Digital Business

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For the purposes of our research, *business* is an organization in which *human, physical, financial and knowledge resources* are assembled with the aim of gaining rewards, e.g., profit, by creating (or buying) and selling products or services to a particular market.

It follows from this definition that the key business management activity must be the acquisition and the allocation of human, physical, financial and knowledge resources to demands.

Then, a *Digital Business* is a business in which the allocation of resources to demands is primarily done by *intelligent digital systems,* in real time.

In other words, in a digital business, Artificial Intelligence (AI) is replacing Human Intelligence (HI) in making low-risk, high-speed, routine resource allocation decisions – the domain in which AI is superior to HI.

There are, of course, domains in which AI cannot compete with HI (yet) - strategic thinking, imaginative design, discovery of exceptional business opportunities, exceptional leadership and tasks requiring dexterity, such as crafts, as shown in Table 1.

Tasks	**HUMAN INTELLIGENCE**	**ARTIFICIAL INTELLIGENCE**
High cognitive intelligence	Researchers, strategists, philosophers, designers of complex and complicated systems	
High emotional intelligence	Team coordinators, politicians, customer service providers, marketing and sales executives, nurses, teachers	
High artistic intelligence	Architects, interior decorators, painters, composers, novelists, script writers, film directors, actors, graphic designers, furniture designers, fashion designers, landscape designers	
High money-making intelligence	Investors, bankers, entrepreneurs	
High dexterity	Plumbers, electricians, builders, decorators; footballers	
Moderate intelligence, high speed & precision, working 24 hours a day		The allocation of resources to demands (in production, supply chains, purchasing, transport, health care

Table 2. Human and artificial intelligence: current division of labour

Why Digital Business?

At the time this text was written (December 2020), 4.66 billion people actively used the internet – 59% of the world population. Considering that 20 years ago there were only just over 300 million users, the growth is truly astonishing. The internet-based global market is now exceedingly complex with billions of participants making, modifying or cancelling deals with unprecedented speed.

As a consequence, organisations trading on the internet-based global market are exposed to frequent unpredictable disruptive events (changes in demand, delays, failures, fraud, cyberattacks) and traditional resource allocation systems designed for stable market conditions, simply cannot cope.

Under conditions of market complexity, the allocation of resources to demands must be done in real time, which means that rescheduling of affected resources when an unpredictable change in demand occurs, must be completed before the next disruption occurs.

Such a dynamic scheduling and rescheduling of resources requires rapid decision making that can be done only by intelligent digital systems.

Digital Transformation

Digital Transformation is defined here as a process by which traditional businesses are transformed into digital businesses.

To survive and succeed in the *Digital Economy*, sooner or later, all traditional businesses will have to undergo this transformation.

Creating New Digital Businesses

Currently, we are passing through a stage of intensive creation of new businesses in new domains, exemplified by the production and deployment of electric cars, trucks, aircraft, drones and flying cars.

It would be a regrettable waste of precious resources to launch such a business as a traditional organisation, supported by a variety of currently popular software packages that lack intelligence and cannot well interact with each other, only to discover that the newly created enterprise must be subjected to digital transformation.

It is an urgent matter to make entrepreneurs aware that the core of a new business must be intelligent business infrastructure consisting of seamlessly connected intelligent resource allocation systems.

Resource Allocation

The allocation of resources to demands is the most fundamental activity in human life. Choosing our socks in the morning, taking an umbrella or sunglasses when going shopping, selecting a route when driving, buying a pair of shoes, deciding where to have holidays, renting accommodation – these and thousands of similar decisions are, in fact, decisions concerned with the allocation of resources to demands. Most of these decisions are simple and we can handle them with ease. However, some of them (such as budgeting, managing investments and maintaining up to date personal diaries of busy individuals) are quite complex.

In business, it is difficult to find a decision that is not concerned with the allocation of resources to demands. Ordering, purchasing, transporting, warehousing, supplying, producing, distributing, maintaining, planning, budgeting, scheduling, remunerating and invoicing are fundamental business processes, which cannot be accomplished without the appropriate human, physical, financial and knowledge resources being allocated where and when required.

