IHE Report

System Dynamics Modeling: A Decision Support Tool to Improve Care for Hip & Knee Osteoarthritis

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System Dynamics Modeling: A Decision Support Tool to Improve Care for Hip & Knee Osteoarthritis

Prepared by:

Deborah Marshall (Principal Investigator), *Associate Professor and Canada Research Chair, Health Services and Systems Research, Community Health Sciences, University of Calgary*

Paul Rogers, *Associate Professor, Schulich School of Engineering, University of Calgary*

Thomas Rohleder, *Senior Associate Consultant, The Division of Health Care Policy and Research, Mayo Clinic, Minnesota*

Sonia Vanderby, *Post-Doctoral Fellow, University of Toronto*

Other Contributors:

Anderson Chuck, Health Economist & Manager, Decision Analytic Modeling Unit, Institute of Health Economics and Adjunct Assistant Professor, Department of Anesthesiology and Pain Medicine, University of Alberta

David Cooke, Adjunct Associate Professor, Haskayne School of Business, University of Calgary

Peter Faris, Director of Analysis, Alberta Bone and Joint Health Institute

Cy Frank, Executive Director, Alberta Bone and Joint Health Institute

Ken Fyie, Student, Department of Community Health Sciences, University of Calgary

Egon Jonsson, Executive Director and CEO, Institute of Health Economics

Stacy Kozak, Advisor, Design and Information Sharing, Alberta Bone and Joint Health Institute

Robert Lee, Research Assistant Professor, University of New Mexico

Tom Noseworthy, Department Head, Department of Community Health Sciences, University of Calgary

Carla Rodrigues, Post-Doctoral Fellow, Department of Community Health Sciences, University of Calgary

Judy Seidel, Senior Epidemiologist, Alberta Health Services, University of Calgary

Tracy Wasylak, Vice-President, South Health Campus & Co-Chair, Bone & Joint Clinical Network, Calgary Health Region

Sherry Weaver, PhD Student, Haskayne Business School, University of Calgary

Stephen Weiss, Chief Operating Officer, Alberta Bone and Joint Health Institute

Jennifer Yelland, Research Associate, University of Calgary

TABLE OF CONTENTS

Foreword

Since the 1950 system dynamics (SD) modeling has been used in industry and in corporate decision making, primarily to better understand industrial processes. More recently, this methodology has been used in the public and private sectors for health policy analysis. SD modeling presents an opportunity to simulate the impact of different health policy options permitting service planners and policy-makers to choose the option that best meets anticipated needs. SD can be a powerful tool for informing strategic decision-making leading to increased agility in planning, organizing and coordinating health care services.

This booklet provides an overview of the SD approach and its potential applications in improving access to health services and quality of care. The specific application addressed here is the improvement of care of patients with hip and knee osteoarthritis (OA), as this is a pressing issue in Canada today. The specific health system and population addressed here is the Province of Alberta. Although initially targeted towards a specific condition and system, we expect that the approach will be generalizable to the improvement of the system of care for patients with other health conditions.

As an initial step, a select group of health services researchers and policy-makers met in Banff, Alberta in May 2009 for a workshop "Beyond Markov - how do we best model the impact of health interventions?" - to discuss modeling as a decision-support tool for planning the delivery of high quality care to Albertans with hip and knee OA. Over the course of a two-day workshop, they examined a preliminary SD model, debated its merits, feasibility, and considered its scope and boundaries. SD can be a powerful tool for informing strategic decision-making in planning, organizing and coordinating health care services.

Dr. Tom Feasby:
Dean of the Faculty of Medicine,
University of Calgary

Dr. Cyril Frank:
Executive Director, Alberta Bone and Joint Health Institute

Dr. Egon Jonsson:
Executive Director and CEO,
Institute of Health Economics,
Professor, University of Alberta,
University of Calgary

Dr. Tom Noseworthy:
Department Head, Department of Community Health Sciences,
Univeristy of Calgary

Tracy Wasylak:
Vice-President, South Health Campus & Co-Chair,
Bone & Joint Clinical Network

Executive summary

Systems thinking has been widely used to develop strategies for responding to emerging needs and priorities within complex and dynamic systems, and system dynamics (SD) modeling has proven a highly effective enabler of systems thinking. While SD modeling has gained popularity as a tool in business and other social systems, its potential as a tool for making strategic decisions as new needs and priorities emerge in the public health care system has not been fully realized. The system for hip and knee OA care was selected as a starting point for SD modeling in light of its complexity and dynamic nature, the prevalence of the disease, demographic health trends, and problems with service delivery.

OA affects one in 10, [1;2] or approximately 278,000 Albertans. The most common form of arthritis, it usually attacks the weight-bearing joints, striking most often in the hips and knees, and is responsible for most hip and knee replacement surgeries. OA occurs when cartilage, a tough elastic substance that allows the bones to move smoothly, deteriorates leaving the bones to grind against each other. This causes the bones to degenerate, resulting in pain and stiffness.[3] As the condition worsens, loss of mobility and, in extreme cases, dysfunction and deformity can occur.

The prevalence of OA increases with age and the risk of developing OA increases with excess body weight. Alberta's population is aging, living longer, and one-quarter of Albertans are obese.[4] The 55-and-older population in Alberta is forecast to increase by 75% from 2006 to 2020, and by 127% from 2006 to 2035.[4] These demographic factors suggest the incidence of OA will increase in Alberta's population. Approximately 7,900 hip and knee replacements were expected to be performed in Alberta in 2009. Annual need for these surgeries is expected to reach almost 11,700 by 2016 and exceed 13,300 by 2020 in response to population growth and aging alone. On average, it costs approximately $12,378 to replace a hip or a knee in Alberta.[5;6]

In addition, patients experience long waiting periods for access to specialist consultation and surgery. While hip and knee replacements are among the priority areas for reduced wait times, these patients continue to experience some of the longest waits compared with patients in the other priority areas. Personal and public costs escalate as patients consume drugs and system resources to manage their pain while waiting, and expected outcomes may worsen with long waiting times.

Using the available data and interviews with experts, researchers designed a preliminary SD model structure and organized a workshop involving international experts in SD modeling, health services researchers, analysts and policy-makers from Alberta to discuss its merits. The workshop was

called “Beyond Markov - how do we best model the impact of health care interventions”. Workshop participants concluded that a SD model for hip and knee OA care in Alberta would be feasible to build and could serve as an informative and practical decision-support tool for service planners and policy-makers. They agreed that the dynamic and complex nature of care together with problems in service delivery, increasing prevalence of OA and escalating health care costs make a SD model both appropriate and advantageous in Alberta.

The SD model will be capable of simulating changes in resources, services, service delivery mechanisms and policies to reveal their impact on the overall system of OA care or on particular areas of the system. In this way, it will be a powerful decision-support tool as decision-makers face emerging developments in the complex and dynamic environment of hip and knee OA care, such as increasing wait times, growing patient backlogs and budget restrictions, and the inevitable tradeoffs that are required between services and resources to respond appropriately to these challenges.

The impact of health policy changes simulated by the SD model will be measured using the six dimensions of quality identified by Alberta’s Health Quality Network – accessibility, acceptability, appropriateness, safety, effectiveness and efficiency. These dimensions encompass both system performance outcomes and patient outcomes.

Health services researchers, together with international experts in SD modeling, and support from the Alberta Bone and Joint Health Institute (ABJHI) will advance the SD model from the preliminary stage through full development of a comprehensive decision-support tool, seeking guidance from clinicians and health policy experts on its scope and relevance. They will design, test, and apply a SD model for the delivery of care to patients who have hip or knee OA as a decision-support tool in planning, organizing and coordinating public health care. Once its power and versatility are demonstrated in hip and knee OA in Alberta, the model may be extended and applied to other provinces in Canada where care paths may differ. Further, this systems modeling approach could be applied to other areas of medicine.

CHAPTER 1:

An overview of hip and knee osteoarthritis (OA) – risk factors, burden of illness and management

Osteoarthritis (OA) is a degenerative joint disease that is the most common form of arthritis. OA occurs when the joint cartilage and adjacent bone degenerate, causing pain, stiffness, loss of mobility and in extreme cases, loss of function and deformity.[3;5] The disease usually occurs in weight-bearing joints and the hands, striking most often in the hips and knees.

Who is affected by OA? What are the risk factors for hip and knee OA?

Four million Canadians were affected by arthritis in 2005 resulting in an estimated cost of $4.4 billion per year.[7] Approximately one in 10 people develop OA over their lifetime,[2;8] or 278,000 Albertans. It has been estimated that 70% of Albertans have OA by the age of 70.[9]

OA is most common among the elderly, however it can occur at any age. The 2000/2001 Statistics Canada Canadian Community Health Survey (CCHS) reported increasing arthritis prevalence with advancing age in both men and women – the prevalence of OA increases from 10% among those 35 years and older to 40% among those aged 65 years and older.[10] Of those who suffer from OA, 80% have limitation of movement and 25% are unable to perform major daily life activities.[11]

Females are more likely to be diagnosed with OA than males. Hip and knee OA has a higher prevalence and incidence in women than in men,[12;13] with women making up almost two-thirds of people with arthritis (21.4% versus 13.2%).[13] While men have significantly lower risk of OA in the knee and hip than women, the risk of OA in other joints is similar for men and women.[13]

Other risk factors for developing OA include: excess weight, congenital abnormalities, previous traumas, occupational factors (hip), and physical activity (knee).[14-24] Prospective data on women suggest the risk of developing OA in the knee increases by approximately 15% for each additional kg/m^2 of body mass index (BMI) above 27, which is the mid-range of overweight.[20] The role of weight and BMI in the development of OA in the hip is more controversial.[14;25;26] Liu et al. estimated 27% of hip replacements and 69% of knee replacements performed in 2007 on middle-aged women in the United Kingdom were attributable to obesity.[27]

How does OA progress?

The natural disease history of OA is poorly understood. Its etiology is complex and includes changes in bone, cartilage, adjacent soft tissue, and their effects on each other.[25] OA is chronic and progressive, it can manifest with or without symptoms.[28;29] Intense wear and degeneration of joint tissue may cause stiffness of the joint, pain and disability.

