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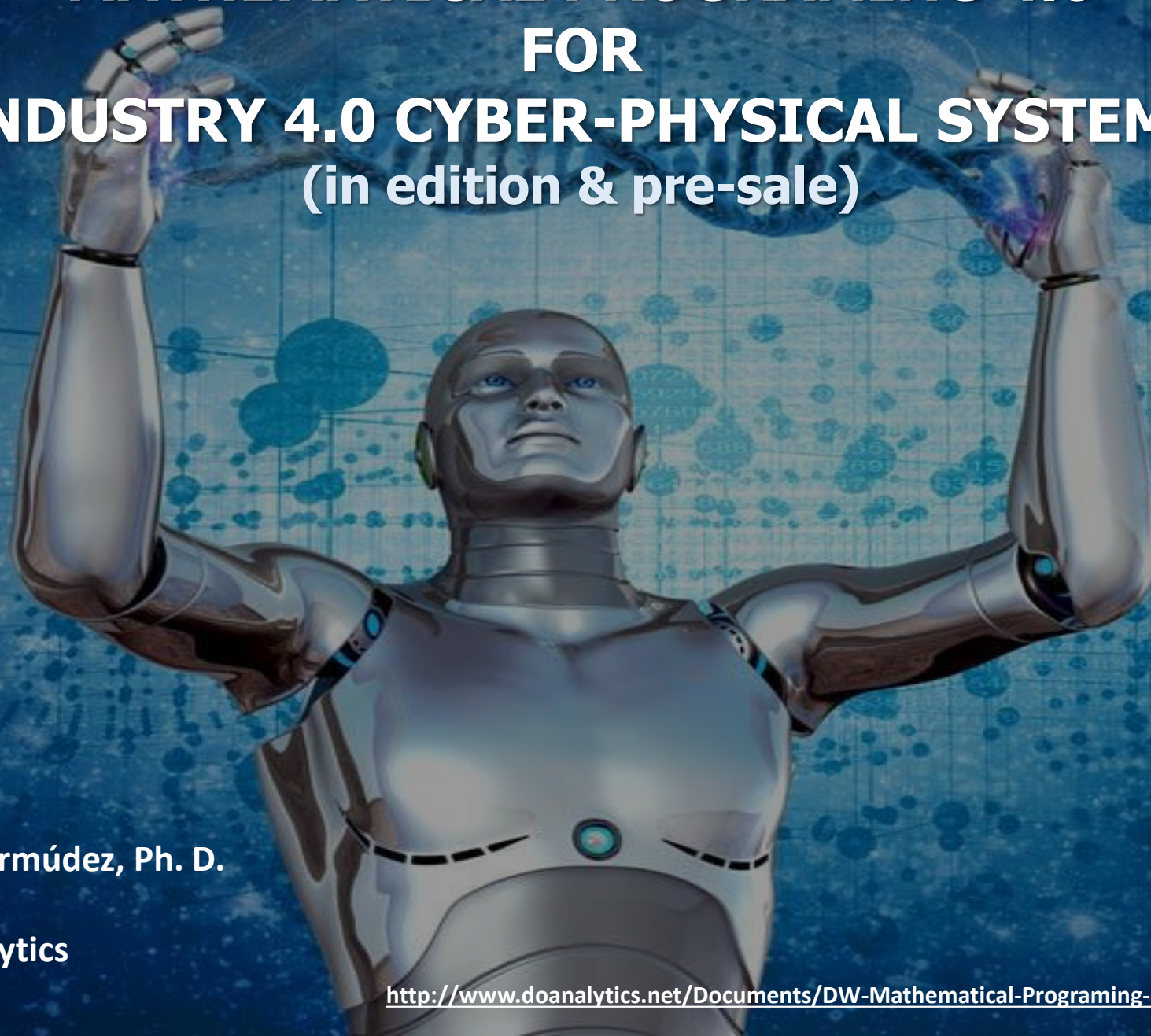


# BOOKS





# MATHEMATICAL PROGRAMING 4.0 FOR INDUSTRY 4.0 CYBER-PHYSICAL SYSTEMS (in edition & pre-sale)



**Author**  
**Eng. Jesus Velásquez-Bermúdez, Ph. D.**  
**Chief Scientist**  
**DecisionWare - DO Analytics**  
**Bogotá, Colombia**

<http://www.doanalytics.net/Documents/DW-Mathematical-Programing-Industry-Cyber-Physical-Systems.pdf>

## RESUME

The book is oriented to teach large-scale optimization courses, it presents the results of research and technological development carried out by the Eng. Jesús Maria Velásquez-Bermúdez, Ph. D., in 45 years of practice of the profession of Programmer Mathematician, starting from the year 1974; user of the theories of large-scale optimization since 1978, primarily the theory of J. F. Benders. The collection of written material has been funded entirely by DecisionWare (**DW**), company with about twenty-five years (since 1995) in the market of the Mathematical Programming. The book collects experience and knowledge generated in real-life projects carried out since 1978.

All this knowledge is preserved at the level of the state-of-the-art of Mathematical Programming and the Computer Science by the cognitive robots developed by **DW (OPTEX and SAAM)**, as the way to keep updated models that have worked and evolved since 1991. At the present time (beginning in 2017) the software is being updated in accordance with the new concepts of cyber-physical spaces that support the new revolution **Industry 4.0** that connect the industrial growth with the assessment of the knowledge and with the ability to produce new knowledge from: i) past knowledge and ii) new information which generates continually big data, giving origin to the **knowledge-intensive industries**.

