Five Challenges in Resource Optimization

Towards more effective resource management

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Overview: In Search of Operational Excellence

Increasing competition is continually pushing businesses towards more efficient processes, and slimmer margins. Highly capitalized industries have to ensure that their resources are used most effectively. Yet at the same time, businesses must adjust to rapidly changing customer requirements and supply chain conditions.

The key to achieving operational excellence, therefore, is in the effective and flexible management of resources, and this means optimizing and scheduling people, processes, vehicles, equipment, and materials so that utilization is maximized while business goals are met.

Such resource optimization and scheduling, in any real-world industrial environment, is not possible without the use of sophisticated computer systems. There are five challenges that need to be overcome, however, for truly effective computer-based support, and most traditional solutions are unable to address these challenges in meaningful ways. What's needed in today's solutions is the ability to:

1. Turn a large volume of data into meaningful information, and then into effective decisions;

2. Ensure software accuracy and solution relevance;

3. Increase solution speed and power, while dealing with operational complexity;

4. Provide decision support swiftly and flexibly during operations, with rapid reaction to unplanned events and operational disruptions;

5. Flexibly and intelligently interact with the user (at all levels of the organization) to leverage their knowledge.

New technologies are now being introduced that do address these challenges. The technologies stem from an emerging field that brings together techniques from two established disciplines: Operations Research (OR) and Artificial Intelligence (AI). We call this field *Operations Intelligence,* and it is founded on work that applies AI techniques to issues traditionally addressed by OR. It has given rise to some very economically important technologies and products: Operations Intelligence offers a track record of solid practical accomplishment through software solutions that provide real, commercial, competitive advantage.

Operations Intelligence solutions that are currently emerging are robust enough to offer real competitive advantage. Opportunities to improve performance are plentiful, for both the public sector, and for businesses large and small, in virtually all industries. Any organization that is striving for operational excellence should be aware of this development. Managers need to investigate how Operations Intelligence can be applied to achieve higher profitability through more effective resource management.

Operational Excellence and Competitive Advantage

In today's business environment, increased competitive pressure is forcing organizations to re-examine how they run their operations and how they allocate and manage their resources. Market dynamics are all adding to the complexity. In the end, it all boils down to execution: businesses that apply responsive, agile and lean operations will realize competitive advantage through operational excellence:

- **Responsive** organizations anticipate changing market demands and rapidly adapt operations to satisfy them;
- **Agile** organizations quickly reconfigure operations and supply chains to achieve optimal cost and service levels;
- **Lean** organizations minimize waste of resources and activities.

Effective execution is really about *time*, *resources*, and how we can make *better decisions* about how we can use time and resources efficiently.

Operational excellence is about optimizing time and resources and keeping them optimized.

Scheduling is the task of optimizing time and resources

Managing resources and time better requires resource optimization, which focuses on calculating the best possible utilization of resources that are needed to achieve a result (such as minimizing cost or process time, or maximizing throughput, service levels, or profits). Optimizing time and resources is known as scheduling; to be more precise, scheduling is the process of assigning activities to resources over time[1].

Optimization is about making better decisions.

Optimization is not just efficient and effective in an economic sense—it allows businesses to accommodate customer and employee preferences while taking into consideration a much wider set of requirements. Customers wait less and get better service. Employees can easily arrange their schedules around shift and vacation preferences without disrupting business operations or service levels. People can make highly informed decisions more quickly and more accurately than ever before.

Resource scheduling issues are difficult to resolve manually, and software applications are usually employed to assist in the process. The trouble with such traditional applications, however, is that they are actually quite limited in terms of sophistication, and they don't really stand up to challenges found in the real world.

Challenges in Resource Optimization

We know what the goal is: optimizing resources. We have software tools to help achieve this goal. Where's the problem?

The reality is that there isn't one problem: there are at least five. Traditional software solutions cannot effectively address the following five challenges in resource optimization:

1. Turning a large volume of data into meaningful information, and then into effective decisions;

2. Ensuring software accuracy and solution relevance;

3. Increasing the speed of solution generation, together with the power of the solution, while dealing with operational complexity;

4. Providing decision support swiftly and flexibly during operations, with rapid reaction to unplanned events and operational disruptions;

[1] Planning is closely related to scheduling. The practical difference between planning and scheduling involves a tradeoff of time horizon versus the level of detail. The less detailed, the more the problem is considered a planning problem.