Longitudinal studies found limited evidence that functional status and pain change during the first three years of follow-up after diagnosis with hip and knee OA, but thereafter there is a lasting period of decline.[29]

What are the current treatments for OA?

There is currently no cure for OA. However, different treatments help to relieve pain, stiffness and maintain or improve physical function. Most people with OA receive pharmacological or non-pharmacological treatment or a combination of these treatment types. Pharmacological treatment often involves analgesics alone or together with non-steroidal anti-inflammatory drugs. These are commonly combined with non-pharmacological treatment consisting of patient education and physical and occupational therapy.[30] Non-surgical interventions, such as injectable compounds, viscosupplements, and physiotherapy are treatment options for patients who do not respond to pharmacological and non-pharmacological treatments.[30]

The only effective intervention for end-stage OA with severe joint damage is reconstruction or replacement of the joint with a prosthesis. Surgery is required in approximately 10% of people who have OA in hips or knees.[31] It is the treatment of last resort, and even when recommended, some patients refuse joint replacement due to fear of the procedure. Nonetheless, hip and knee replacements are among the most successful surgical procedures in orthopaedics, and are a proven method of alleviating pain and restoring function, mobility and quality of life.[32] Their success rates are as high as 95% after 10 years and 90% after 20 years.[33] Despite the small percentage of people with OA who require surgery, hip and knee replacements are a large draw on public health care budgets as the implants and procedures are expensive.

While highly successful, hip and knee replacements, like any invasive surgical procedure, present a risk of adverse events and complications. A complication may require revision surgery on the operated joint. Prostheses may wear out over time and need to be replaced. According to the Canadian Joint Replacement Registry (CJRR)[34], 86% of all hip replacements in Canada in 2006-2007 were primary joint surgeries and 14% were revisions. Among knee replacements in the same period, 94% were primary joint surgeries while 6% were revisions.[34] Previous studies reported a cumulative incidence of 0.8% revision one year after surgery and 2.0% revision after surgery.[35]

What is the burden of illness of severe hip and knee OA?

Canada's demographic changes– aging, living longer, and growing more obese – indicate its population will require increased care for OA, creating a level of demand that the country's already overburdened health care system will be challenged to meet.[4;8] The CJRR reported 37,943 hospitalizations for knee replacement and 24,253 hospitalizations for hip replacement in Canada in 2006-2007, excluding Quebec. This represented an increase of 9% for knee replacement hospitalizations and 6% for hip replacement hospitalizations over the past year. The increase in hospitalizations over a 10-year period to 2006-2007 was 140% for knee replacement and 101% for hip replacement.[4]

In 2008, there were more than 7,300 hip and knee replacement surgeries of all types in Alberta. On average, it costs approximately $12,378 to replace a hip or knee in Alberta.[9] Given all other health care costs staying constant, this higher projected demand for hip and knee replacements will potentially drive up overall public health care expenses with a significant impact on the Alberta public health care budget, or lack of investment causing significant impacts to waiting time.

The 55-and-older population in Alberta is forecast to increase by 75% from 2006 to 2020, and by 127% from 2006 to 2035.[11] A demographic change of this magnitude will have significant implications for the public health system, as aging is a well established risk factor for both hip and knee OA.[12] By 2016, the Alberta Bone and Joint Health Institute estimates that approximately 11,700 Albertans will need a hip or knee replacement and the need will exceed 13,300 in 2020.[5] The underlying rate of hip and knee replacements used for this projection is likely understated, as patient willingness to have surgery is also expected to increase as joint replacement technology improves and the public becomes more aware of its benefits and success rate. New technology is making replacement an option for younger patients with OA while growing rates of obesity in the young signal an increasing need for replacement. This has implications for eventual revision surgery, as the lifetime of prosthesis is not unlimited. Kurtz, et al.[36] reported a mean revision burden of 17.5% for total hip replacements and 8.2% for total knee replacements that increased with increased age.

The median wait time for a hip or knee replacement in Canada declined by 13 days to 169 days in 2006-2007, compared with the preceding year.[34] Growing demand for primary and revision hip and knee replacements are among the main reasons for long wait times in Canada. Studies have evaluated the effects of management strategies on wait times and the impact of wait times on OA patients' pre- and post-surgical functional, clinical outcomes and quality of life.[37-39] Changes in functioning for hip and knee OA patients waiting more than six months are unclear and likely underestimated because of a lack of high quality studies.[40;41] These information gaps provide further justification for additional research in this area.

CHAPTER 2:

An overview of system dynamics modeling

What is system dynamics (SD) modeling?

SD is a simulation modeling approach for representing and studying a complex social or physical system. SD models aim to represent a system holistically, explicitly including the interactions between its components that causes system behaviour. The modern foundations of SD were developed in the mid-1950s[42] and were originally developed to help corporate managers improve their understanding of industrial processes. SD is now being used throughout the public and private sectors for policy analysis and forecasting. Systems can be represented as models on a computer to simulate the effect of changes in variables. Using the SD model, managers can create "what-if" scenarios by changing variables to see how the system's performance will be altered and can use the information to manipulate the system to achieve a desired outcome.

An SD model involves "flows" of one of more thing(s) that may accumulate in different "stocks", with the change in a particular "stock" depending on the rate of "flows" in or out of it over time. Feedback loops are typically present that cause changes in a stock, and usually after some delay, influence the future value of that stock in either a positive or negative manner. Therefore, a stock is measured at a specific point in time while a flow is measured over a period of time or per unit of time. Mathematically, the relationships between the stock, flow, and auxiliary variables involved in a SD model comprise a system of nonlinear ordinary differential equations that can be "solved" via numerical integration to yield system behaviour over time.

Preliminary modeling of a system often involves the development of a *causal loop diagram* (CLD) highlighting the "direction" of the relationships between the variables involved in a system (without distinguishing stocks from flows). Figure 1 shows a CLD of part of the treatment system for OA patients. An arrow marked with a "+" ("-") indicates that, all things being equal, an increase in the variable at the tail of the arrow causes an increase (decrease) in the variable at the head of the arrow. For example: as the 'Severity of OA' increases the 'Demand for GP' increases. See the text in the appendix, under the heading "Interpretation of causal loop diagram". Using a computer simulated SD model for OA treatment, a variable such as "GP Capacity" can be increased or decreased to different levels to see the extent to which these changes influence the number of patients waiting for treatment. Altering the variable "GP Capacity" will also affect other components in the system.

What kind of information can be obtained by using a system dynamics model?

SD is a powerful methodology for framing, understanding and discussing complex issues and problems, and predicting how systems will be affected by changes in variables over time. It is particularly relevant when applied to health systems, which are highly dynamic and complex involving many interacting feedback loops, non-linear relationships, and diverse variables arising from human behaviour. Using a SD model, system performance in critical areas such as waiting time, resource use, and cost can be predicted based on specified values of inputs such as patient demand for care, human and financial resources, health care policies, and treatment options.

A SD model can serve as a tool for identifying options that result in allocative efficiency, the process of allocating restricted resources to derive the best outcomes for given financial investments.[43] Allocative efficiency is particularly relevant during periods of resource scarcity and budget restrictions.

Alberta already has a well established health technology assessment process (health technology assessments typically includes systematic reviews, meta-analyses, economic analyses, etc.). The province is currently forming clinical networks comprising multidisciplinary groups of clinicians who will guide and advise the province's health authority. The clinical networks are being formed in different areas of medical care, including bone and joint, and are important for allocating resources.

In hip and knee OA care, a SD model would be capable of simulating the impact of changes in resources on patient and system outcomes. It would serve as a powerful tool for estimating the expected benefit from intended proposed investment. In this way, it will reveal the value of the investment for Albertans.

Although to our knowledge the application of SD to hip and knee OA care is novel, SD has been applied in studies examining different aspects of health care system performance including:

(a) Emergency and Urgent Care: examining and understanding the relationship between emergency and urgent admissions and the rest of the system, identifying the implications of fluctuating and unpredictable demands for emergency admission for the management of hospital bed capacity, quantifying the risk of insufficient capacity for patients requiring immediate admission, and testing a range of scenarios to determine their effectiveness in meeting future targets.[44-50]

(b) Epidemic and Disease Progression: modeling the spread and progression of diseases such as AIDS, dengue fever, diabetes, and evaluating public intervention policies.[51-54]

(c) Health Care Policy: converting the complex inputs from a project examining the public health network into a feasible and potentially successful plan to implement and evaluate the network project, as well as understanding the role and interrelationships of public health professionals;[55] explaining the rising prevalence of chronic illnesses and the consequent treatment of complications, and understanding the impact of managing known risk factors to prevent illness onset;[42] developing policy guidelines for health services, including the use of intermediate care facilities aimed at preventing patients needing hospital treatment and community care;[56] understanding the consequences of service innovations on the level of a local care economy over time.[57]

(d) Others: redesigning phlebotomy and specimen collection centres (or patient service centres) at a medical diagnostic laboratory; and exploring the potential effects of alternative policies on the demand for services for cardiac catheterization.[58]

How can SD integrate with economic evaluation modeling in health care?

Economic evaluation modeling is routinely employed to support health policy decision-makers by enabling cost and benefit comparisons between procedure and/or technology alternatives.[59]

In the past, many modeling approaches have been used when conducting economic evaluation of health care technologies such as: decision trees, Markov models[60] and individual sampling modeling. These models are applicable when interactions between individuals are not important because they assume the individuals in the model are independent. However, when interactions between individuals are a significant factor, methods such as discrete-event simulation (DES) and SD are more useful. DES is appropriate for modeling an individual level, whereas SD is best applied at an aggregated level.[57]

The SD cohort-based approach models the state of the system in terms of continuous variables that change over time. It enables the rate of change in the system to be a function of the stocks and flows.

Traditional cost-effectiveness analyses using decision trees, Markov models or other standard modeling methods can inform administrators about the relative expenditure and outcomes of one course of action compared with others. However, they are static and don't account for the dynamic interactions between elements in the broader health care system.

