UNIVERSITÉ DE LORRAINE

École doctorale IAEM Lorraine

Développement d'une stratégie de regroupement dynamique d'actions de maintenance pour un système de production géographiquement dispersé

THÈSE

présentée et soutenue publiquement le 10 Septembre 2019

pour l'obtention du

Doctorat de l'Université de Lorraine

(en Automatique, Traitement du Signal et des Images, Génie Informatique)

par

Ho Si Hung NGUYEN

Composition du jury

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Encadrants :	B. Iung	Professeur à l'Université de Lorraine
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Centre National de la Recherche Scientifique (CNRS)

Centre de Recherche en Automatique de Nancy (CRAN)— UMR 7039

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Abstract

In the recent years, the Geographically Dispersed Production System (GDPS) with a number of advantages such as saving the product delivered costs (closed to the clients), improving quality of services (short delivery time, high quality after-sales services) has been extensively developed by many manufacturing companies to ensure their competitiveness. In operation, the GPDS faces many challenges concerning standards, regulation, production management, and especially maintenance planning and optimization due to the geographical dispersion of production sites. However, few studies have been developed for maintenance strategies of GDPSs.

To face this challenge, the main objective of this thesis is to develop a dynamic grouping maintenance strategy for a GDPS with consideration of dependencies between at both component and site level (economic, geographical dependencies) and impacts of dynamic contexts (i.e. varying deterioration rate of components, change of maintenance routes, maintenance opportunities, etc.). In this strategy, maintenance routing and scheduling are jointly considered in a global model. The model aims at finding an optimal maintenance and routing plan. For this purpose, a cost structure and a dependence model jointly considering economic and geographical dependence are formulated. They are used as a basis for the development of the global model of maintenance routing and scheduling. In addition, to find a joint optimal maintenance and routing plan, advanced algorithms using jointly Genetic Algorithm and Branch and Bound are proposed. Finally, a numerical study is investigated to evaluate the performance and the advantage as well as limits of the proposed maintenance strategy.

Keywords: Geographically dispersed production systems, dynamic grouping maintenance, economic dependence, geographical dependence, maintenance routing, joint optimization, genetic algorithm.

Résumé

Ces dernières années, un nouveau type de système de production nommé système de production géographiquement dispersé (GDPS) est prôné par de nombreuses entreprises manufacturières internationales. Par cette vision « dispersée », il présente un certain nombre d'avantages tels que l'économie des coûts du produit livré (puisque proche des clients), l'amélioration de la qualité des services (délais de livraison courts, services après-vente de haute qualité) favorisant la pérennité et la compétitivité des entreprises dans un contexte de compétition mondiale. Cependant l'exploitation multi-sites d'un GPDS est confronté à de nombreux défis concernant les normes, les réglementations, la maîtrise des flux de production, et en particulier la planification et l'optimisation de la maintenance en raison de la dispersion géographique des sites de production. Sur ce dernier point et plus globalement la définition d'une stratégie de maintenance adaptée au GDPS, peu d'études ont été menées compte tenu de la jeunesse du sujet et de la complexité des GDPSs (ex. multi-sites, multi-composants).

Cette thèse se positionne donc sur ce sujet émergeant avec comme objectif de développer une stratégie de maintenance de regroupement dynamique pour un GDPS en tenant compte de dépendances à la fois aux niveaux composants et sites de production (dépendances économique et géographique) et des impacts des contextes dynamiques (à savoir, taux de détérioration variable des composants, modification des itinéraires de maintenance, possibilités de maintenance, etc.) auxquels il est soumis. Dans cette stratégie, les itinéraires de maintenance et l'ordonnancement sont considérés conjointement dans un modèle global. Le modèle vise à trouver un plan optimal de maintenance et de routage des ressources de maintenance. A cette fin, une structure de coûts et un modèle de dépendance qui prend en compte conjointement la dépendance économique et géographique sont formulés. Ils servent de base à l'élaboration du modèle global de planification et d'ordonnancement de la maintenance et du routage. De plus, pour la recherche de la solution optimale, des algorithmes d'optimisation basés sur l'algorithme génétique et l'algorithme Branch and Bound sont proposés. Enfin, une étude numérique est investiguée pour évaluer la performance, les avantages et aussi les limites de la stratégie proposée.

Mots-clés: Systèmes de production géographiquement dispersés (GDPS), Regroupement dynamique de maintenance, dépendances économique et géographique, itinéraire de maintenance, optimisation conjointe, algorithme génétique.