The book is aimed at professionals, researchers, teachers, advanced students who are interested in generating new knowledge through mathematics methodologies (algorithms) for the markets of Advanced Analytics solutions (predictive and prescriptive). and the generation of software according to: i) parallel computing (multi-CPU with multi-cores, multi-GPUs, multi-tensor processors and quantic computers), and ii) distributed optimization (multiple agents operating simultaneously in real time).

The book is in phase of editing and review. All the material is already written (95%), but it is in the phase of integration. The "final" version of the book will be available in January 2020.

To acquire it, there are three possibilities:

1. Buy it at the stage of pre-sale, with discount
2. Buy it when it will be ready
3. Participate in the review process and receive 3 digital copies of the book.

<http://www.doanalytics.net/Documents/Mathematical-Programing-Future-4.0.pdf>

# MATHEMATICAL PROGRAMING 4.0 FOR INDUSTRY 4.0 CYBER-PHYSICAL SYSTEMS

## THEORY CHAPTERS & CLASSES

### PART I – MATHEMATICAL PROGRAMMING & CYBER-PHYSICAL SYSTEMS

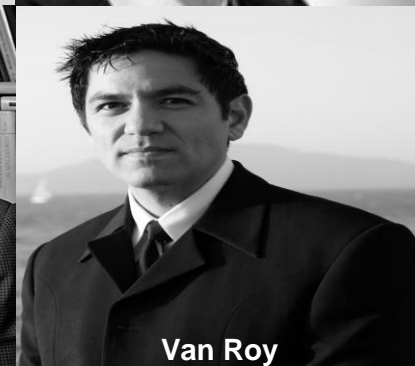
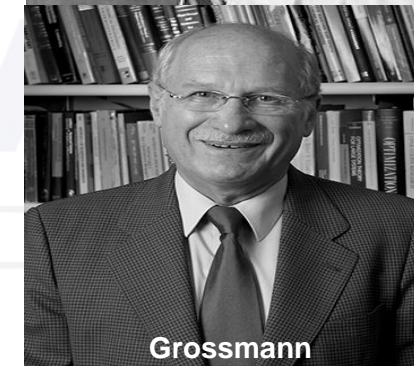
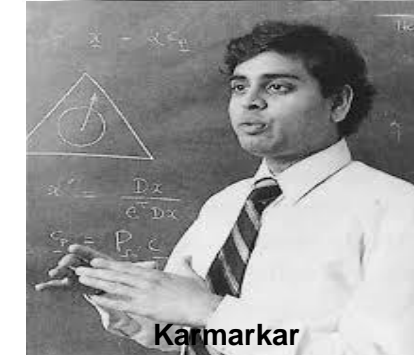
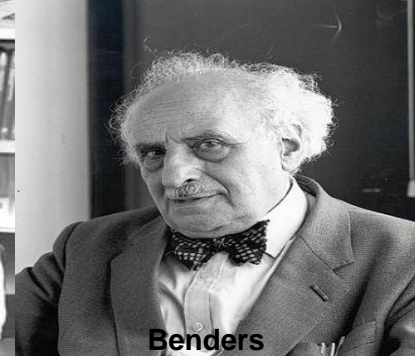
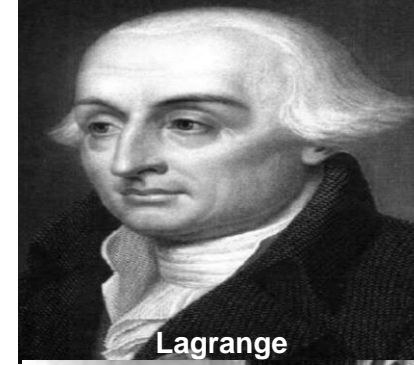
1. The Future: Mathematical Programming 4.0
2. Optimization Fundamentals
3. Economics: Fundamentals

### PART II – LARGE SCALE OPTIMIZATION METHODOLOGIES

1. Partitioning and Decomposition of Large-Scale Models
2. J. F. Benders: Theory, Variations and Enhancements
3. Stochastic Programing and Risk Management: Fundamentals
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5. GDDP/G-SDDP – Implementation and Electric Sector Applications
6. Lagrangean & Dantzig-Wolfe Relaxation & Decomposition
7. Stochastic & Dynamic Cross Decomposition.
8. Other Methodologies for Solving Complex Problems
  - Generalized Disjunctive Programming
  - Bilevel Optimization
  - Surrogate Programming. Primal-Dual Surrogate Algorithm
  - Mathematical Programming with Equilibrium Constraints (MPEC)
9. Asynchronous Parallel Optimization
10. Real-Time Distributed Optimization in Cyber-Physical Systems
11. Parallel Optimization as an Artificial Neural Network

### PART III – A NEW PARADIGM: MAKING REAL-LIFE DSS USING ARTIFICIAL INTELLIGENCE

1. Relational Databases and Mathematical Programing
2. Structured Mathematical Modeling
3. Tutorial: An example of Structured Mathematical Modeling
4. Optimization Expert Systems
5. Cognitive Robots: Smart Algorithms that Make Advanced Analytical Algorithms
6. OPTEX Expert Optimization System: A Cognitive Robot for Mathematical Programming
7. Machine Learning (Predictive Advanced Analytics) using Mathematical Programming