To fully understand the impact of an intervention, it may be necessary to extend the analysis into different disciplines, services and settings, such as: primary and specialist care, emergency services, social services, community care, and

residential care. Information regarding the identification of patient referral patterns, waiting times, and how patient flows are affected would be required. It may also be necessary to model multiple interacting diseases, risks, delivery systems and diseased populations, while considering matters of public health care policy. SD offers a method of examining alternative health care interventions on a system basis, capturing many aspects of it to understand how they interact and how these interactions affect system performance. It is well suited to address the dynamic nature and complexity of many public health issues.[42]

How can a system dynamics model be used to better inform policy-makers on care delivery for hip and knee OA in Alberta?

Systems thinking and SD models were introduced to Alberta policy-makers in 2007 as tools for evaluating alternative health policies for emergency care services and colorectal cancer screening.[62] The evaluation of emergency care services involved a causal analysis of overcrowding in hospital emergency departments. The SD model helped to explain underlying causes and structures for long waits in emergency departments and enabled investigators to simulate various scenarios according to different expansion options. In the past the evaluation of colorectal cancer screening used SD modeling to evaluate alternative screening policies. Thus, Alberta Health Services (AHS) has been exposed to SD.

Alberta's integrated care path (ICP) for OA of the hip and knee deals with a complex and dynamic system of care involving integrated services delivered by multiple disciplines in a variety of settings, including hospital, community and home, and many different resources. A multitude of variables are at play. The care path's complexity provides an ideal framework for exploring how SD modeling can be used to evaluate outcomes in terms of care quality and the impact of tradeoffs when balancing access, effectiveness and efficiency. Furthermore, the timing is opportune, as Alberta's aging population and increasing physical activity level indicate a continued rise in demand for non-surgical and surgical treatment of hip and knee OA. SD modeling in this area can readily draw on data that are available from a 12-month randomized, controlled trial that began in April 2005. The trial compared the outcomes of hip and knee replacement patients following the ICP with those of patients who received conventional care in Alberta. The impact on system efficiency was also evaluated. Data from this trial would be instrumental to the validation of the hip and knee OA SD model. Results from this study can be found in Alberta Hip and Knee Joint Replacement Project – Evaluation Report, 2006.

"Listening for Direction",[63] a 2008 report by health agencies in Canada, and other recent reviews of the health care system emphasized that integrated systemic solutions be developed from a broad perspective informed by global best practices featuring a patient-centric approach throughout the care path.[11] "Listening for Direction" described integrated systemic solutions as involving aspects of health care ranging from the work environment to patient flow and health system sustainability, and suggested linking population health to health services. Alberta Health and Wellness concluded that a systems solution should:[11]

- Assess current and future supply and demand for workforce and infrastructure capacity;
- Identify potential future gaps and outline alternative care delivery models to address these gaps;
- Amplify innovations and creative ideas already under way within Alberta, which could be induced to take root on a larger scale; and
- Enable the system to make appropriate tradeoffs between differing priorities to optimize quality, access and sustainability.

Some of the questions that can be analyzed using SD-modeled scenarios are as follow:

a) What **resources** will be needed to produce efficient, effective and sustainable care for patients?

b) What **health policies** should be implemented in joint deterioration prevention programs, the use of different types of hip and knee replacement technologies, and appropriate patient age for these different technologies?

c) How can **health technology assessments based on SD inform decision-makers?** For example, how would expanding partial joint replacement procedures to younger age groups affect demand for services and patient outcomes?

SD can serve as a powerful methodology for simulating how system performance will be altered as aspects of the care path for hip and knee OA or resources change. The results will give decision-makers the insight to make informed choices as they respond to emerging needs and changing priorities affecting access, effectiveness and efficiency. A systems approach using SD is relevant and timely given constrained resources in Alberta's public health care system and the increasing demand for hip and knee replacements.

What components need to be considered in a system dynamics model?

Building a SD model is a multi-stage process. First, the critical behaviours of the system being modelled must be identified. Once these behaviours are known and understood, the stocks and flows, which comprise the basic building blocks of a SD model, can be identified.

Diagrams are then built showing the stocks, which are the variables in the system that accumulate or deplete over time, and the flows, which cause the stocks to accumulate or deplete. Finally, the elements in the system that influence the rate of the flows are added to the diagram. In addition to the diagrams, graphs illustrating critical behaviours over time are also created.

All variables that can be quantified and may influence the flows should be considered to ensure the model is valid. The variables that may influence patient flows in a system such as the care path for OA of the hip and knee may be classified as follows:

- Variables under the short- and long-term influence of system managers. These include activities or decisions of system agents, such as nurses, doctors and administrators, system capacities in areas such as nursing and laboratory testing, and policies related to management issues such as priority setting and decision-making;
- Variables beyond the influence of system managers, such as treatment time, laboratory testing time, demand for services, and patient demographics; and
- Patient-specific variables, such as age, gender, obesity, stage of disease progression, number of injured joints, history of joint injury, genetics, comorbidity, level of activity and social circumstances.

The following questions must be addressed during the process of building a SD model for hip and knee OA care in Alberta:

a. Are the variables in the model appropriate?

b. Are any variables missing?

c. What are the relationship between the variables?

d. Are data available to support each relationship?

In the following section, the proposed SD model for evaluating hip and knee OA treatment in Alberta is discussed in greater detail.

CHAPTER 3:

Building a system dynamics model for hip and knee osteoarthritis

Most system dynamics (SD) models are created in four stages[64] involving sequential steps. In the first stage, conceptualization, the purpose of the system is defined and the problem or undesirable behaviour it is producing is described. The boundaries of the model are also established and its key variables are identified. The basic mechanisms – the feedback loops showing how the variables in the system influence each other dynamically – are illustrated in a causal diagram (see Figure 1). In the second stage, formulation, the causal diagrams are converted to equations of stock levels and flow rates. In the third stage, testing, the model is simulated to test and validate its assumptions, behaviour, and sensitivity to perturbations. In the final stage, implementation, new policies are implemented.

Determining the scope of the model

In determining the scope of the SD model, Banff 'Beyond Markov' workshop participants considered demographic trends indicating an increased incidence of OA in the Alberta population, the frequency with which OA attacks the hips and knees, the high percentage of OA patients who are treatable with non-surgical interventions, and the relatively small but costly and increasing burden of surgical treatment. They concluded that the SD model should be restricted to OA of the hip and knee but it should encompass non-surgical and surgical treatments and extend across family physicians, intervention to manage symptoms, specialist diagnosis, care, surgery, recovery, rehabilitation and follow-up. It should encompass all hip and knee surgery types, including primary total replacement of hips and knees, partial knee replacement, hip resurfacing, and revision surgery.

The decision to focus on OA of the hip and knee was influenced by the availability of an integrated care path (ICP) that has been implemented to varying degrees in the most populous areas of Alberta, as well as rich data on patient and system outcomes from a randomized, controlled study of the ICP.[4] In addition, workshop participants recognized that the priority placed on improving access to hip and knee replacements across Canada makes the SD model a potentially valuable decision-support tool for public health systems in other parts of the country.

Building the model structure

A preliminary SD model for hip and knee OA was developed to stimulate discussion and debate among the clinicians, researchers, analysts and policy-makers who attended the Banff workshop. The model included conceptual stock and flow diagrams to illustrate the *disease system* Figure 2 based on population demographics and the progression of OA in the population, and the *treatment system* Figure 3 including primary care, specialist intervention, medical management, surgical management and post-surgery rehabilitation.

In the conceptualization stage of building the preliminary model, the natural progression of OA in the population, influenced by factors such as age and obesity, was mapped and included in the *disease system* stock and flow diagram. The SD model assumes OA progresses through three stages – mild, moderate and severe – and this progression will occur in people who are not diagnosed with hip or knee OA and, therefore, do not receive appropriate treatment.

The SD model assumes that treatment will slow the natural progression of hip or knee OA. Treatment may include one or a combination of the following: primary care by a family physician, medical management by a multidisciplinary team through a clinic or by a specialist, and acute care for joint replacement. These interventions are captured in the *treatment system* stock and flow diagram, which also includes the following assumptions:

- People with OA will move into a diagnosed state if they are under the care of a family physician who is able to diagnose the disease, or they will remain undiagnosed if they do not have access to a family physician or their family physician fails to diagnose the disease;
- People who are diagnosed will eventually be referred to a specialist, who will recommend medical or surgical management;
- People with disabling OA may receive a joint replacement to restore the joint's mobility and alleviate pain;
- Four joints may be treated – the left and right hips and knees; and
- Joint replacement devices may require replacement due to wear.

Obtaining expert input to the model

Clinicians, researchers, service planners, and policy-makers must be enlisted and actively involved in designing a SD model encompassing treatment that is based on standardized provincial practices and protocols, provided through public resources and paid for by government. SD modelers of hip and knee OA care enlisted clinicians and researchers in designing the preliminary SD model for the Banff workshop. In a series of presentations at the workshop, policy-makers, academics, clinicians and health care service researchers were informed about

system dynamics and the use of SD models as decision-support tools in health care, Alberta's integrated care path for hip and knee OA, and health care policy issues in the province. Breakout sessions were held during which workshop participants were probed for information on OA health care service demand and supply in Alberta and on sources of data with which to populate the SD model. Workshop participants were also asked to provide their perspective on the preliminary model's purpose, boundaries and key variables, including how they influence each other.

Their comments and suggestions, together with further input to be solicited from clinicians will be used to improve the conceptualization and formulation of the SD model in preparation for the simulation stage, which involves testing and validating the model.