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Abbreviations

GDPS	Geographically dispersed production system
GDPSs	Geographically dispersed production systems
CPS	Centralized production system
CM	Corrective maintenance
PM	Preventive maintenance
O&M	Operation and maintenance
GMC	Global maintenance center
LMC	Local maintenance center
ABM	Age-based maintenance
CBM	Condition-based maintenance
MTTF	Mean time To failure
MTW	Maintenance time window
IMO	Individual maintenance optimization
SMaRS	Sequential maintenance routing and scheduling
JMaRS	Joint maintenance routing and scheduling
GA	Genetic algorithm
BAB	Branch and Bound
sBAB	Branch and Bound algorithm based on SMaRS approach
jBAB	Branch and Bound algorithm based on JMaRS approach
GAB	Advanced algorithm based on GA and BAB

Notations

n	The number of components of the system
n_s	The number of production sites of the system
$r_i(t)$	Failure rate of component i
L_{0j}	Travel distances from the global maintenance center (denoted by 0) to site j
L_{j0}	Travel distances from site j to the global maintenance center
AS	Average speed of transport vehicles
d_{mj}	Travel time from site m to site j
β_i, λ_i	Shape and scale parameters of the Weibull distribution of component i
ω_i	Preventive maintenance duration of component i
C_i^{sp}	Spare part cost of component i
C_i^{dt}	Downtime cost of component i
R_j^{dt}	Downtime cost rate at site j
$S_{i_j}^0$	Site-preparation cost of components i at site j
$S_{i_j}^{tr}$	Transportation cost from a global maintenance center to site j containing maintained component
R^{tr}	Transportation cost rate
C_i^{lb}	Labor cost for a preventive maintenance activity of component i
l_i	Skill level of a maintenance team required by component i
$R_i^{lb}(l_i)$	Labor cost rate of maintenance team corresponding to skill level l_i
Δh_i	Penalty cost of component i
x_i^*	Preventive maintenance cycle of component i
ϕ_i^*	Minimal long-term average maintenance cost of component i
t_i^e	Total operational time of component i elapsed from the last replacement
$\omega_{i_j^1}^{\Sigma}$	Cumulative downtime of component i at site j
$t_{i^z}^{'}$	Maintenance execution date of component i at the z^{th} times
t_{i^z}	The tentative maintenance date of a component i at the z^{th} times
Δt_{i^z}	The difference between maintenance execution date and tentative maintenance date of component i
T_{begin}	Beginning date of planning horizon

T_{end}	Ending date of planning horizon
G_k	The k_{th} group of maintenance activities in the planning horizon
$n_j^{G_k}$	The number of components located at site j of group G_k
t_{G_k}	Departure time at global maintenance center of group G_k
$t^*_{G_k}$	Optimal departure time at global maintenance center of group G_k
I_{G_k}	Maintenance itinerary that maintenance team follow to maintain components of group G_k
$I^*_{G_k}$	Optimal maintenance itinerary of group G_k
X	Matrix of routing plan
J_v	Visit order to sites associated with itinerary I_{G_k}
L_{G_k}	Total distance of a maintenance itinerary
$\Delta S_j^{G_k}$	Site-preparation cost saving at site j of the group G_k
$\Delta S^0_{G_k}$	Site-preparation cost saving of group G_k
ΔH_{G_k}	Penalty cost of group G_k
$\Delta C^{lb}_{G_k}$	Labor loss cost of group G_k
l_{G_k}	The highest skill level of maintenance team of group G_k
EPE_{G_k}	Economic profit of group G_k yielded from economic dependence
$\Delta S^{tr}_{G_k}(I_{G_k})$	Transportation cost saving thanks to geographical dependence
EPG_{G_k}	Economic profit of group G_k
$C^p_{G_k}$	Maintenance cost of group G_k
GS	Grouping structure of several groups
EPS	Economic profit of a grouping structure
X	Matrix of routing plan
J_v	Visit order of a maintenance team
$LBTC_q(I_{G_k})$	Lower bound of transportation cost of the routes containing node q
$L_{0\to q}$	Total travel distance of the planned part of the routes from a global maintenance center to node q
$\hat{L}_{q\to 0}$	Expected total travel distance of the unplanned part of the routes from node q to a global maintenance center
$LBPC_q(I_{G_k}, t_{G_k})$	Lower bound of penalty cost of the routes containing node q
$H_{0\to q}$	Total penalty cost related to the planned part of the routes from the maintenance center to node q
$\hat{H}_{q\to 0}$	Expected total penalty costs related to the unplanned part of the routes
$t'^{min}_{i_s}$	The smallest travel time if the maintenance team directly go to site m after leaving node q
$t'^{max}_{i_s}$	The longest travel time if the maintenance team directly go to site m after leaving node q

$h_i(t'_{i_s}, t_{i_s})$	The minimum penalty cost expected
LBC_q	Lower bound cost at node q