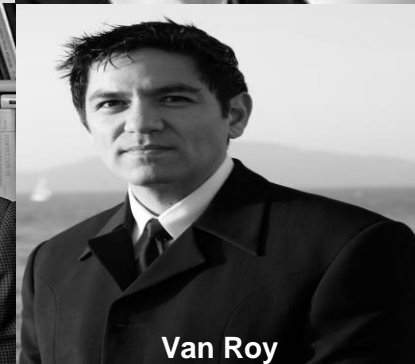
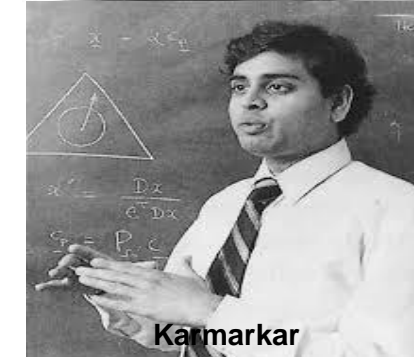
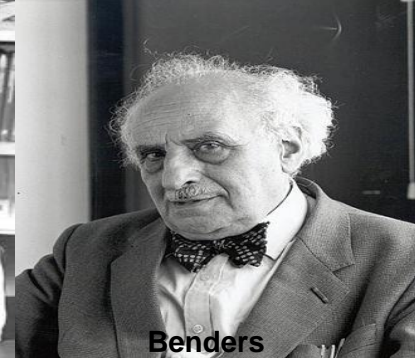
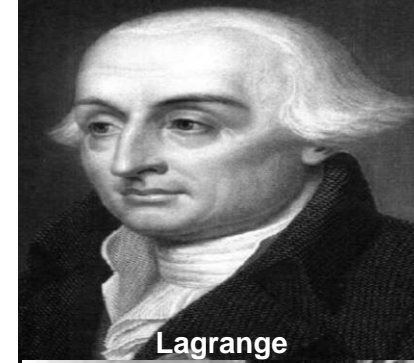
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3. Implementation of a Sales & Operations Planning for a Beer Supply Chain (Tutorial)
4. Integrated Financial & Industrial Operations Planning
5. Advanced Optimization in Bio-Industrials Supply Chains
6. Resilient Logistics Networks Design. Case: Distribution in the Beverage Industry
7. Scheduling Industrial Systems using Continuous Time Modeling
8. Multi-Echelon Dynamic Inventory using Stochastic Optimization
9. Blending in Industrial Processes. Case: Oil Production, Distribution and Marketing
10. Modeling Chemical Process. Case: Advanced Optimization in Cement Plants
11. Oil Pipelines Real-Time Optimization using Non-Convex Hull Approximations
12. Industrial Assets Maintenance Optimization

## PART V – REAL-LIFE APPLICATIONS USING MATHEMATICAL PROGRAMMING 4.0

1. A Decision Support System for Integrated Logistic Regional Planning (Vehicle Routing Problem) and Variations (Tutorial)
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3. Continuous Time-Tabling Optimization – Case: Port Logistics Operations
4. Discrete Time-Tabling Optimization – Case: University/College Scheduling
5. Human Resources Analytics
6. Modeling Energy Markets
7. Smart Grids Real Time Distributed Optimization
8. Predictive Advanced Analytics I: Market Share Modeling using Syndicated Databases
9. Predictive Advanced Analytics II: Fundamentals of Revenue Management



Springer Optimization and Its Applications

Jesús M. Velásquez-Bermúdez · Marzieh Khakifirooz · Mahdi Fathi *Editors*

## Large Scale Optimization in Supply Chains and Smart Manufacturing Theory and Applications

In this book, theory of large scale optimization is introduced with case studies of real-world problems and applications of structured mathematical modeling. The large scale optimization methods are represented by various theories such as Benders' decomposition, logic-based Benders' decomposition, Lagrangian relaxation, Dantzig–Wolfe decomposition, multi-tree decomposition, Van Roy' cross decomposition and parallel decomposition for mathematical programs such as mixed integer nonlinear programming and stochastic programming.

Case studies of large scale optimization in supply chain management, smart manufacturing, and Industry 4.0 are investigated with efficient implementation for real-time solutions. The features of case studies cover a wide range of fields including the Internet of things, advanced transportation systems, energy management, supply chain networks, service systems, operations management, risk management, and financial and sales management.

Instructors, graduate students, researchers, and practitioners, would benefit from this book finding the applicability of large scale optimization in asynchronous parallel optimization, real-time distributed network, and optimizing the knowledge-based expert system for convex and non-convex problems.

ISBN 978-3-030-22787-6



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Velásquez-Bermúdez  
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Large Scale Optimization in Supply  
Chains and Smart Manufacturing

Springer Optimization and Its Applications 149

Jesús M. Velásquez-Bermúdez  
Marzieh Khakifirooz  
Mahdi Fathi *Editors*

# Large Scale Optimization in Supply Chains and Smart Manufacturing

Theory and Applications

 Springer

<https://www.springer.com/gp/book/9783030227876#aboutBook>



# "A MATHEMATICAL PROGRAMING MODEL FOR REGIONAL PLANNING INCORPORATING ECONOMICS, LOGISTICS, INFRASTRUCTURE AND LAND USE"

Series on Computers and Operations Research Vol. 8

## Network Design and Optimization for Smart Cities



Konstantinos Gakis  
Panos Pardalos  
Editors

World Scientific

CHAPTER 1 OF THE BOOK

## "NETWORKS DESIGN AND OPTIMIZATION FOR SMART CITIES"

<http://www.worldscientific.com/worldscibooks/10.1142/10277>



# OPTIMIZACIÓN ESTOCÁSTICA DE PORTAFOLIOS DE INVERSIONES EN EXPLORACIÓN Y PRODUCCIÓN DE PETRÓLEO

LIBRO DE INVESTIGACIÓN

Noé Velázquez-Espinoza  
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Compiladores