Populating the model with data

Reliable information on the OA patient population and associated matters, such as the rate of disease progression and the number and types of health care resources used, are required to build a SD model for hip and knee OA care in Alberta. Data are available from numerous sources, including research studies, hip and knee replacement registries, and administrative databases. SD modelers will review the literature from clinical studies based on relevance to the model. They will hold patient focus groups to generate information about the aspects of care and areas of service that are most important to people with hip and knee OA. They will also extract data from provincial and national health databases, domestic, and foreign registries to build the stock and flow diagrams illustrating variables and their causal relationships in the disease and treatment systems. In particular, they will seek reliable data in the following key areas:

a) Disease System

- Epidemiology, such as OA in the population and rate of disease progression between the mild, moderate and severe stages; and
- Potential risk factors affecting stocks and flows, such as age and body mass.

b) Treatment System

- Treatment alternatives, such as non-pharmacological, pharmacological and surgical interventions;
- Potential system factors affecting stocks and flows, such as the availability of specialists for consultation, operating rooms, and acute care beds;
- Potential patient factors affecting stocks and flows, such as a decision to reject surgery even when it is recommended and the option to choose a surgeon rather than accept the next available surgeon; and

- Patient and health system outcomes in the six dimensions of the Alberta Quality Matrix for Health, including accessibility, acceptability, appropriateness, effectiveness, efficiency and safety (Table 1).[65]

Evaluating the reliability of the model

The SD model will be tested to demonstrate to policy-makers and service planners that they can be confident in its capability to calculate accurately the effects of modifying variables in the Integrated Care Path (ICP) for hip and knee OA. The model will be able to simulate changes – for example, an increase in family practitioners or surgeons – to reveal the outcome on other areas of care delivery, such as patient outcomes and cost of care. Such simulations are intended to give policy-makers and service planners the insight they need to make informed choices in response to emerging needs and shifting priorities while attempting to protect and enhance health care access, effectiveness and efficiency.

The model will be calibrated using historical population and resource utilization data to determine whether simulations produce accurate results. Testing will include face validity, which requires intuitive judgments by clinicians and others familiar with the health system about whether the SD model is a reasonable representation of the system and its boundaries and behaviour, and will serve as a sound decision-support tool. Quantitative model testing will involve subjecting it to extreme conditions, assessing its structure, and running dimensional consistency and integration error tests to determine whether the equations and results are sensitive to perturbations, extreme values or other alterations in the SD model structure.[66] The model will be reassessed and adjusted accordingly in response to shortfalls in performance.

The broad scope of the SD model for hip and knee OA presents unique challenges to the validation process. In addition to comparing the output of the model with the actual system using different performance measures, the model will be subjected to structure, structure behaviour and behaviour pattern validation as described by Barlas.[67] The emphasis will be on evaluating the model for its ability to predict trends or patterns as opposed to predicting specific values. A sound SD model for hip and knee OA will provide valuable information on trend relationships and the lag time for policies to take effect.

Simulation and evaluation of different health policy interventions with the SD model

The SD model uses a series of mathematical relationships to identify the possible patient and system outcomes resulting from an intervention or perturbation. The base case model simulation will provide the expected value of each outcome as resources or aspects of the care path are changed.[66] The fully specified SD model will serve as a decision-support tool for evaluating the outcomes in terms of care quality and system performance.

Quality of care will be evaluated on the dimensions of accessibility, acceptability, appropriateness, effectiveness, efficiency, and safety, which encompass both patient outcomes and health system performance. In the base case simulation, the model will use key performance indicators to measure the quality of care for patients in the ICP compared with the quality of care for patients who are not following the ICP. For example, accessibility will be measured by estimating the percentage of OA patients in each of the two groups who will receive a first specialist consultation within a specified period from their referral date. The model will measure safety by estimating the number of patients who have a complication (e.g. deep vein thrombosis, myocardial infarction) and require a revision. Effectiveness will be measured by comparing the pain and function improvement of patients in each group, based on SF-36 and WOMAC scores.[68-72] Efficiency will be measured by estimating the amount of public health care resources, such as physician visits, length of stay, operating room time and rehabilitation sessions, used to treat patients in the two groups.

Extensive sensitivity analysis will be conducted recognizing that complete and high-quality data inputs will not be available for all parameters in this comprehensive SD model of integrated OA care. This analysis will determine the effect of uncertainty on each of the quality of care outcomes and enable SD modellers to identify critical information about hip and knee OA health services and to suggest how gaps in quality might be addressed.

CHAPTER 4:

The Alberta Context

Long waits for hip and knee replacement surgeries are a way of rationing services to control rapidly rising health care costs and have been the subject of considerable controversy in Canadian health policy. While hip and knee replacement is among the priority areas identified by Canada's First Ministers for reduced wait times, these patients continue to experience some of the longest waits compared with patients in the other priority areas – cardiac bypass, cataract surgery, cancer radiation therapy, and diagnostic imaging. Personal and public costs escalate as hip and knee patients consume drugs and scarce health system resources to manage their condition while waiting.[38;39;73] Demographics in Alberta signal growing prevalence and rates of osteoarthritis (OA), the main cause of hip and knee wear leading to joint replacement.[9] As OA prevalence increases, need for health care intervention and waits for surgery will increase, the only effective treatment for end-stage OA, will become longer. This will further undermine the public system's sustainability unless available resources are used more efficiently or more resources are made available to improve care access and effectiveness.

The evidence based clinical pathway for hip and knee osteoarthritis was developed by the Alberta Bone and Joint Health Institute (ABJHI), with support from Alberta Health and Wellness (AHW), the Regional Health Authorities (RHA) and the Alberta Orthopedic Society. ABJHI is a key contributor to the National Core Model of Care for hip and knee replacement surgery, and to the Bone Joint Canada (BJC) Toolkit that was developed as a reference guide to implement the National Core Model of Care. The Toolkit includes the ABJHI Evaluation Framework of key performance indicators which delineates the dimensions of Quality Care and has been recommended by BJC to assist in guiding improvements for hip and knee replacement surgery.

On a regional level, the Western Canada Waiting List (WCWL) Project has focused efforts on developing and refining practical tools for prioritizing patients for access to medical services on the basis of need and potential to benefit. Specifically, it sought to develop physician-scored, valid, reliable, practical, and clinically transparent measures to prioritize patients for selected wait-list services. Funded by the federal government, the WCWL Project engaged 19 organizations to reduce wait times in five clinical areas, including hip and knee replacement surgery. Conner-Spady et al.[74] tested the reliability and validity of the WCWL Project priority criteria score (PCS) for prioritizing patients waiting for hip or knee replacement. Results from that study supported the validity of the PCS as a

measure of surgeon-rated urgency for hip or knee arthroplasty. However, authors suggested that evaluative studies are needed to assess the acceptability and validity of the priority tools and the establishment of maximum acceptable wait times in clinical practice.

Initiatives supported by grants from the Canadian Institutes for Health Research Emerging Team Grant (Principal Investigator Dr. Tom Noseworthy) and the Alberta Heritage Foundation for Medical Research Integrated Team Grant (Principal Investigator Dr. Cy Frank) are examining the sustainability of wait times management strategies for joint replacement.

Integrated care delivery for hip and knee OA in Alberta

A comprehensive analysis and redesign of care for hip and knee replacement patients in 2003-2004 was the genesis of a provincial effort to reduce wait times and improve service quality and efficiency in Alberta. Initiated by the Alberta Orthopaedic Society (AOS), the redesign culminated in a new evidence-based continuum of care encompassing referral, patient assessment, patient optimization, surgery, in-patient care, sub-acute care, recovery and ongoing monitoring.[5;75]

A central feature of the new care continuum is an integrated care path (ICP) setting out standardized protocols and practices.[76] The ICP is a multidisciplinary management plan structured to facilitate consistent application of evidence-based best care practices in the most efficient and effective manner possible. The ICP structures care chronologically in four stages: referral through to optimization for surgery, surgery, inpatient care, and recovery. Underlying principles of the ICP include: care is based on the best published evidence available and expert opinion where published evidence was not available; patient referrals are standardized; and care is fully integrated, delivered by a multidisciplinary team, and organized and managed by specialized clinics. Recognizing that care is delivered in a variety of locations (hospital, clinic, sub-acute facility, community) and provided or supported by many types of practitioners and staff (family physicians, surgeons, nurses, therapists, administrators) the concept of centralized "hip and knee clinics" was introduced. Hip and knee clinics provide dedicated case managers to organize and coordinate care. A standardized referral process and template was created to support appropriate screening and booking of patients.

Based on the results of assessment at the hip and knee clinic, patients who do not require surgery at that time receive a non-surgical treatment plan. Patients who need surgery are assigned a case managers and multidisciplinary team, which is responsible for all aspects of their care. Surgical "optimization" occurs over a period of 4-20 weeks during which the team prepares patients for surgery medically, socially, psychologically and functionally. This optimization is intended

to reduce the risk of complications and increase the likelihood of improved outcomes from surgery as well as to ensure patients are able to transition safely and efficiently to life at home upon discharge after surgery. The ICP stipulates inpatient care and activities, such as mobilization and pain management standards that are intended to facilitate rapid recovery. Through appropriate pre-operative preparation, surgical practises and inpatient care, the ICP targets a safe discharge from the hospital within four days of surgery. During the recovery phase, standard practices for rehabilitation, daily activity and monitoring are outlined.

A 12-month randomized, controlled trial was launched in 2005 to compare the new continuum with the conventional approach to hip and knee replacement. The Alberta Hip and Knee Replacement Pilot Project involved 3,434 patients who were randomly assigned to the ICP or the conventional approach for joint replacement. Due to accelerated access in the ICP, within the study timeframe, a total of 1,066 patients received surgery in the ICP and 504 patients received surgery in the conventional approach.[32]

Results of the pilot were mapped to the six dimensions of quality that comprise the Alberta Quality Matrix for Health, as defined by the Health Quality Council of Alberta, an independent organization promoting patient safety and health service quality.[65] Improvements were achieved in accessibility, efficiency, acceptability, effectiveness and appropriateness. In the sixth dimension – safety – rates of major medical complications or adverse events following surgery between patients in the new continuum and those who received conventional care were similar to historic rates in Alberta, and there was no statistical evidence that they were higher.[4]

The new continuum of care has been implemented fully or partially in Edmonton, Red Deer and Calgary, where approximately 80% of all hip and knee replacements in Alberta are currently performed. Other areas of the province such as Medicine Hat, Grand Prairie and Camrose, are beginning to implement the ICP.