Traditional Allocation

Traditional methods exclusively rely on batch-mode optimisers, such as ERP (enterprise resource planning) systems or on manual planning supported by spreadsheets. The idea is to collect all demands, to list available resources and to employ mathematical optimisation algorithms to work out the optimal allocation of resources to demands. Typically, to plan production in a large manufacturing plant, hugely expensive ERP systems work overnight to produce production schedules for the next day. For supply chains, it is often necessary for a group of resource and demand managers to meet weekly to look at the ERP outputs and make adjustments to schedules. Transportation businesses use extensively human resources (dispatchers) to collect demands and schedule transportation resources using telephones. Airlines use specialised batch-mode allocation optimisers.

The traditional approach works well whenever supply/demand conditions are stable, as was the case in the last century – in the industrial economy.

Real-Time Allocation

In the 21st century, as we rapidly migrate from the industrial to knowledge economy, as exemplified by the internet-based global market, the dynamics of demand and supply is such that it is necessary to switch from batch-mode to real-time scheduling. The world changes so rapidly that it is not rational to collect data on resources and demand and optimise the allocation for hours only to experience a flood of changes that make the optimal schedule unworkable.

We need methods capable of modifying only *affected parts of the schedule* as fast as the changes to demand occur.

Complex Adaptive Systems

Definition

Complex adaptive systems [1], [2], [3], [4] are open (interact with their environments) and consist of autonomous members, called *agents*, engaged in intense interaction by exchanging messages; their behaviour emerges from the interaction of agents and is therefore uncertain without being random - it follows discernible patterns.

The term autonomous implies that members are not centrally controlled.

In contrast to deterministic algorithms, which will always complete the same task in the same way, complex adaptive systems can autonomously (without being instructed) selforganise (reschedule critical resources) [5], [6] whenever necessary to

- Neutralise unpredictable changes in their environment (adaptability)
- Defend itself against fraud or hacking (resilience)
- Improve own performance (spontaneous self-improvement)

Such a sophisticated behaviour of complex adaptive digital systems is possible because they exhibit emergent intelligence [7], [8].

Architecture

Architecture of a complex adaptive digital system is shown in Fig. 1. Key elements are

- Knowledge base, where domain knowledge is concentrated, consisting of ontology (conceptual knowledge) and data (factual knowledge)
- Virtual world, in which digital agents negotiate with each other how to solve given tasks
- Interfaces between the virtual world and the real world, which enable the exchange of information between agents in the virtual world and the real world of business

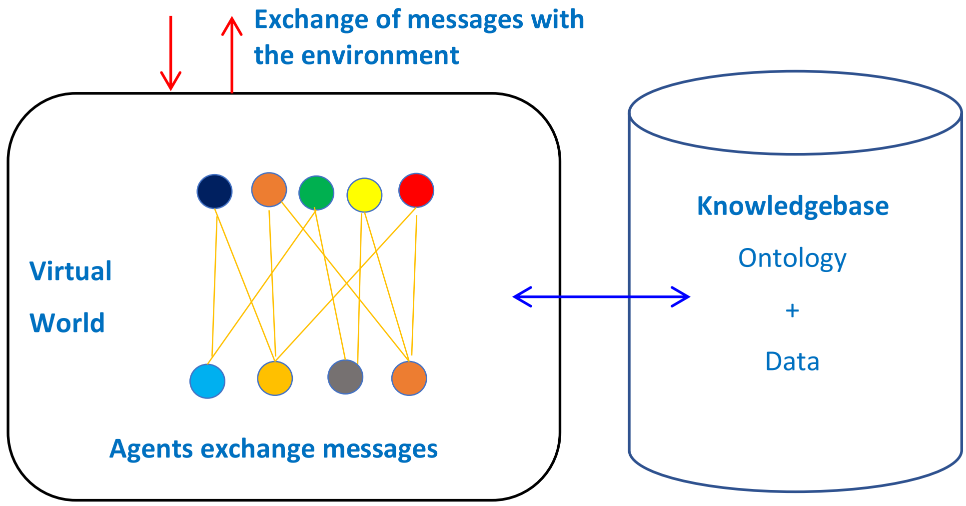

Fig. 1. Architecture of a complex adaptive digital system

Intelligent Real-Time Resource Allocation System (Scheduler)

Definition

Intelligent real-time scheduler is a complex adaptive digital system, designed to manage the allocation of human, physical, financial and knowledge resources to demands in situations in which demand changes unpredictably and frequently, and therefore there is a need to complete the rescheduling of affected resources between the two consecutive changes in demand [5].