**Gestión y finanzas**  
para GERENTES de PROYECTOS

Universidad  
**Externado**  
de Colombia

CHAPTER 1 OF THE BOOK

**"GESTIÓN Y FINANZAS PARA GERENTES DE PROYECTOS"**

<https://publicaciones.uexternado.edu.co/gestion-y-finanzas-para-gerentes-de-proyectos-finanzas.html>



# PAPERS



WATER RESOURCES RESEARCH, VOL. 35, NO. 7, PAGES 2269–2271, JULY 1999

## **Dual dynamic programming: A note on implementation**

Jesús Velásquez

DecisionWare, Ltda, Bogotá, Colombia

Pedro J. Restrepo

Optimal Decision Engineering Corporation, Boulder, Colorado

Rafael Campo

Bogotá, Colombia

**Abstract.** This paper presents a correction to the dual dynamic programming algorithm, which was initially published by *Pereira and Pinto* [1985]. We show that as originally published, the algorithm is correct only for two-stage problems. For problems with three or more stages, there is a term that must be added to the original equations of Pereira and Pinto in order to meet the Benders decomposition requirements. In addition to the mathematical derivation we include an updated description of the algorithm.



Annals of Operations Research 117, 21–31, 2002  
© 2002 Kluwer Academic Publishers. Manufactured in The Netherlands.

# GDDP: Generalized Dual Dynamic Programming Theory

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*DecisionWare Ltd., Avenida 15 No. 119A-43, Oficina 402, Edificio Los Hexágonos, Bogotá, Colombia*

**Abstract.** This document presents theoretical considerations about the solution of dynamic optimization problems integrating the Benders Theory, the Dynamic Programming approach and the concepts of Control Theory. The so called Generalized Dual Dynamic Programming Theory (GDDP) can be considered as an extension of two previous approaches known as Dual Dynamic Programming (DDP): The first is the work developed by Pereira and Pinto [3–5], which was revised by Velásquez and others [8,9]. The second is the work developed by Read and others [2,6,7].

**Keywords:** Benders decomposition, dynamic programming, dual dynamic programming, control theory

# TECHNO-ECONOMIC WHITE PAPERS & SLIDE PRESENTATIONS





# OPCHAIN-RPO

REGIONAL PLANNING OPTIMIZATION

INTEGRATED REGIONAL PLANNING

CITIES & REGIONS:  
SMART, ANALYTICAL & SUSTAINABLE

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Chapter 1 in the book "Networks Design and Optimization for Smart Cities"

[http://www.doanalytics.net/Documents/A\\_Mathematical\\_Programing\\_Model\\_for\\_Regional\\_Planning.pdf](http://www.doanalytics.net/Documents/A_Mathematical_Programing_Model_for_Regional_Planning.pdf)

### **A Decision Support System for Regional Planning of Large Regions using Mathematical Programming**

<http://www.doanalytics.net/Documents/A-Decision-Support-System-for-Regional-Planning-of-Large-Regions-Using-Mathematical-Programing.pdf>

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### **Planificación del Ordenamiento Territorial**

<http://www.doanalytics.net/Documents/DW-DT-038-OPCHAIN-RPO-POT-Planificacion-Ordenamiento-Territorial.pdf>

### **Modelamiento del Equilibrio Económico Regional**

<http://www.doanalytics.net/Documents/DW-DT-043-2012-Modelamiento-del-Equilibrio-Economico-Regional.pdf>

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### **Planificación Regional Integrada**

<http://www.doanalytics.net/Documents/OPCHAIN-RPO-Planificacion-Regional-Integrada.pdf>

## WEB-CONFERENCES

### **Planificación Regional Integrada: Ciudades y Regiones Analíticas, Inteligentes y Sostenibles**

[http://www.doanalytics.net/Videos/Planificacion\\_Regional\\_Integrada\\_Julio\\_2016\\_x264.rar](http://www.doanalytics.net/Videos/Planificacion_Regional_Integrada_Julio_2016_x264.rar)





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BLENDING & TRANSPORT OF MATERIALS  
WATER USE MANAGEMENT & OPTIMIZATION  
ENERGY EFFICIENCY: DESIGN & OPERATIONS  
INTEGRATED PLANNING OF MINING COMPLEXES  
SALES & OPERATIONS INTEGRATED OPTIMIZATION (S&OP)**



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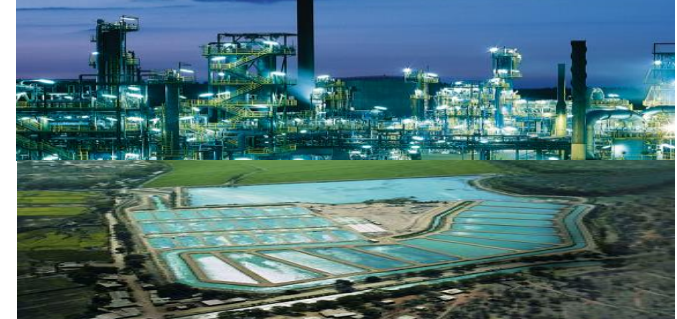
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# MATHEMATICAL OPTIMIZATION WHITE PAPERS & PRESENTATIONS



## BENDERS DECOMPOSITION USING UNIFIED CUTS

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**Chief Scientist, DO Analytics LLC**  
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### ABSTRACT

In 1995, Velasquez (1995, 2002) raises the theoretical analysis related with the solution of large optimization problems using the Partitioning Benders Theory (1962) applied to the decomposition of dynamic systems and/or stochastic optimization problems when they have a special structure, which lies in the area of dual feasibility of the subproblems that is equal for all of them; in such a case, solving a single sub-problem it is possible to generate Benders cuts for all sub-problems. This analysis was not followed by the publication of the experimental results of this methodology. This article revisits Velasquez studies complementing them with the analysis of the implementation and the presentation of experimental results using models oriented to the electric sector. The cuts generated using the original ideas are defined as **Unified Benders Cuts Theory (UBC)**. The application of **UBC** speeds up the solution time and make possible the solution of a large-scale optimization problem as a coordinated sum of very simple problems.