How can the efficiency of the delivery of hip and knee OA care services in Alberta be improved by applying a SD model?

A SD model can be used by service planners and policy-makers as a tool for making informed choices, affecting care access and effectiveness, and system efficiency. A SD model for hip and knee OA can simulate the impact of changes in resources, services, service delivery mechanisms and policies to reveal their impact on the overall system of care or on particular parts of the system. In this way, it can be a powerful support tool as decision-makers face emerging developments in the complex and dynamic environment of hip and knee OA care, such as increasing wait times, growing patient backlogs and budget

restrictions, and the inevitable tradeoffs that are required in services and resources to respond appropriately to these challenges. For example, a SD model can simulate changes required in resources and services to achieve different wait time targets while revealing the impact on patient outcomes and whether the changes are cost-effective.

In the highly complex world of health care, there are a multitude of performance indicators across the six dimensions of quality (accessibility, acceptability, appropriateness, safety, effectiveness and efficiency)[65] that will be used in the SD model to measure the impact of changes on the care system. Among the many indicators, wait times are a simple concept to grasp and are an aspect of service than can be measured providing there is consensus on how and what to measure. Wait times have, as a result, become the most potent public and political issue in public health in Alberta, as in other parts of Canada. They are expected to be a high priority in a SD model intended to help guide services and policies. There are multiple points along an integrated care path at which wait times can be lengthy, such as care by a general practitioner, consultation with specialists including orthopaedic surgeons and rheumatologists, diagnostic tests and surgery. Long waits at these service points in hip and knee OA care increase the risk of sub-optimal outcomes for patients.[77] SD modelers along with clinical and system experts will need to establish appropriate benchmarks for wait times and other performance indicators in hip and knee OA care and, the SD model will need to forecast outcomes for each of them.

Participants in the Banff workshop on SD modeling identified the following as impediments to meeting performance benchmarks, recognizing tradeoffs will have to be made in services and resources as population needs change in the health care system:

- Competition for resources that are costly and in short supply;
- Shortages of health care providers, such as orthopedic surgeons and general practitioners;
- Limited hours of availability of professionals and practitioners;
- Rationing of operating room time and lack of hospital beds; and
- Lack of resources to support post-surgery rehabilitation.

In the process of designing a SD model that captures and measures a multitude of performance indicators, many issues must be considered, such as:

- The accuracy of information with regards to:
    - Demand and capacity for OA care;
    - Quantities of resources required to meet future demand; and
    - Predictions about patient and system outcomes as variables are changed and tradeoffs are made.

- The numbers of health care professionals and practitioners required to deliver quality care and meet current and future demand; and
- Whether variables in the system that are beyond the influence of managers, such as treatment time, diagnostic tests, demand for services and patient demographics, can be altered to produce desired outcomes in the system.

What perspectives and boundaries should be considered for modeling hip and knee OA care in Alberta?

Workshop participants emphasized the importance of reflecting the perspective of multiple stakeholders in conceptualizing, testing and validating the SD model. Stakeholders were identified as policy-makers, patients, academics and clinicians.

Workshop participants also pointed out that the SD model should be patient-centric, making it especially critical to seek information from clinicians and patients that can be used to inform its design. Clinicians are usually well apprised of patient needs and preferences and witness first-hand the impact optimal and sub-optimal service delivery has on patients and the health system. They are also positioned to provide clinical judgment when evidence does not exist or is insufficient to guide protocols and practices. Moreover, they will need to be consulted on future changes in the system. Patients must be consulted to ensure SD modelers understand their needs and preferences and capture them in the model's design.

One of the major challenges of designing a SD model is agreeing on its boundaries, including the extent to which resources are modeled. The following potentially divisive issues will need to be settled:

- Whether and how the model should:
  - Consider geographic issues, such as variations in the quality of care and in public resources in urban and rural areas;
  - Consider socio-economic issues, such as the availability of health care services to native populations on reserves;
  - Be applied to all hip and knee replacement procedure types, including primary total knee and hip replacements, partial knee replacement, hip resurfacing and revision surgery; and
  - Have a time horizon for the variables and outcomes to be measured,
  - Concentrate on what the system of hip and knee OA care does today, on what it should do in future, or on both.

- Which of the many potential variables in care will be captured in the SD model;
- How to calculate the availability of resources that are in limited supply and used for multiple purposes, such as hospital beds, operating rooms, and diagnostic facilities;
- Whether there is sufficient control over multiple-purpose resources to alter them to produce different patient and system outcomes in hip and knee OA care;
- Whether the model should include the possibility of expanding resources outside the hospital setting, such as long-term care facilities, home care, physiotherapy and occupational therapy;
- Whether the model should include patients who are kept in hospital longer than necessary because they do not have home support, require long-term care or have other needs that cannot be met immediately; and
- To what extent the model should account for patient needs following discharge from hospital, such as follow-up with a general practitioner, home visits and therapy.

What are the main challenges of applying SD models to hip and knee OA care in the Alberta context?

Workshop participants identified two main challenges: a) the availability of relevant data to populate the SD model, and b) linkage with all relevant stakeholders to ensure that the model is designed to support the relevant health system issues in hip and knee OA care delivery.

a) Availability of relevant data

The SD model requires information about the patient population and associated health services ranging from the rate of disease progression in hip and knee OA to the number and types of health care resources used. Modelers will select the best evidence for each model parameter from among multiple data sources, considering the study design in the hierarchy of evidence and the relevance of the study context to Alberta practice patterns.[78]

Workshop participants proposed populating the SD model with data from the Alberta Hip and Knee Replacement Project clinical trial. Additional data will be required from other local, national and international sources including studies, hip and knee replacement registries, and administrative databases. Details of preliminary data requirements and proposed sources are described in Table 2 and summarized below.

Hip and knee osteoarthritis disease system

Data are required in two main categories for the OA disease system component of the model: a) population and demographics, and b) OA disease progression. Birth and death estimates in the Alberta population will come from the Alberta Population Registry and Alberta Vital Statistics, which are the most reliable and comprehensive sources for these data.[79] Since administrative databases do not contain information about people who have not had a medical encounter, the progression of undiagnosed hip and knee OA (from mild to moderate and disabling) will be estimated from epidemiological population studies in the literature.[80] Demographic characteristics related to the development of OA include age, gender can be obtained from the Alberta Population Registry,[80] while obesity levels can be calculated from data in the Canadian Community Health Survey.[81;82] The proportion of people who develop arthritis and are diagnosed with it will be estimated from the AHW physician claims dataset based on recorded visits related to OA. The number of patients under physician care for OA and the number of visits to general practitioners, specialists and orthopaedic surgeons will be determined from the AHS physician claims dataset.[69;70;79] Together, the population estimates and rate of development and progression of OA will provide the information needed to forecast demand for hip and knee OA services in Alberta.

Data for the OA treatment system component of the model are required on: a) initial hip or knee OA care; b) medical management; c) specialist assessment; d) surgical management; e) post-surgery rehabilitation; and, f) long-term outcomes. Once referred to a specialist, patients might start medical management, become a candidate for surgery, or not be a candidate for treatment. The proportion of hip and knee OA patients receiving each type of care will be estimated from AHW administrative data.

Hip and knee osteoarthritis treatment system model

AHS data and the Alberta Hip and Knee Replacement Project clinical trial data will be used to determine resource use for hip and knee OA services. AHS will provide aggregate information on the number of visits to general practitioners and the number of specialists visits for follow up and to perform surgeries. Information on the number of operating rooms and amount of time the rooms are used for hip and knee surgery can be attained from AHS.

The data on outcomes and resource use by patients diagnosed with hip and knee OA will come from the Alberta Hip and Knee Replacement Project clinical trial, which provides detailed baseline patient information, health resource use information, vital statistics and other patient and system outcomes for all randomized patients who received surgery from two years prior to randomization through two years following randomization.

Medical management includes different non-surgical treatments for OA (e.g., drug and physical therapy). The Alberta Hip and Knee Replacement Project clinical trial data will be used to estimate the types of therapies used, the percentage of patients using each type of therapy, and how many of those patients are referred to surgery after medical management.

The Alberta Hip and Knee Replacement Project clinical trial used standardized data collection templates to prospectively collect outcome information on the 1,570 surgical patients within the trial timeframe. The information, encompassing the six dimensions of quality (Table 1), was collected at three months and one year post-surgery. The method of collecting the information and the data collected were as follows:

i) Patient self-reported questionnaires at baseline, three months, and 12 months after surgery. Included are patient demographics, medication use, and generic and disease-specific health-related quality of life (HRQoL) measured by Medical Outcomes Study 36-item Short Form (SF-36 – physical function)[83;84] and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)[3], comorbidities, patient satisfaction, and adverse events;

ii) Patient charts. Included are body mass index, comorbid conditions, medication use, ambulatory and inpatient chart reviews on wait times, health care resource use and adverse events; and

iii) Administrative databases (data for two years prior to and two years following randomization). Included are AHW inpatient data and AHW physician billing claims with patient demographics, health care resource use, admissions and readmissions to hospital, and date of death. Direct and indirect AHS resource use for pre-surgical, surgical, post-surgical rehabilitation, and recovery periods are also available.

Estimates of long-term outcomes, such as the rate of revisions beyond the timeframe of the Alberta Hip and Knee Replacement Project clinical trial, will be obtained from the national hip and knee registry in Canada [Canadian Joint Replacement Registry (CJRR)], with additional information provided by the Norwegian Registry.[34;85]

SD modeling requires continuously updating data sources to ensure they are current, appropriate, and useful for guiding services and policy. The data required to measure performance indicators across the six dimensions of quality is broader than Alberta and most other health care authorities in Canada collect routinely. The ABJHI will be collecting data on an ongoing basis which captures performance indicators for the six dimensions of care.

