Zy,0.001:NEXT(96$);
;	Model statements for module:  BasicProcess.Dispose 29 (Dispose 29)
96$	ASSIGN:	Dispose 29.NumberOut=Dispose 29.NumberOut + 1;
263$	DISPOSE:	Yes;
9$	DETECT:	StPf,Either,0,0.001:NEXT(96$);
14$	DETECT:	StMP,Negative,0,0.001:NEXT(96$);
;	Model statements for module:  BasicProcess.Assign 39 (Machine en panne Q)
18$	ASSIGN:	BLOC_Q=0:
		VerifdisPn2=0:NEXT(21$);
;	Model statements for module:  BasicProcess.Record 5 (Panne2)
21$	COUNT:	Panne2,1:NEXT(19$);
265$	DELAY:	LOGN( 0.006, 0.0008 ,NumStream),,VA:NEXT(274$);
;	Model statements for module:  BasicProcess.Assign 38 (Machine dispo Q)
17$	ASSIGN:	BLOC_Q=1:
		VerifdisPn2=1:NEXT(38$);
;	Model statements for module:  AdvancedProcess.Signal 2 (panne)
38$	SIGNAL:	200:NEXT(23$);
26$	DETECT:	StMP,Negative,Zx,0.01:NEXT(27$);
318$	DELAY:	EXPO(1.2, NumStream),,VA:NEXT(327$);
;	Model statements for module:  BasicProcess.Record 10 (order Number)
32$	COUNT:	order Number,1:NEXT(45$);
;	Model statements for module:  BasicProcess.Assign 53 (Assign 53)
45$	ASSIGN:	Numerolot=NC(order Number):
		%p=0.02:
		Pa=EP(-(%p*n)):NEXT(31$);
;	Model statements for module:  BasicProcess.Process 23 (Simpling Process)
369$	DELAY:	n * UnitSamplingT,,VA:NEXT(378$);
28$	BRANCH,	1:
		With,Pa,35$,Yes:
		With,1-Pa,34$,Yes;
;	Model statements for module:  BasicProcess.Assign 44 (Accpeted lot)
35$	ASSIGN:	AcceptOrRefuse=1:
		vreturn=vreturn+%p*(Q-n):
```

```
                    NCPINCONFO1=ANINT(%wQua*%p * (Q - n)):
                    NCPINCONF11=ANINT((1-%wQua)*%p * (Q - n)):
                    addp=addp+NCPINCONFO1:
                    addp11=addp11+NCPINCONF11:NEXT(29$);
;    Model statements for module:  BasicProcess.Record 8 (Number of Accepted lot)
29$         COUNT:        Number of Accepted lot,1:NEXT(54$);
;    Model statements for module:  BasicProcess.Assign 42 (Assign 42)
25$ ASSIGN: StMP=StMP +(AcceptOrRefuse* Q)+((1-AcceptOrRefuse)*(Q-ANINT(%p *
Q))):
          SpMP=SpMP+(AcceptOrRefuse* Q)+((1-AcceptOrRefuse)*(Q-ANINT(%p * Q))):
                    AOQ=(addp+addp11) /  ((NC(Number of Accepted lot) *Q)+Quantiref):
                    AOQProd=addp /  ((NC(Number of Accepted lot) *Q)+Quantiref):
                    debutcommande=1:
                    NCPINCONFO2=NCPINCONFO1:NEXT(87$);
87$         ASSIGN:       decisionlot22(NC(order Number))=AcceptOrRefuse:
                    Propordelot11(NC(order Number))=%p:NEXT(15$);
;    Model statements for module:  BasicProcess.Dispose 21 (Dispose 21)
15$         ASSIGN:       Dispose 21.NumberOut=Dispose 21.NumberOut + 1;
419$        DISPOSE:      Yes;
;    Model statements for module:  BasicProcess.Assign 57 (Assign 57)
55$         ASSIGN:       valeurintrestSMP=StMP:
                    verification1=1:NEXT(25$);
;    Model statements for module:  BasicProcess.Assign 43 (Assign 43)
34$         ASSIGN:       DecisionReturnorC=1:
                    AcceptOrRefuse=0:
                    NbrPiecNConRepla=NbrPiecNConRepla+ANINT(%p * Q):
                    Quantiref=Quantiref+(Q-ANINT(%p*Q)):NEXT(30$);
;    Model statements for module:  BasicProcess.Record 9 (Refused lot)
30$         COUNT:        Refused lot,1:NEXT(33$);
;    Model statements for module:  BasicProcess.Process 24 (100% inspection)
421$        DELAY:        (Q-n) * UnitSamplingT,,VA:NEXT(430$);
39$         DETECT:       consomlotentier,Positive,Q,0.001;
92$         BRANCH,       1:
                    If,decisionlot22(Nbrlotconsomer)==1,90$,Yes:
                    Else,91$,Yes;
;    Model statements for module:  BasicProcess.Record 15 (Confideconsom)
90$         COUNT:        Confideconsom,1:NEXT(40$);
;    Model statements for module:  BasicProcess.Assign 50 (Assign 50)
40$         ASSIGN:       consomlotentier=0:NEXT(91$);
```