Key words: Benders Decomposition, Unified Benders Cuts, Electric Sector Optimization

# **GDDP: GENERALIZED DUAL DYNAMIC PROGRAMMING. THEORY & ELECTRIC SECTOR APPLICATIONS**

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**Chief Scientist, DecisionWare - DO Analytics LLC**  
[jesus.velasquez@decisionware.net](mailto:jesus.velasquez@decisionware.net)

## **ABSTRACT**

This technical paper presents theoretical considerations about the solution of dynamic optimization problems integrating the Benders Theory, the Dynamic Programming approach and the concepts of Control Theory. The so called Generalized Dual Dynamic Programming Theory (**GDDP**) was initially published by Velasquez (2002); it can be considered as an extension of previous approach known as Dual Dynamic Programming (**DDP**) (Pereira and Pinto, 1985, 1991) which is a variation of Nested Benders (**NB**) methodologies (Murphy 2013). From the point of view of Dynamic Programming (**DP**), the main difference between the traditional Nested Benders (**NB**) methodologies and **GDDP** is that the conceptual formulation **NB** considers all the variables of the problem as state variables, while the **GDDP** makes a distinction between state variables and control variables. This distinction permits a more detailed algorithm in which the sub-problems are smaller than in the **NB**. The **NB** has been widely used in the economic dispatch of power systems. The main limitation of **NB**, including **DDP**, is that it only solves linear models.

The paper of Velasquez (2002) was not followed by the publication of the experimental results of **GDDP**. This article revisits Velasquez studies extending the theory, analyzing the implementation and presenting experimental results, using models oriented to the electric sector

# Mixed Non-Linear Economic Dispatch Using G-SDDP with Unified Benders Cuts

Jesus Velásquez-Bermúdez, Eng. D.  
Chief Scientist, DecisionWare - DO Analytics LLC  
[jesus.velasquez@decisionware.net](mailto:jesus.velasquez@decisionware.net)

Submitted to 2018 IEEE PES Transmission & Distribution Conference

*Abstract* - This paper presents the computational implementation of the Generalized Dual Dynamic Programming (**GDDP**), whose theory was developed by J. M. Velasquez (2002), and its use in electric sector applications. The **GDDP** is based on the chained application Benders Partition Theory (**BT**) (Benders, 1962) applied to the solution of multi-period dynamic problems using the Dynamic Programming (**DP**) and the Discrete Control Theory (**DCT**) approaches. In the implementation is used the concept of Unified Benders Cuts (**UBC**) (Velasquez, 2018a). Applications to the Economic Dispatch problem are presented using Generalized Stochastic Dual Dynamic Programming (**G-SDDP**), the stochastic version of **GDDP**.

# G-SDDP AND RISK MANAGEMENT: THEORY & SUPPLY CHAINS DESIGN

Jesus Velásquez-Bermúdez, Eng. D.  
Chief Scientist, DecisionWare - DO Analytics LLC  
[jesus.velasquez@decisionware.net](mailto:jesus.velasquez@decisionware.net)

## ABSTRACT

This technical paper presents theoretical considerations about the use of Generalized Stochastic Dual Dynamic Programming Theory (**G-SDDP**) (Velasquez, 2018c) applied to the problem of supply chain design including risk management constraints, oriented to obtain robust and resilient supply networks. **G-SDDP** integrates Benders Theory (**BT**) and Dynamic Programming (**DP**) approach to solve large scale stochastic optimization problems. From **DP** the **GDDP** takes the concepts of state and control variables which facilitates the modeling of dynamic systems.

Traditionally the optimal design of supply chains under uncertainty has been solved using Stochastic Nested Benders (**SNB**) methodologies that considers all the variables of the problem as state variables. The **GDDP** permits a more detailed algorithm in which the sub-problems are smaller than in the **SNB**. The **GDDP** solves large-scale optimization problems as a coordinated sum of very simple problems; it entails a significant increase in speed up to solve problems and in the dimensionality of these.

The risk management is introduced in **G-SDDP** by Conditional Value-at-Risk (**CVaR**) constraint following the approach develop by Rockafellar and Uryasev (2000).

# G-SDDP AND RISK MANAGEMENT: THEORY & SUPPLY CHAINS DESIGN

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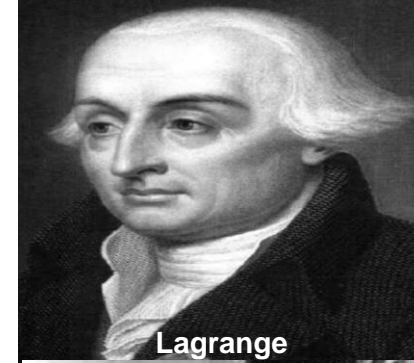
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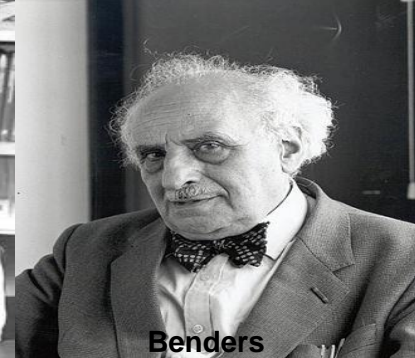
Lagrange