For example, the intelligent real-time scheduler designed to schedule 2,000 minicabs in London, can reschedule vehicles in the vicinity of the client's address, affected by unpredictable changes if traffic conditions, every few seconds [9].

Architecture

Fig. 2 shows architecture of an intelligent real-time scheduler.

A business process (such as a supply chain) that requires the real-time allocation of resources is depicted in the upper block of the diagram named "real world".

An agent-based model of the business process is depicted in the lower block, named "digital world".

Information on the current state of the business process as well as the occurrences of disruptive events (such as, changes in demand or failures of resources) is passed from the real world to the digital world.

Based on this information and using knowledge on how the business process should operate, stored in the knowledgebase, agents decide the best allocation under prevailing circumstances, and convey the result to the business process by sending a text to an operator or coded instructions directly to the relevant physical device (aircraft, road vehicle, machine-tool or robot).

Agents compete or collaborate with each other, depending on the prevailing conditions. Typically, a Demand Agent would send a specification of required resources to Resource Agents and would select the best of the received bids. Resource Agents may choose to offer their services to Demand Agents without waiting for requests and may decide to employ resources with a discount.

Agents always consult knowledgebase before composing a message or interpreting a received message.

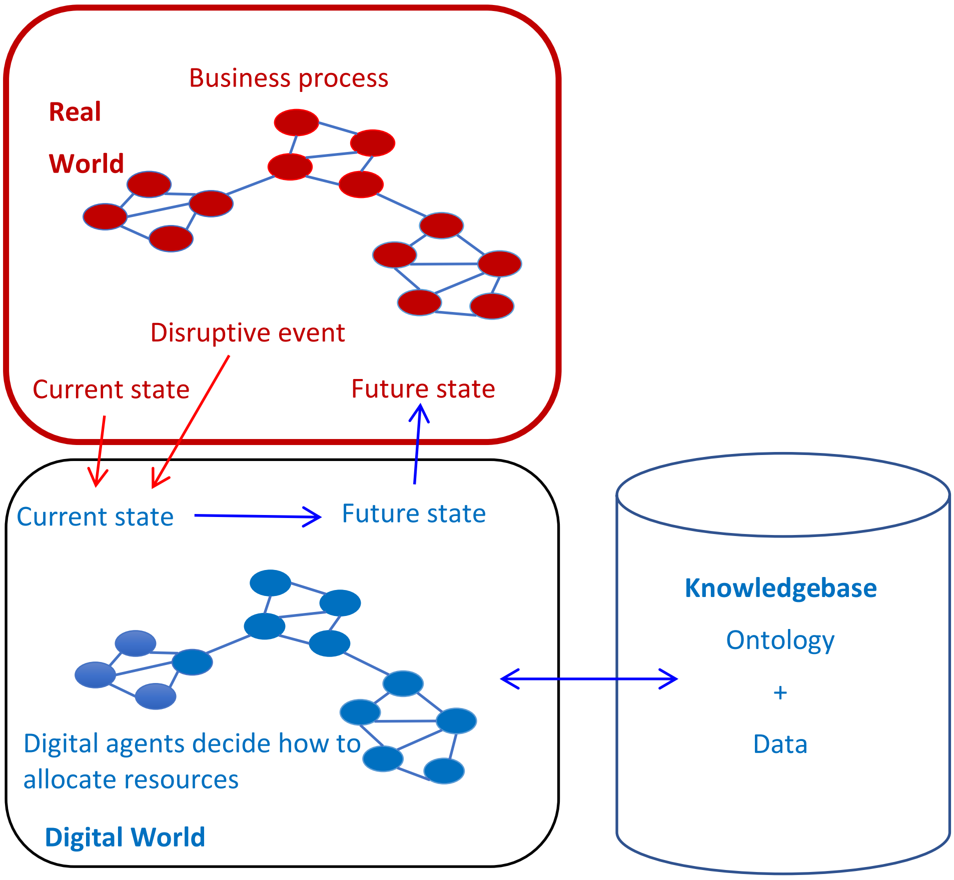

Fig. 2. Intelligent real-time scheduler

An Example – AirTaxi Scheduling by Agent Negotiation

Let's remind ourselves that *agents* are computational object (usually short algorithms) that solve problems by collaborating or competing with each other by means of exchanging messages.