A provincial hip and knee registry has been proposed for Alberta. If established, a registry of this type would be a valuable source of continuously updated data with which to populate a SD model.

b) Linkage with relevant stakeholders

Workshop participants recommended participation among those involved in health care management and service delivery in Alberta, including physicians, surgeons, administrators, researchers, and policy-makers to ensure that the model is designed to support the relevant health system issues in hip and knee OA care delivery. They also emphasized the need to strengthen the linkage between academia and government on all aspects and stages of SD modeling.

CHAPTER 5:

Conclusions and Next Steps

The Banff workshop participants concluded that a systems dynamic (SD) model for hip and knee Osteoarthritis (OA) care in Alberta would be feasible to build and would serve as a practical decision-support tool for service planners and policy-makers. They agreed that the dynamic and complex nature of hip and knee OA care together with lengthy wait times for surgery, growing patient backlogs and demographics signaling increased patient demand on the public system make a SD model both appropriate and advantageous in Alberta. Workshop participants, including international experts in SD modeling, clinicians, researchers, analysts and policy-makers, proposed applying the SD model on a limited basis to provide proof of concept and opportunity for fine-tuning prior to making it available provincially.

Workshop participants indicated that a practical SD model for hip and knee OA care must be capable of assessing the potential effects of emerging health technologies on the quality of patient care and system costs, including the potential for improved devices and techniques to increase patient demand for surgery. They also identified the following principles as critical to a SD model that will be appropriate and useful in Alberta:

1. All health care practices and technologies in the model are evidence-based;
2. A patient-centered approach is followed in all aspects, recognizing that improved patient outcome trumps all other goals;
3. Surgeons, physicians and administrators are engaged in the process of reviewing the SD model; and
4. A time horizon is selected that is relevant and useful for planning services and developing policy.

The impact of changes in services or policies made on the basis of information generated by the SD model is measured using the six dimensions of quality identified by Alberta's Health Quality Network – accessibility, acceptability, appropriateness, safety, effectiveness and efficiency.[65]

In summary, it was concluded that SD modeling is a viable approach for a hip and knee OA decision-support tool. At the workshop, an approach for building a SD model was presented, data needs to populate the model were described, and the challenges to consider in the process were highlighted. A similar strategy and approach can be applied to other regions and other areas of medicine involving complex and dynamic systems of care across Canada.

Next steps

The next steps for advancing from a preliminary system dynamics (SD) model to a comprehensive model that can be applied as a decision-making tool are:

a) Finalize the model's scope and boundaries;

b) Identify all of the patient and system outcomes to be measured, such as waiting times for consultation and surgery, revision rate, mortality, fractures and other adverse events and complications, surgery time, length of hospital stay, pain and physical and social function;

c) Define the processes that have an impact on the outcomes;

d) Hold focus group sessions to identify the aspects of care and areas of service that are most important to people with hip and knee osteoarthritis (OA);

e) Obtain from the Alberta Bone and Joint Health Institute (ABJHI) complete data from the Hip and Knee Replacement project - a randomized controlled trial of Alberta's Integrated Care Path (ICP) for hip and knee OA;

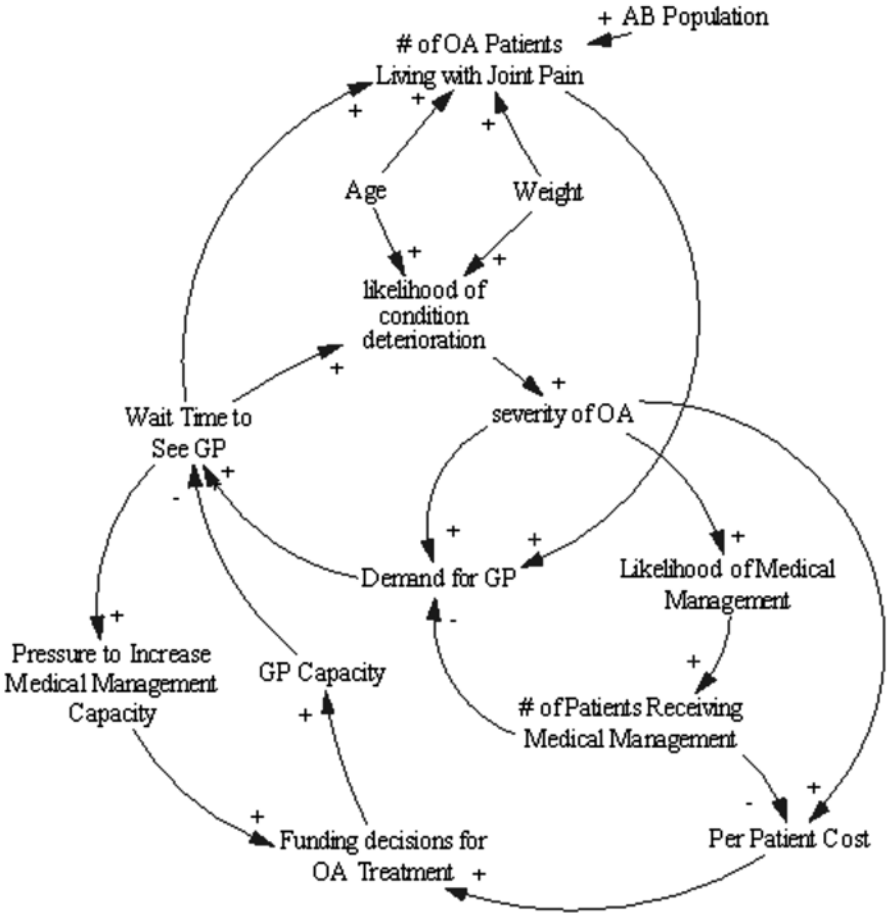
f) Complete data collection from provincial databases, literature, and international registries;

g) Assess the benefits and costs of the Integrated Care Path (ICP) compared with conventional care;

h) Identify bottlenecks and service problems, such as limited operating room time, shortages of resources including surgeons, physicians, and hospital beds, long waiting periods for consultation and surgery; and propose solutions to the service problems identified above.

Appendix

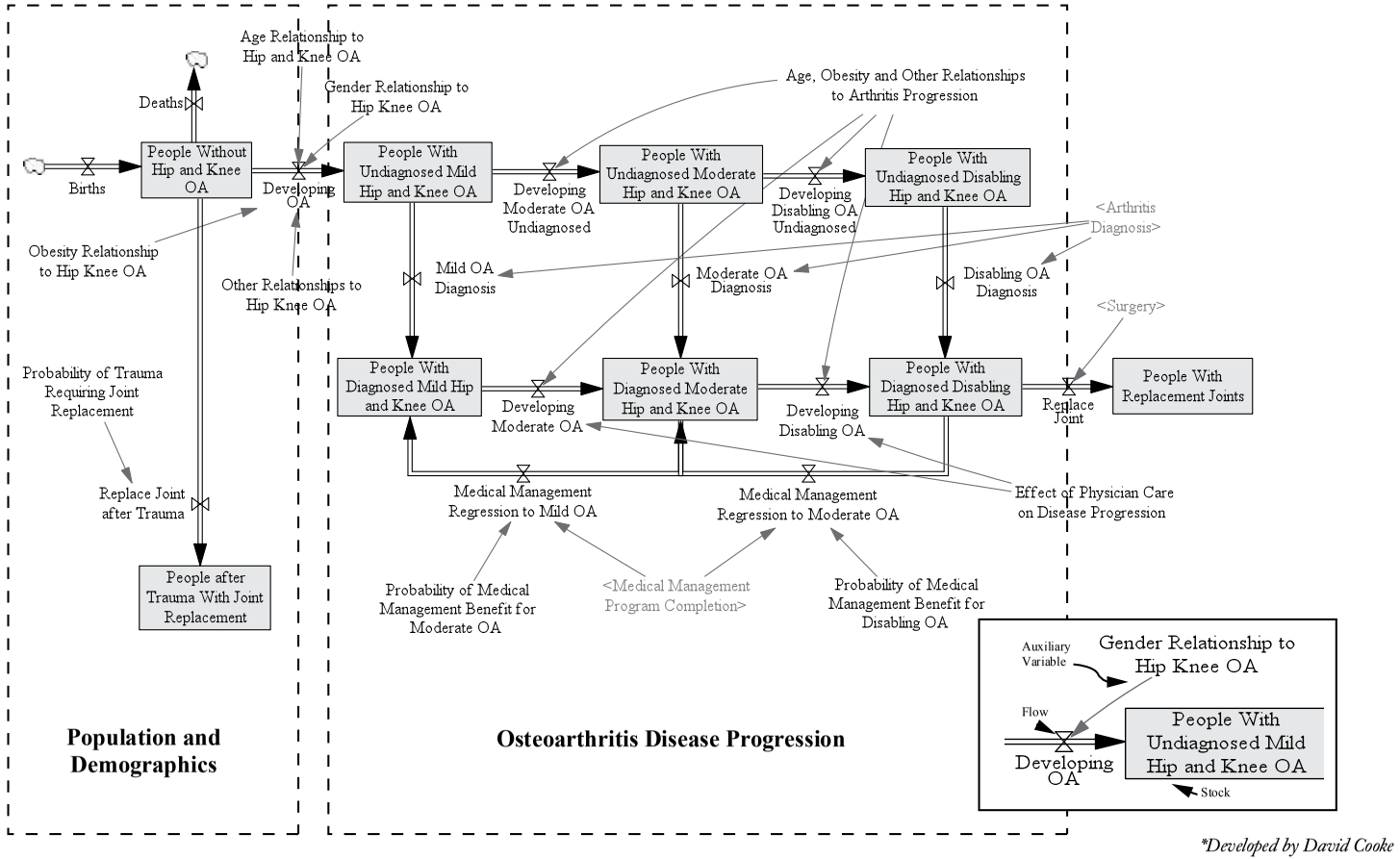
Figure 1. Hip and knee osteoarthritis medical management causal loop