5. Flexibly and intelligently interacting with the user (at all levels of the organization) to leverage their knowledge.

The Quantity Challenge: Managing data volume

"Having data doesn't give you productivity. Having better decisions gives you productivity "

- Michael Trick, Professor, Tepper School of Business, Carnegie-Mellon.

More operational data is available to management today than ever before. Through the use of sophisticated applications for RFID, ERP, CRM, and supply-chain management, almost any *fact* about some aspect of operations is instantly available. At the same time, making good *decisions* about operational situations remains difficult. More data or better information does not translate to better decisions: knowing where every truck is at any point, or what every worker is doing when a new order arrives, does not mean that we know how to act in a given situation. Making robust and reliable business decisions requires more than just providing operational data and more than simply providing relevant information. It also entails assisting in the actual decision-making process. Often, this is far from straightforward.

Frequently, organizations try to overcome this barrier to effective decision making by using different types of tools for operations analytics. These include data mining and statistical pattern recognition. The real question, however, is what support can be given in the decision process itself? What information can be presented to planners, managers, and operators so that better decisions will result?

The Relevancy Challenge: Balancing speed and solution usefulness

Software tools that are used to manage and optimize the use of resources need to employ both a model of the situation, and a method to find solutions.

Modeling: Formalized problem solving begins with creating a statement of the situation; that is, a model that defines the issue and relevant parameters. This modeling process is necessary for virtually every situation, since the context will be different for each one. A model can be expressed in a dedicated modeling language, or as a computer program written in, for instance, C++ or Java.

Solving: The optimization task is resolved by processing the model using a computational process called a "reasoning engine" or a "solver". This software has, at its core, highly sophisticated algorithms that are able to intelligently sort through data and analyze possible approaches to devise a solution. Usually, the solver engines are embedded in software applications.

When modeling a complex real world situation, there will always be concessions in fidelity: not all aspects of the situation can be incorporated into the model. What is included and what is omitted may make a large difference in speed and solution relevance.

To illustrate this point further, consider some of the specialized techniques used today: linear programming, integer programming, and matching. If the situation being modeled has characteristics that are aligned with one of these techniques, then a solution can be created more efficiently. For instance, situations where all constraints are linear can be solved very efficiently using linear programming [Dantzig 1963]. Integer programming represents an important advance over linear programming in modeling power[2], but is much less efficient.

The consequence of the use of these traditional techniques is that many situations that arise today are "shoe-horned" into models that are actually not an appropriate fit. For instance, there has been a tendency to model many real world problems as though they were linear, even when they are not. What's the result? Optimization or scheduling is possible (indeed, it's performed every day in countless enterprises in this way) but the results are questionable: schedules obtained using these methods, for example, are likely to be warped, simplified, and have very little relevance to the issue at hand[3]. Furthermore, modeling real world situations using these technique is often difficult or unsuccessful, simply because the real world presents characteristics that are too rich.

The Complexity Challenge

More operational data is available to management today than ever before. At the same time, making good decisions about operational situations remains problematic. Why is this?

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[2] With integer programming, we can represent discrete quantities such as integer production quantities (staff, inventory, etc.), scheduling constraints, and discrete decisions.

[3] For instance, suppose we have to acquire warehouse space in which to store finished goods, and the warehouses are available in a set size. A Linear Programming solution may suggest that we purchase 0.7 warehouses at some location and 0.6 warehouses somewhere else.

The problem with dealing with complex business issues is not so much that there are many interconnected facts and decision points. It's really that the number of possible ways that they can be connected to build a solution or make a reliable decision grows exponentially with small increases in the amount of data. Consider the situation when a company like UPS or United Airlines wants to model and plan routes through its network. Even a modest number of different points in the network results in a massive set of routing options: for example, 25 individual nodes lead to 1.6^{25} alternatives! Actenum Corporation tackled this issue when investigating methods of scheduling television broadcasts of games in a major sporting league: the number of possible schedules for a single season was calculated to be 10^{640}.

This is what computer scientists call a combinatorial explosion, and it's found even in common amusements and games like tic-tac-toe, Rubik's Cube, or chess. In 1950, for example, Claude Shannon, a Bell Laboratories mathematician, calculated that the number of possible distinct decision points in a chess game is around 10^{120}. Some perspective can be gained on the magnitude of that number by remembering that the estimated number of atoms in the Universe is 10^{80}.