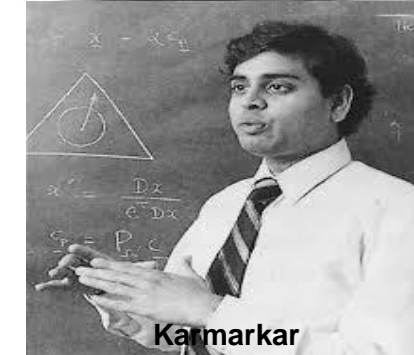
Dantzig



Bellman



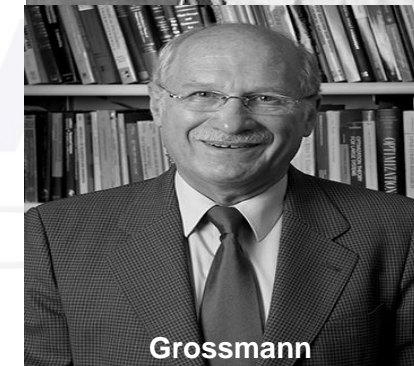
Benders



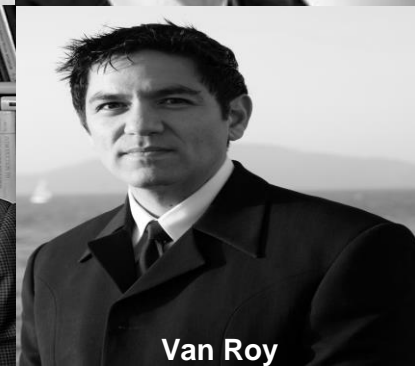
Karmarkar



Bixby



Grossmann



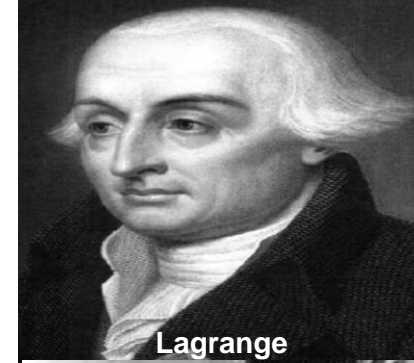
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## Stochastic & Dynamic Benders Theory – Electricity Sector Applications

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## Dynamic Machine Learning using a Multi-State Kalman Filter

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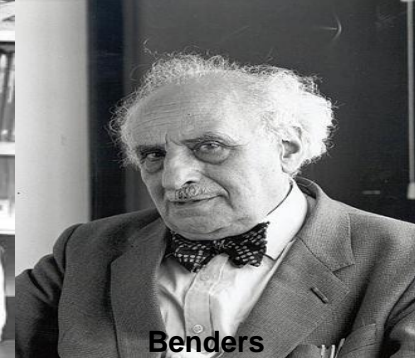
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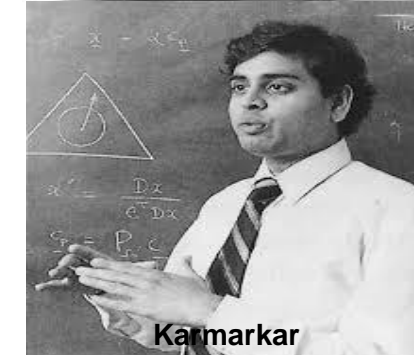
Dantzig



Bellman



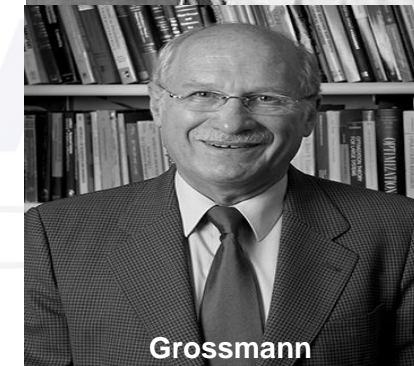
Benders



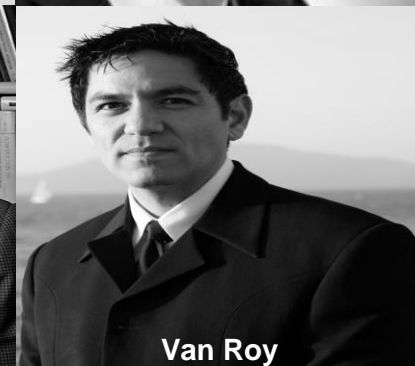
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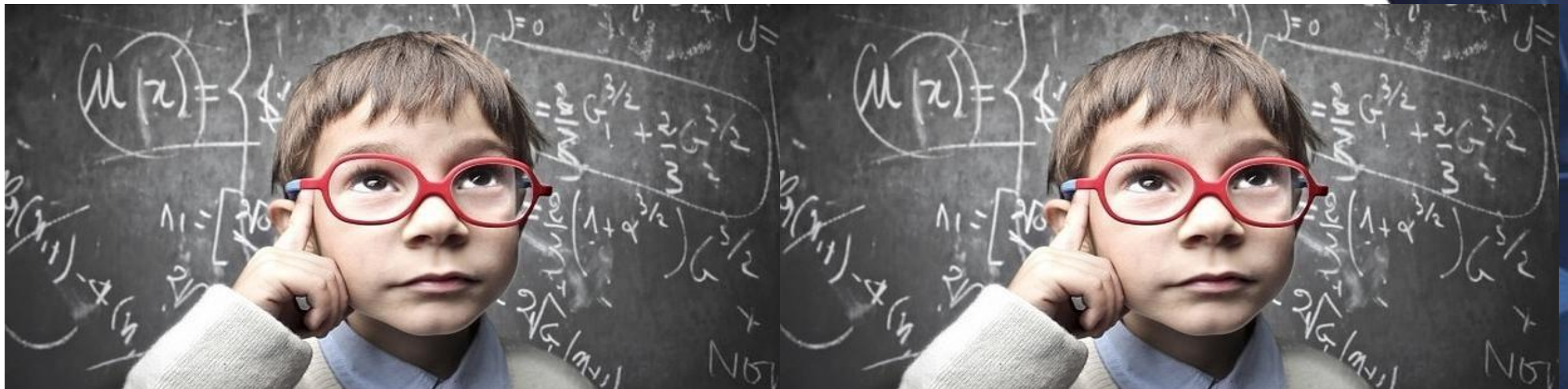
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**MACHINE LEARNING - ARTIFICIAL NEURAL NETS  
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# **ANALÍTICA AVANZADA & OPTIMIZACIÓN APLICADAS AL SECTOR ELÉCTRICO**