Interpretation of causal loop diagram

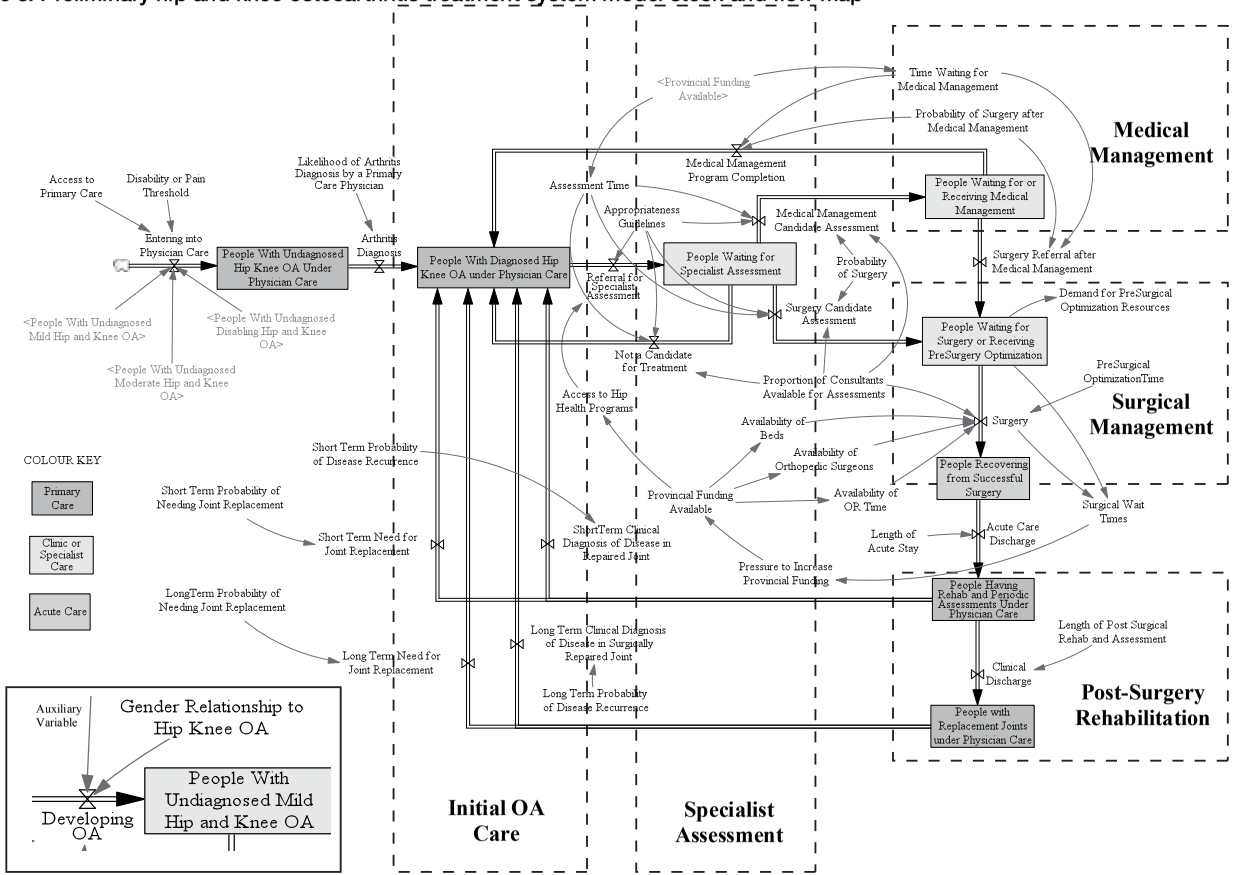
- Within the Alberta population there are a 'Number of OA Patients Living with Joint Pain'. As risk factors such as 'age and/or weight' increase, the 'Number of OA Patients living with Joint Pain', the 'likelihood of condition deterioration' and 'demand for GP' increase.
- With an increase in the 'likelihood of condition deterioration' the 'severity of OA' will increase.
- As the 'severity of OA' increases the 'Demand for GP', 'Likelihood of Medical Management' and 'Per patient Cost' increase.
- As the 'Likelihood of Medical Management' increases, the 'Number of Patients Receiving Medical Management' increases resulting in a decreased 'Demand for GP' and 'Per Patient Cost'.
- As the 'Demand for GP' increases the 'Wait Time to See GP' increases leading to an increase in the 'Number of OA Patients Living with Joint Pain' and 'likelihood of condition deterioration'.
- An increase in 'Wait Time to see GP' will result in 'Pressure to Increase Medical Management Capacity' leading to increased 'Funding decisions for OA Treatment'. This will lead to an increase in 'GP Capacity' that will decrease the 'Wait Time to See GP'.
- Finally, as the 'severity of OA' increases there will be an increase in the 'Per Patient Cost' leading to an increase in pressure on 'Funding decisions for OA treatment'.

Figure 2. Preliminary hip and knee osteoarthritis disease system model stock and flow map*



*Developed by David Cooke

Figure 3. Preliminary hip and knee osteoarthritis treatment system model stock and flow map*



*Developed by David Cooke

Table 1. Alberta Quality Matrix for Health, Health Quality Council of Alberta, Adapted from National Health Care Quality Report, Institute of Medicine Task Force, 2001[65]

Dimension of Quality of Care	Definition	Example of Performance Indicators from the Measurement Framework
Accessibility	Health services are obtained in the most suitable setting in a reasonable time and distance.	Percentage of patients who received their first consult within a specified number of days from the date their referral was received. Percentage of patients who received surgery within a specified number of weeks from the date of their decision to have surgery.
Acceptability	Health services are respectful and responsive to user needs, preferences and expectations.	Time from surgery to follow-up appointments. Patient "experience" satisfaction score.
Safety	Mitigate risks to avoid unintended or harmful results.	Number of procedure-related post-discharge complications. Percentage of patients requiring a revision.
Effectiveness	Health services are provided based on scientific knowledge to achieve desired outcomes.	Point change on SF-36 and WOMAC from Baseline to 12-month follow-up.
Appropriateness	Health services are relevant to user needs and are based on accepted or evidenced-based practice.	Percentage of patients assigned appropriately to medical management or surgical treatment. Percentage of case compliant with the clinical pathway.
Efficiency	Resources are optimally used in achieving desired outcomes.	Overall cost per OA case (professional, clinic, testing and community care costs).

Table 2. Preliminary list of system model data requirements and sources

Population and Demographics
Alberta Population Registry[a] This registry is maintained by Alberta Health and Wellness (AHW). It maintains information on individuals in Alberta belonging to the provincial health care insurance plan. This is the best source for information on births per year, deaths per year, and the population of Alberta, including total population and population age and gender. **Alberta Vital Statistics**[b] This database will provide mortality data for the province of Alberta. Causes of death are classified by ICD-9 codes. **Canadian Community Health Survey**[c] This survey, from Statistics Canada, provides information on the health of Canadians. This will provide aggregated data (by age) on the obesity (defined as BMI>25) and physical activity level of Albertans.
Osteoarthritis Disease Progression
Alberta Hip and Knee Replacement Project (AB H&K)[d] Pilot study data available from ABJHI includes two years of pre-operative data. This includes the diagnoses of different levels of osteoarthritis via WOMAC and SF-36 scores. Medical management is tracked, allowing for the effects on differing levels (mild, moderate, and disabling) of osteoarthritis to be noted.
Initial Osteoarthritis (OA) Care
Alberta Hip and Knee Replacement Project (AB H&K) Wait times to see a physician, via conventional care and the new ABJHI clinical pathway, are noted. **Alberta Health and Wellness (AHW) physician claims data** The physician claims dataset tracks the attending clinician, and the patient diagnosis. Specialist visits due to hip or knee osteoarthritis will be aggregated from this data.
Medical Management
Alberta Hip and Knee Replacement Project (AB H&K) Information from 2-years pre-surgery, including wait time and prescription information, is available from the trial data. The probability of surgery or non-surgical medical management can be calculated from the data **Alberta Health and Wellness pharmacy claims data** The pharmacy claims dataset tracks a select group of the population, identifying usage and expenditures on prescription medication. This data will be used as a secondary source to the AB H&K data on drug usage.

Specialist Assessment
Alberta Hip and Knee Replacement Project (AB H&K) Information about the number of patients who need pre-surgery optimization is collected by the trial. Time requirements for patients on average can be calculated from trial data. **Alberta Health and Wellness physician claim data** Information on the number of specialists in Alberta can be obtained from the physician claim dataset.
Surgical Management
Alberta Hip and Knee Replacement Project (AB H&K) Wait time from the first specialist visit to surgery is recorded by ABJHI. Information about the surgeries, such as resource utilization and type of replacement, can also be taken from the trial. **Alberta Health and Wellness claim data** The AHW physician claims dataset is the most complete source of information on the number of surgeries per year in Alberta. Length-of-stay and diagnosis information can also be obtained from AHW data. **Alberta Health Services (AHS) data** Alberta Health Services operates the hospitals in the province of Alberta. Information regarding utilization of hospital resources, such as the operating time and operating room available will be available from AHS.
Post-Surgery Rehabilitation
Alberta Hip and Knee Replacement Project (AB H&K) Rehabilitation needs after surgery, such as the amount of time and family help needed for care-giving, are available from the trial.

Post-surgical Outcomes

Alberta Hip and Knee Replacement Project (AB H&K)

Post-surgery health measures, such as the WOMAC and SF-36, are recorded for one year. This will give the probability of short-term pain recorded in the operated joint or in a different joint.