This phenomenon is pervasive in modern businesses. Most individuals involved with resource allocation, scheduling, planning, routing, product configuration and production, yield management, warehouse layout and management, and logistics face the issue every day.

Traditional "brute force" computer methods fail dismally when applied to such situations. A computer exploring even a billion variations a second would take more than 10^{100} years to analyze a chess game completely (the universe is thought to be 10^{10} years old)! It is clear that when, for example, order volumes increase, using simple methods to plan production often results in unreliable visibility over production control, failure to meet promised delivery deadlines, and failure to predict shortfalls in production resources. This situation is complicated further by the complexity and dynamism of the production process itself.

The Reactivity Challenge: Managing changes on the day of operations

Effective management of an organization's resources and assets is of vital importance. Planning and scheduling is a critical part of this management activity, but existing technologies used for this purpose are *proactive*, rather than *reactive*. They are used to create tomorrow's or next week's schedules, but this is only half the story.

Disruption v t. To interrupt or impede progress, movement, or a procedure.

Recovery n. To return to a normal condition.

Almost without fail, unplanned events occur on the 'day of operations', and schedule disruption becomes a major issue. The weather does not cooperate. People do not show up when they are expected. A vital piece of equipment is not available. Customer requirements change. These unplanned events occur everywhere a plan is taken into the operational environment, whether in the airline industry, the processing industry, transportation, defense, or perishable commodities. When things like this happen, even the most carefully-prepared schedules will drift from their intended course, and often become useless. Real scheduling problems are dynamic and must be resolved as the environment and/or requirements change. Schedules often slip and must be rebuilt, on the fly, during execution.

Various ways are used to work around disruption, including inserting slack into schedules to make it easier to update them. Such workarounds, however, are expensive and often do not work; besides, they defeat the purpose behind creating the schedule in the first place. Time pressures are intense, and in many situations unplanned events cause cascading problems which overwhelm manual *ad hoc* resolution efforts.

Consider this real world situation that Actenum recently encountered: at a major seaport's pulp warehouse, three crews can unload railroad cars while two other crews are loading a ship. The load/unload process is carefully scheduled, since it is only practical when the pulp is placed into bins in such a way that the crews do not interfere with each other. If a ship arrives requesting a larger volume of a type of pulp than what was initially ordered (as happened recently) the foreman has to manually determine the best way of fulfilling the changed order, using a whiteboard with an architectural layout of the warehouse. No automated support is available to accommodate the change request without creating a future problem for the warehouse crews. (In the recent situation, after waiting for three hours while the foreman tried to work out how best to fulfill the changed order, the ship's captain told him to forget about it.)

In this situation, the foreman is asked to quickly solve a scheduling problem that appears to be reasonably straightforward, but which, in reality, is very complex. The task becomes increasingly difficult as more pressure is put on the person scheduling.

The Interactivity Challenge: Empowering the user

What are really needed today are optimization and scheduling systems that amplify the ability of users to solve problems, instead of simply automating their responsibilities. Productivity usually increases when employees are empowered rather than replaced by automation, yet traditional scheduling systems either address user interaction or optimization, but not both.

For most scheduling issues, research has shown that the computer can perform some tasks better alone, while some tasks require joint work, and some tasks are better performed by the human [Horvitz & Paek 1999]. Computer systems that support this type of interaction are called 'mixed initiative systems'.

The two expert approach: Human and computer.

This approach is also sometimes called a "two expert approach". A classic example of a "one expert approach" is the traditional Microsoft Project application. In this case the user is the expert. The software provides a nice user interface and database, but does not assist users in making scheduling decisions or helping them to find better schedules.

Two important principles guiding the process for increased quality and resource utilization are:

1. **Empower people to make decisions and keep the process moving.**
2. **Allow people with the best understanding of the problem to make the decision.**

This can be achieved by providing these people with the proper decisions support in the shape of mixed-initiative dynamic rescheduling systems.

In contrast, mixed-initiative systems integrate human and automated reasoning to take advantage of their respective reasoning styles and computational strengths. The benefit of such systems is the potential to combine the resources available to both; the challenge is to manage the interaction and responsibilities encountered in joint decision making. But the approach leverages in-house expertise rather than replacing it, and provides better scheduling and optimization solutions faster than either the human or the computer working alone.

Mixed-initiative solutions are especially critical in complex and dynamic scheduling, where the combinatorial element renders the solution space inhumanly large. A mixed-initiative scheduling system allows the user to interact at any point with the solution while providing assistance to find good, better and best value solutions. In this way, the user's own domain knowledge is respected, while the automated agent relieves the user of the burden of complexity.