**OBJETIVO:**

**ENSEÑAR A LOS PARTICIPANTES LAS METODOLOGÍAS DE MODELAJE MATEMÁTICO Y LA IMPLEMENTACIÓN DE LOS ALGORITMOS PROPIOS DE LA ANALÍTICA AVANZADA NECESARIOS PARA OPTIMIZAR LA TOMA DE DECISIONES EN EL SECTOR ELÉCTRICO**

**BASADO EN METODOLOGÍAS MATEMÁTICAS Y TECNOLOGÍAS UTILIZADAS EN CASOS REALES  
INCLUYE LICENCIAS TEMPORALES DE GAMS Y DE OPTEX  
(VIGENCIA AÑO 2019)**

**TARIFA REDUCIDA PARA ESTUDIANTES**



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**OPTIMIZACIÓN APLICADA A  
CADENAS DE PRODUCTIVAS INDUSTRIALES  
SUPPLY CHAIN OPTIMIZATION**

**ANALÍTICA AVANZADA PREDICTIVA  
APLICACIONES INDUSTRIALES  
DEMAND CHAIN OPTIMIZATION**

**ANALÍTICA AVANZADA & OPTIMIZACIÓN UTILIZANDO**



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**MATHEMATICAL PROGRAMMING 4.0  
S&OP SALES & OPERATIONS PLANNING**

**PLANIFICACIÓN DE LA SIEMBRA  
OPTIMIZACIÓN DE INVENTARIOS  
GESTIÓN ÓPTIMA DE LA ENERGÍA  
OPTIMIZACIÓN DEL ESLABÓN INDUSTRIAL  
MODELAMIENTO AVANZADO DE LA DEMANDA  
PROYECCIÓN DE VARIABLES HIDRO CLIMÁTICAS  
PLANIFICACIÓN/PROGRAMACIÓN DE LA COSECHA  
PLANES MAESTRO DE SUMINISTRO DE ALIMENTOS  
OPTIMIZACIÓN DEL ESLABÓN PRIMARIO (GRANJAS)  
PLANIFICACIÓN INTEGRADA DEL SECTOR AGROINDUSTRIAL  
PLANIFICACIÓN/PROGRAMACIÓN DEL CORTE DE ANIMALES  
PRODUCCIÓN Y DISTRIBUCIÓN DE NUTRIENTES CONCENTRADOS  
GESTIÓN DE RIESGOS FINANCIEROS EN CADENAS AGROINDUSTRIALES  
AVAILABLE-TO-PROMISE (ATP): ATENCIÓN COMPROMISOS COMERCIALES  
SINCRONIZACIÓN ÓPTIMA DEL ESLABÓN PRIMARIO CON EL ESLABÓN INDUSTRIAL**



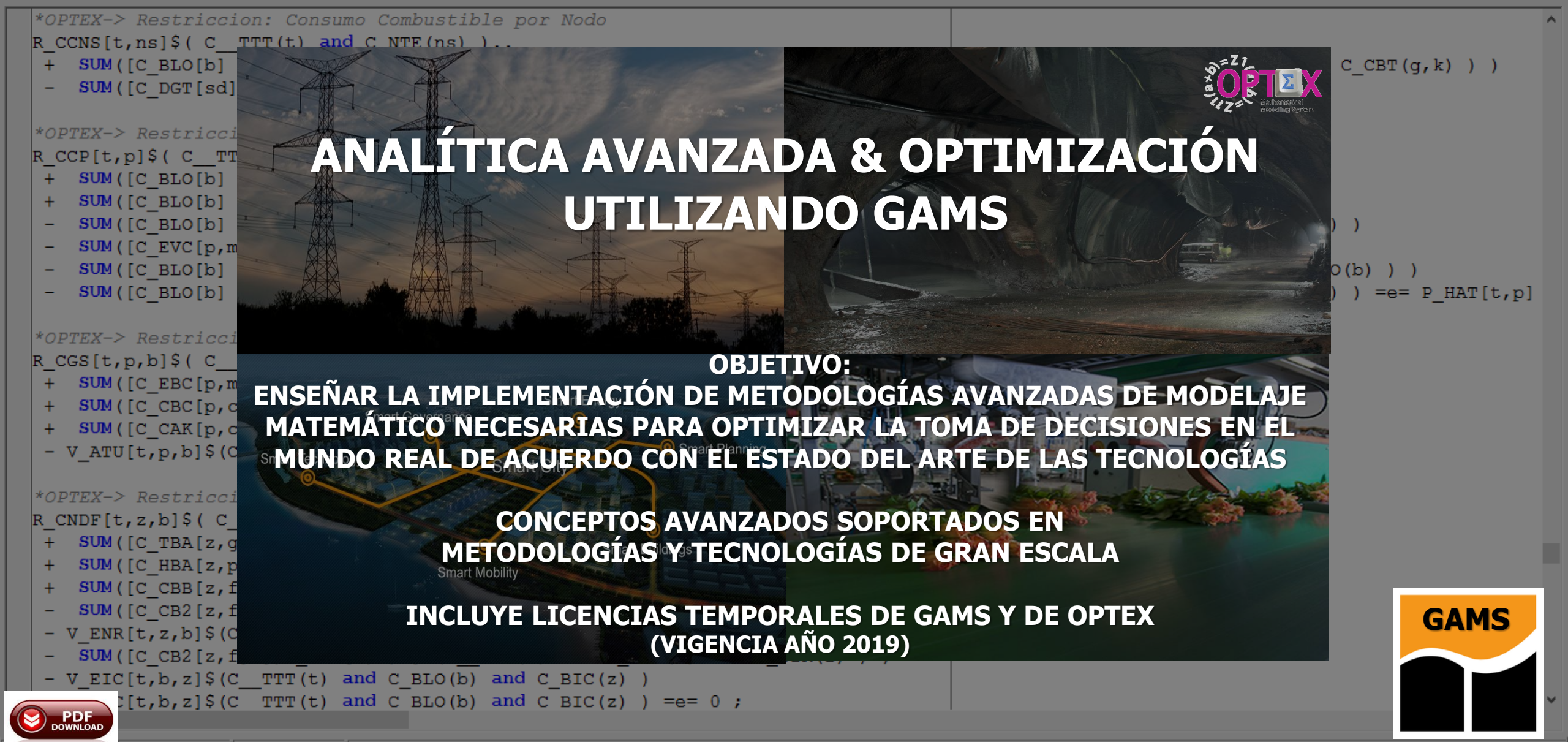
## ANALÍTICA AVANZADA & OPTIMIZACIÓN UTILIZANDO GAMS