Registry Data

Longer-term data is not available through ABJHI. Registries, such as the Canadian Joint Replacement Registry (CJRR)[34], will provide aggregated data on revisions in Canada. Further information from the Norwegian Registry will allow for sensitivity analysis of revision rates.[85]

[a] Alberta Health and Wellness (AHW) Databases: All residents of Alberta require a personal health number (PHN) for services provided by Alberta hospitals, physicians, and pharmacists through the Alberta Health Care Insurance Plan (AHCIP). This allows administrators to track each resident's use of the public health system, and provides a source of detailed input information on medical procedures in Alberta. Only anonymized, aggregated data will be used in this research to ensure privacy. Specific relevant databases for this research include:[79]

1. Physician claims. This dataset contains billing records submitted by physicians, along with a billing code based on the Alberta Schedule of Medical Benefits for each procedure. PHN, gender, age, service intervention and dates, and billing information are recorded for each procedure.
2. Inpatient claims. This dataset contains records for patients who record an acute care stay at an Alberta hospital. Measures include length of stay, average direct cost, average indirect cost, and number of cases where cost was measured. These are aggregated and measured by case mix group. Patient age, gender, PHN, patient region, procedure code, case-mix groups and Canadian Classification of Health Interventions (CCI) codes are noted for each reported hospital visit. Records are not comprehensive and, hence, this will be used as a supplemental source for the Discharge Abstract Database (noted below).
3. Pharmacy claims. Drug benefits in Alberta are paid by government, private health care insurance, and individuals. AHW tracks costs and usage of in-hospital drugs through the hospital claims dataset. The AHCIP does not pay for drugs used outside the hospital. Alberta Blue Cross provides private supplemental medical coverage for many Albertans, including pharmaceutical coverage. The cost of drugs is updated yearly in the Alberta Health and Wellness Drug Benefit List, while usage information can be obtained from Alberta Blue Cross for patients under 65 years of age, and for patients 65 and older who receive supplemental coverage from the province.
4. Population Registry. This dataset gives registration information for anyone who is eligible to register for AHCIP. Eligibility information is cross-checked against vital statistics. These are used by Alberta Health and Wellness for provincial population estimates.

[b] Vital Statistics: This database contains information on all births, deaths and stillbirths since 1979.[79] Information is administered by Service Alberta. Cause of death is recorded by a physician or coroner on a death certificate and an algorithm is applied to determine the underlying cause of death according to World Health Organization criteria. The cause of death is reported using ICD-9 codes in Alberta Vital Statistics Annual Reviews, and the patient's PHN can be used to link to other databases.

[c] The Canadian Community Health Survey - The Canadian Community Health Survey (CCHS) was created by the federal government as a successor to previous health surveys of Canadians.[82] The cost of survey design, data collection and preliminary data analysis is funded by Statistics Canada. The CCHS aims to:

- Aid in the development of public policy;
- provide data for analytic studies that will assist in understanding the determinants of health;
- collect data on the economic, social, demographic, occupational and environmental correlates of health; and
- increase the understanding of the relationship between health status and health care utilization.

The CCHS surveys approximately 100,000-130,000 individuals in each cycle (132,221 in the latest publicly available cycle, 3.1, in 2005). The CCHS aims for a cross-section of the Canadian population across all provinces and territories as well as a population range across health jurisdictions within each province and territory. Publicly available data for the CCHS dates to 2000. Previous surveys are available via the National Population Health Survey (NPHS) dating to 1994. Data is collected via phone and in-person surveys. A common set of questions is given to all respondents, including questions with self-reported answers on health and physical activity, such as BMI, and time spent on certain physical activities. This survey will provide aggregate information on obesity and other health status measures for population inputs into the model.

[d] The Alberta Bone and Joint Health Institute Alberta Hip and Knee Replacement Project: The Alberta Bone and Joint Health Institute (ABJHI), in conjunction with the Alberta Orthopaedic Society, Alberta Health and Wellness, and regional health authorities in Alberta, designed a new clinical pathway for hip and knee replacements. Funding for a prospective trial to evaluate the new pathway came primarily from Alberta Health and Wellness for infrastructure and services required, and from ABJHI for project design and management. The main objective of the trial was to determine whether the new care pathway would result in better patient care and reduced wait times for hip and knee replacement patients in Alberta.[4] This involved analysis from the initial consultation with a physician through surgery and follow-up. Patients continue to be questioned every 12 months in post-surgery consultations. An article describing this project, "The Alberta hip and knee replacement project: A model for health technology assessment based on comparative effectiveness of clinical pathways," was published in the International Journal of Technology Assessment in Health Care in 2009.[86]

[e] National Joint Replacement Registries

The Canadian Joint Replacement Registry (CJRR)[34] - The Canadian Joint Replacement Registry contains data collected since 1994. It was developed by the Canadian Institute for Health Information (CIHI) in conjunction with orthopaedic surgeons in Canada. More than 500 surgeons, representing every province and territory, participate in the registry. Paper forms are received from physicians and electronic forms are received from hospitals. The main objective is to collect information on hip and knee replacements and evaluate clinical procedures, and to monitor the progress of joint replacement patients over time. Reports are issued combining CJRR data with information from two other databases at CIHI: the Discharge Abstract Database (DAD) and the Hospital Morbidity Database (HMDB). In 2006-07, the most recent year of CJRR results, 41% of the 72,469 hospitalizations for hip and knee replacements had additional information recorded beyond what is recorded in DAD and the HMDB, including additional patient, clinical, and surgical information.

The Norwegian Arthroplasty Registry[85] - The Norwegian Arthroplasty Register began registering total hip replacements in 1987. In 1994, registration was extended to include insertion of all types of artificial joints. The aims of the registry are to describe the epidemiology of joint arthroplasty and to identify factors associated with an increased risk for revision. The registry contains information on 121,755 hip prosthesis operations and 28,427 knee replacements for the 1994-2006 period.

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Beyond Markov Workshop – Participant's List

Diane Bischak, Associate Professor, Haskayne Business School, University of Calgary

*Anderson Chuck, Health Economist & Manager, Decision Analytic Modeling Unit, Institute of Health Economics and Adjunct Assistant Professor, Department of Anesthesiology and Pain Medicine, University of Alberta

**David Cooke, Adjunct Assistant Professor, Haskayne Business School, University of Calgary

**Stafford Dean, Vice President, Data Integration, Measurement & Reporting, Alberta Health Services

*Herb Emery, Professor and Svare Chair in Health Economics, Department of Community Health Sciences, University of Calgary

Ed Enns, Senior Advisor, Design and Information Sharing, Alberta Bone and Joint Health Institute

*Peter Faris, Director of Analysis, Alberta Bone and Joint Health Institute

Elisabeth Fenwick, Senior Lecturer for Public Health and Health Policy, University of Glasgow

Ilia Ferrusi, PhD Student, McMaster University

Ken Fyie, Student, Department of Community Health Sciences, University of Calgary

**Stacy Kozak, Advisor, Design and Information Sharing, Alberta Bone and Joint Health Institute

Robert Lee, Research Assistant Professor, University of New Mexico

Kirsten Long, Assistant Professor, Health Sciences Research, Mayo Clinic College of Medicine

**Deborah Marshall (Principal Investigator), Associate Professor and Canada Research Chair, Health Services and Systems Research, Community Health Sciences, University of Calgary

**Tom Noseworthy, Professor and Department Chair, Department of Community Health Sciences, University of Calgary

Paul Rogers, Associate Professor, Schulich School of Engineering, University of Calgary

**Thomas Rohleder, Senior Associate Consultant, The Division of Health Care Policy and Research, Mayo Clinic, Minnesota

Carla Rodrigues, Post-Doctoral Fellow, Department of Community Health Sciences, University of Calgary

Judy Seidel, Senior Epidemiologist, Alberta Health Services, University of Calgary

Sonia Vanderby, Post-Doctoral Fellow, University of Toronto

Sherry Weaver, PhD Student, Haskayne Business School, University of Calgary

Stephen Weiss, Chief Operating Officer, Alberta Bone and Joint Health Institute

Samuel Xu, PhD Student, Haskayne Business School, University of Calgary

Staff support:

Dot Brown, Administrative Assistant for Deborah Marshall, Department of Community Health Sciences, University of Calgary

Ruthanne Cameron, Research Assistant, McMaster University

Len Cocolicchio, Chief Communications, Alberta Bone and Joint Health Institute

**Facilitator*

***Presenter*

We are grateful to the following organizations who supported this workshop:

1. **CIHR (Canadian Institute of Health Research)** CIHR is the Government of Canada's agency responsible for funding health research in Canada. CIHR was created in 2000 under the authority of the CIHR *Act* and reports to Parliament through the Minister of Health.
2. **Calgary Institute for Population and Public Health (CIPPH):** brings together over 160 of Alberta's researchers and health professionals– drawn from multiple university faculties and schools, health service providers, government agencies and community organizations. Their collective vision is to devise innovative responses to address our most pressing public health and policy challenges. The Institute not only fosters the development and dissemination of trans-disciplinary knowledge, but also acts to transfer the latest and best knowledge between scientific communities, policy makers and the public, thereby facilitating rapid uptake and practical application of knowledge to improve health outcomes.

3. **ABJHI (Alberta Bone and Joint Health Institute)** The Alberta Bone & Joint Health Institute is the umbrella organization for bone and joint health care, research and education throughout Alberta. Being a non-profit organization, our work is supported by partnerships with universities, regional health authorities, medical and health practitioners, researchers, educators, government and private donors. Our mission is to be the leading agent for continuous improvement in bone and joint health and health care for Albertans. Our goal is to create an innovative, sustainable bone and joint health care model that is patient-centered, significantly improves access, quality and efficiency in the public system, and advances research and knowledge to ensure the care patients receive is effective. Our work is dedicated to improving Albertans' health and wellness, regardless of location, age and social condition.

4. **IHE (Institute of Health Economics)** The Institute of Health Economics (IHE) is a non-profit provincial research organization committed to producing, gathering, and disseminating health research findings from health economics, health policy, health technology assessment and comparative effectiveness to improve the delivery of health care and support a sustainable future. The Institute of Health Economics is governed by a Board of Directors from Government, Academia, Health Service Delivery and Industry. It operates the provincial HTA program, is a technical member of the WHO Health Evidence Network, secretariat for Health Technology Assessment International (HTAi) and member of the International Network of Health Technology Assessment Agencies. The IHE operates a Decision Analytic Modeling Unit which supports activities to enhance provincial capacity in modeling and analytic techniques.

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INSTITUTE OF
HEALTH ECONOMICS
ALBERTA CANADA

Institute of Health Economics
1200 – 10405 Jasper Avenue
Edmonton, AB Canada T5J 3N4

Tel. 780.448.4881 Fax. 780.448.0018
info@ihe.ca

www.ihe.ca

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