Meeting the challenges

Optimization and effective resource management have been extensively investigated by researchers in the fields of Operations Research (OR) and Artificial Intelligence (AI). The approaches taken in the two fields, however, are different. While OR has its roots in mathematics and computing science, AI has its roots in formal logic and computing science[4]. By applying techniques from AI to areas traditionally addressed by OR, we are advancing the "state of the art" in optimization and scheduling solutions, and a new field is emerging: we call this field Operations Intelligence, or OI.

OI combines the mathematical approaches of OR with the flexibility and creativity of AI. Technologies that are based on OI approaches are enabling the deployment of fast, flexible software systems that address difficult practical situations. This, in turn, is making the achievement of operational excellence a reality for an increasing number of businesses. Software solutions are now available that offer real, commercial, competitive advantage. For instance:

Technologies that have emerged from research in the fields of Artificial Intelligence and Operations Research have created an opportunity to develop practical commercial applications that for the first time can effectively manage many complex *and* dynamic problems.

1. Sears combined Operations Intelligence technologies with a Geographical Information System to create a vehicle routing and scheduling system to run its delivery and home service fleets more efficiently, resulting in $42 million in annual savings [Weigel & Cao 1999].

2. The European steel producer Usinor introduced an Operations Intelligence based system that saves the company $1.55 per ton of steel produced, or about $17.5 million a year. The system has also reduced emissions and doubled the life span of their furnaces [Cordes 2001].

3. British Telecom used Operations Intelligence technology to schedule 20,000 repair and service engineers, resulting in an annual saving of $150 million a year on operational costs [Lesaint et Al 2000].

4. Visteon Automotive Systems improved productivity by 30% in their Ford parts production plant. They also avoided a $10 million expansion charge [Edelman Visteon 1999].

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[4] Furthermore, OR is focused on mathematical analysis, while the areas of AI under discussion here largely grew into an experimental science. As a result, while OR is concerned with completeness and optimality guarantees, AI is focused on non-complete heuristic methods.

5. Hong Kong International Terminals used Operations Intelligence technologies to increase capacity by 50% with no increase in staff, giving annual savings of over $30 million and avoiding the expenditure of over $300 million on construction of new container berths [Informs Edelman 1999].

6. Samsung reduced manufacturing times to capture an additional $1 billion in sales of semiconductor devices [Leachman et Al 2002].

7. NBC used Operations Intelligence to improve advertising sales plans, increasing revenues by more than $200 million [Bollapragada et Al 2002].

Managing complexity in a rapidly changing and uncertain business environment, and most probably in close collaboration with a user, is beyond the capabilities of traditional methods.

OI-based optimization software has, at its core, highly sophisticated algorithms adept at intelligently sorting through huge amounts of data and analyzing possible approaches to devise an optimized solution. Such software tools can improve decision-making speed and quality by providing businesses with responsive, accurate, real-time solutions to complex business problems, ranging from high-level planning to tactical operations[5].

OI-based software solutions also make it possible to address situations that have, until now, remained out of reach. Such situations involve classes of problems that are actually ubiquitous and of high importance in the real world: those that are hard to model mathematically; those with non-linear constraints, or a mix of constraints and preferences; those which require rapidly finding practical and flexible solutions rather than spending time chasing optimality; those which change constantly; and those who need human assistance when solving.

OI software solutions address the challenges mentioned earlier head-on, and provide solutions to scheduling and optimization situations that are far superior, devised more rapidly, and that are more flexibile in the face of unplanned events, than traditional solutions.

The Relevancy challenge: Tools based on Operations Intelligence have very high modeling power.

For example, constraint programming, an important discipline in OI, permits more flexible and succinct models than traditional Mathematical Programming methods. The

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[5] Note that optimization does not necessarily mean finding optimal solutions. Trying to find optimal solutions to most complex real world problems is both unnecessary and mathematically impossible, and thus a fool's errand. When defining optimization as calculating "the best possible utilization of resource", we mean best possible *in light of available time and computational means.*

models have more natural formulations and more direct relevance to the situations being modeled. This significantly reduces the time and cost of developing, deploying, maintaining, and validating solutions. At the same time, those solutions are highly efficient.

The Complexity challenge: Operations Intelligence technologies are overcoming the barriers to success.