**OBJETIVO:**  
**ENSEÑAR LA IMPLEMENTACIÓN DE METODOLOGÍAS AVANZADAS DE MODELAJE MATEMÁTICO NECESARIAS PARA OPTIMIZAR LA TOMA DE DECISIONES EN EL MUNDO REAL DE ACUERDO CON EL ESTADO DEL ARTE DE LAS TECNOLOGÍAS**

**CONCEPTOS AVANZADOS SOPORTADOS EN METODOLOGÍAS Y TECNOLOGÍAS DE GRAN ESCALA**

**INCLUYE LICENCIAS TEMPORALES DE GAMS Y DE OPTeX (VIGENCIA AÑO 2019)**



# **J. F. BENDERS THEORY & APPLICATIONS**

## **PAST, PRESENT & FUTURE OF LARGE-SCALE OPTIMIZATION**

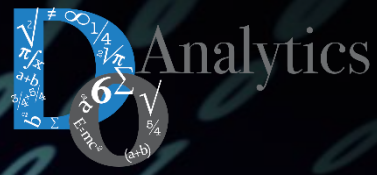
- Large Scale Optimization Fundamentals
- Benders Theory
  - Partitioning & Decomposition Theory
  - Duality Theory
  - Economic Interpretation
- Benders Extensions
  - Extended Benders Decomposition (Non-Linear Subproblems)
  - Mixed Integer Subproblems
  - Logic Based Benders Decomposition
  - Multilevel Benders Partitioning
- Solving MIP/MINLP Coordinators
  - Two Stage Benders Coordinators
  - MIP Inexact Solutions
- Accelerating Benders Theory
  - Cuts: Standard, Decoupled, Unified, Inexact, Subrogate
  - Strong Cuts (Pareto Optimal)
  - Managing Cuts
- Enhancing Mathematical Formulation
- Lagrangean Relaxation
- Cross Decomposition: Benders Theory & Lagrangean Relaxation
- Dynamic Programming & Discrete Optimal Control
- Dynamic Benders Theory
  - Nested Benders & Dual Dynamic Programming (DDP)
  - Generalized Dual Dynamic Programming (GDDP)
- Stochastic Optimization & Risk Management
  - Benders Methodologies (Nested Benders, SDDP, G-SDDP, SDDiP)
  - Lagrangean Relaxation
  - Efficient Sampling Techniques
  - Risk Management (VaR, CVaR, ... )
  - Jensen Inequalities
- Especial Methodologies: Large Scale Machine Learning, Disjunctive Programming, Equilibrium
- Optimization Technologies:
  - CPLEX, LINGO, OPTEX, AMPL, GAMS, MOSEL, ...
  - Source Codes in GAMS via OPTEX-MMS
- Future of Optimization
  - Asynchronous Parallel Optimization
  - Continuous & Distributed Optimization
  - Optimization Expert Systems & Robots

**OPTIMIZATION IS EVERYWHERE**

**APPLICATIONS: ENERGY (OIL, ELECTRICITY & GAS), TRANSPORT, FINANCE, REGIONAL PLANNING, DISASTER MANAGEMENT, SUPPLY/DEMAND CHAIN, CHEMICAL, MINES & METALLURGICAL, HEALTH**

# RESEARCH & DEVELOPMENT (R&D) PROJECTS





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G-SDDP  
GENERALIZED  
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**"the computer-based mathematical modeling is  
the greatest invention of all times"**

**Herbert Simon**

**Premio Nobel en Economía (1978)**

**"for his pioneering research into the decision-making process within economic organizations"**





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# OPCHAIN

OPTIMIZING THE VALUE CHAIN

## ADVANCED ANALYTICAL & OPTIMIZATION MODELS

### EXPERIENCE & MAIN PROJECTS

productivity



# ADVANCED ANALYTICAL & OPTIMIZATION MODELS

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