```
;    Model statements for module:  BasicProcess.Assign 51 (Assign 51)
43$         ASSIGN:       Nbrlotconsomer=Nbrlotconsomer+1:NEXT(46$);
46$         BRANCH,       1:
                    If,decisionlot22(Nbrlotconsomer)==1,49$,Yes:
                    Else,86$,Yes;
;     Model statements for module:  AdvancedProcess.Signal 5 (lot en consommation est celui
accep)
49$         SIGNAL:       40:NEXT(85$);
;     Model statements for module:  BasicProcess.Record 13 (Record 13)
85$         COUNT:        Record 13,1:NEXT(97$);
;     Model statements for module:  BasicProcess.Record 14 (Record 14)
86$         COUNT:        Record 14,1:NEXT(98$);
;     Model statements for module:  BasicProcess.Assign 79 (Assign 79)
58$         DETECT:       consomlotentier,Positive,valeurintrestSMP,0.001:NEXT(59$);
;     Model statements for module:  AdvancedProcess.Signal 6 (Signal 6)
59$         SIGNAL:       10:NEXT(62$);
;     Model statements for module:  BasicProcess.Assign 60 (Assign 60)
62$         ASSIGN:       verification1=0:NEXT(95$);
88$         DETECT:       consomlotentier,Positive,Q-ANINT(%p* Q ),0.001;
93$         BRANCH,       1:
                    If,decisionlot22(Nbrlotconsomer)==1,91$,Yes:
                    Else,89$,Yes;
;     Model statements for module:  BasicProcess.Assign 76 (Assign 76)
89$         ASSIGN:       consomlotentier=0:                  NEXT(94$);
```

Routine C++

```
extern "C" void cdecl cstate  ()
{
SMREAL      DStockPF;
SMREAL      DStockMP;
SMREAL      Dconsomlotentier;
SMREAL      dStPF;
SMREAL      dStMP;
SMREAL      dconsomlotentier;
SMREAL      valuePF;
SMREAL      valueMP;
SMREAL      dBLOC;
SMREAL      dBLOC_Q;
SMREAL      dDem1;
```

```
SMREAL       dTauxP1;
SMREAL       dOrder;
SMREAL       dUm1;
SMREAL        dZx;
SMREAL        dZy;
SMREAL       dZp;
SMREAL        dQ;
SMREAL        dAOQ;
SMREAL       dAOQProd;
SMREAL       dDecisionReturnorC;
SMREAL       dp;
SMREAL       dCSatisfaction;
SMREAL       dAcceptOrRefuse;
SMREAL       ddebutcommande;