While the complexity problem is assumed to be a mathematical barrier that can never be solved in the general case, OI technologies have been spectacularly successful on many real world situations. For instance, using Constraint Programming instead of integer programming for a large sports scheduling problem resulted in a decrease of processing time from 24 hours to a few seconds [Henz 2001].

The Reactivity Challenge: Managing plan 'drift', operations disruption and schedule recovery.

OI technologies have enabled the development of a new generation of scheduling tools which support users in managing complex business decisions in the operational environment. The new tools make it possible to find practical and workable solutions very rapidly for many situations. This has expanded the field of scheduling from the proactive, preparatory planning phase, to the operational phase. While planning still have to be done carefully, it is now possible to be adaptable in real-time. Users can now make decisions when unforeseen events occur, and can easily handle operational disruption and schedule recovery.

The Interactivity challenge: Leverage businesses in-house expertise, empower human users.

The sports scheduling example above is not only about creating solutions faster; it completely changes the way that the scheduling tool is used. OI technologies allow free interaction with the user. The scheduling and optimization process can be interrogated at any time; preferences and constraints can be changed, retracted or added during the solution process. The user can freeze parts of the solution and ask the system to continue to improve on other parts. This means that, for the first time, a true "mixed initiative" approach can be taken to optimization and scheduling challenges: two experts, the system and the user, can together quickly home in on good solutions.

Conclusion

Traditional software solutions for addressing resource optimization and scheduling in today's industrial operations fail to meet five important challenges:

1. Turning a large volume of data into meaningful information, and then into effective decisions;

2. Ensuring software accuracy and solution relevance;

3. Increasing solution speed and power, while dealing with operational complexity;

4. Providing decision support swiftly and flexibly during operations, with rapid reaction to unplanned events and operational disruptions;

5. Flexibly and intelligently interacting with the user (at all levels of the organization) to leverage their knowledge.

Recent research and development in combining techniques from Operations Research and Artificial Intelligence meet these challenges through technologies from the field of *Operations Intelligence*. These key technologies are available in modern software tools that help to gain an operational 'edge', and thus competitive advantage. Such tools are able to cope with previously intractable situations, for example, where the number of decision pathways combine to overwhelm traditional solutions.

Any organization that is faced with strategic optimization and resource management issues can benefit from the application of Operations Intelligence software solutions. Six signs that a business could benefit from OI software tools are:

Six signs that you could benefit from Operations Intelligence

1. When operational plans start to drift off course, or schedules are disrupted on a regular basis. Your existing systems are not designed for disruption, and you can only manage this by adding slack to your schedules. You need a solution that can quickly get you back on track and help you to recover your operations with minimal disruption.

2. Unplanned events and uncertainty are normal features of your business day and you spend a lot of time working out recovery scenarios.

3. The person who manages your operations will retire next year. He/she is good at their job, but you have not been successful in transferring their skills to others in your organization.

4. You have to make complex decisions. Modern operations are complex, and multiple decision points combine in a way that makes finding a satisfactory solution problematic.

5. You are having problems with business processes. One or more of your processes needs to work a lot more effectively. Many day-to-day decisions are not being

made well, and it is having an impact on your bottom line.

6. You face stiff competition. Others in your field may be introducing modern OI technologies to gain competitive advantage.

About this whitepaper

About the Author

Dr. Morten Irgens is the CEO of Actenum Corporation. He has 20 years of experience in technology transfer from academia to industry. His career background includes positions as a Research Scientist at the Department of Knowledge Based Systems at the Center for Industrial Research and as a Research Scientist at the Department of Optimization at SINTEF Applied Mathematics. Dr. Irgens has also been Associate Editor of the Artificial Intelligence Journal, Editor-In-Chief of Nordic Artificial Intelligence Magazine, and Chairman of the Norwegian Artificial Intelligence Society. Dr. Irgens holds a Ph.D. in Computing Science from Simon Fraser University and a Cand. Scient. in Informatics from the University of Oslo.

About Actenum Corporation

Actenum Corporation develops Operations Intelligence solutions for planning, scheduling, optimization and decision making, using techniques from the fields of Artificial Intelligence and Operational Research. The company specializes in solutions that are well suited for operational issues where tight user interaction and rapid solution generation is required. Actenum's products can be used for calculating the best utilization of resources, resources like people, time, processes, vehicles, equipment and materials, and for recovering from disrupted operations.

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