static SMINT  StPF     =1;
static SMINT  StMP     =2;
static SMINT  consomlotentier=3;
static SMINT  SpPF     =4;
static SMINT  SnPF     =5;
static SMINT  SpMP     =6;
static SMINT  SnMP     =7;
static SMINT  BLOC     =8;
static SMINT  Dem1     =9;
static SMINT  TauxP1   =10;
static SMINT  Order    =11;
static SMINT  Um1      =12;
static SMINT  Zx       =13;
static SMINT  Zy       =14;
static SMINT  Q        =15;
static SMINT  AOQ      =16;
static SMINT  DecisionReturnorC =17;
static SMINT  p=18;
static SMINT  CSatisfaction=19;
static SMINT  AcceptOrRefuse=20;
static SMINT  BLOC_Q=22;
static SMINT  Zp=23;
static SMINT  debutcommande=24;
static SMINT  AOQProd=26;
```

```
dBLOC = getss(&BLOC);
dBLOC_Q = getss(&BLOC_Q);
dDem1 = getss(&Dem1);
dTauxP1 = getss(&TauxP1);
dOrder = getss(&Order);
dUm1 = getss(&Um1);
dZx= getss(&Zx);
dZy= getss(&Zy);
dQ= getss(&Q);
dAOQ= getss(&AOQ);
dAOQProd=getss(&AOQProd);
dDecisionReturnorC=getss(&DecisionReturnorC);
dp=getss(&p);
dCSatisfaction=getss(&CSatisfaction);
dAcceptOrRefuse=getss(&AcceptOrRefuse);
dStPF  = getss(&StPF );
dStMP  = getss(&StMP );
dconsomlotentier=getss(&consomlotentier);
dZp= getss(&Zp);
ddebutcommande=getss(&debutcommande);

if (dStMP  < 0)
        { dTauxP1 =  0; }

if (dStMP == 0)
        { dTauxP1 =  0;}

if(dStPF  > dZy)
        {dTauxP1 = 0;}
else if (dStPF == dZy)
        {if (dStMP>0)
                {dTauxP1 = dDem1/(1-dAOQ);}
        else
                {dTauxP1 = 0;}
        }
else
        {if (dStMP>0)
                {dTauxP1 = dUm1;}
```

```
            else
                    {dTauxP1 = 0;}
            }

if          (dStMP  > dZx)
            {dOrder=0; setss(&Order, &dOrder);}
else
            {dOrder=1; setss(&Order, &dOrder);}

if (dBLOC==0)
            {dTauxP1=0;}

if (dBLOC_Q==0)
            {dTauxP1=0;}

DStockPF = (dTauxP1 * dBLOC*dBLOC_Q) - (dDem1/(1-dAOQ));
DStockMP = -dTauxP1 * dBLOC*dBLOC_Q;
Dconsomlotentier=   (dTauxP1 * dBLOC*dBLOC_Q*ddebutcommande);
setd(&StPF , &DStockPF);
setss(&TauxP1, &dTauxP1);
setd(&StMP , &DStockMP);
setd(&consomlotentier , &Dconsomlotentier);

if (dStPF  >= 0)
            {valuePF = dStPF ; setss(&SpPF , &valuePF);}
else
            {valuePF = 0; setss(&SpPF , &valuePF);}

 if (dStPF  < 0)
            {valuePF = -dStPF ; setss(&SnPF , &valuePF);}
else
            {valuePF = 0; setss(&SnPF , &valuePF);}

if (dStPF  > 0)
            {dCSatisfaction = 1 ;setss(&CSatisfaction , &dCSatisfaction);}
else
            {dCSatisfaction = 0 ;  setss(&CSatisfaction , &dCSatisfaction);}

if (dStMP  >= 0)
```

```
        {valueMP = dStMP ; setss(&SpMP , &valueMP);}
 else
        {valueMP = 0; setss(&SpMP , &valueMP);}

if (dStMP  < 0)
        {valueMP = -dStMP ; setss(&SnMP , &valueMP);}
else
        {valueMP = 0; setss(&SnMP , &valueMP);}

return;
}
```

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