Let's assume that the business process is an air taxi operation.

Real-time flight scheduling by agent negotiation would look (in a somewhat simplified form) as follows.

- A passenger A requests a seat for a flight from airport 1 to airport 2.
- PassengerA Agent is assigned to the passenger and the agent initiates creation of Flight12.
- Flight12 Agent is assigned to the new flight.
- Flight12 Agent sends messages
  - To Aircraft Agents, asking for available aircraft, when an available aircraft could reach airport 1 and what would be the cost of delivering the aircraft.
  - To Pilot Agents, asking for available pilots, when an available pilot could reach airport 1 and at what cost.
- Agents of available aircraft and pilots may compete with each other for the assignments.
- After receiving answers, Flight12 Agent calculates cost of the Flight12 and sends offers to Passenger1 Agent and to the selected Aircraft and Pilot Agents.

If several passengers request seats for flights on the same day, agents will offer to passengers a variety of optional prices based on (1) travelling alone, (2) sharing seats on the same flight, (3) diverting the flight to pick up other passengers from a closely located airport, etc.

Similar negotiations are conducted between agents for flight routing, resolving conflicts in demands, detecting fraud and cyberattacks and for improving airtaxi financial performance.

A detailed record of agent negotiations is stored and used off-line for learning how to improve the decision-making processes and to calculate costs of individual transactions.

Replacing long computational searches for optimal schedules with the agent communication increases the speed of scheduling several orders of magnitudes. This enables the scheduler to calculate real costs of every seat, on every flight, dynamically, and to make customised offers to every passenger.

Applications

The author's team has designed and delivered intelligent real-time schedulers for a large number of clients, including, road transport, taxis [9], rent-a-car companies [10], seagoing tankers, railways [11] supply chains [12], [13], aircraft manufacturing and for delivery of cargo to the International Space Station [14]. A large-scale case study is included below.

Another Example – An Intelligent Real-Time Supply Chain Scheduler

Functions

The System provides the following functions:

Design of a Supply Chain

The System has a built-in simulator, which can be used to evaluate different supply chain configurations (including warehouse locations) and different inventory levels for a variety of demands.

Real-Time Supply Chain Scheduling

The System provides the following outputs in real time:

- Real-time demand forecasts
- Real-time dispatch schedule
- Real-time supply schedule
- Real-time relocation schedule
- Real-time production schedule
- Real-time procurement schedule
- Real-time inventory levels and schedule
- Real-time financial analysis showing production and supply costs and profit down to individual item level

Features

- Schedules individual orders
- Forecasts demand for any horizon and any detail – minutes, hours, days or weeks
- Takes into account both channel and transport capacities
- Considers storage space availability
- Incorporates flexible storage cost models
- Finds the most cost-effective delivery channel for every specific situation
- Provides multi-stage production planning based on material requirements, equipment, etc.
- Considers different prices for products in different locations of the supply chain
- Considers contractual obligations when scheduling production and supply
- Is capable of building safety stocks for service level management
- Manages order postponement in supply chains with limited capacity
- Balances the product range when it is not possible to maintain the full assortment
- Proposes changes in network settings if necessary

- Provides consolidation and minimises delivery costs
- Handles constraints on relocation and production in specific parts of a supply chain
- Considers product quarantine and product due date
- Interacts effectively with ERP (enterprise resource planning) systems

Benefits

Improved Order Fulfilment

Real time scheduling eliminates (or at least reduces) occurrences of delayed, modified and cancelled deliveries and thus substantially improves order fulfilment. Coca Cola Germany achieved 7% improvement in order fulfilment within the first month of subscription to the service. Also, the System enables suppliers to meet service level agreement requirements and to accommodate late changes to orders, therefore increasing customer satisfaction.

Improved Profit

Subscribers to the System require less production and logistics resources and lower levels of stocks to achieve higher levels of production and deliveries, which leads to substantial cost reduction and profit improvement. The System generates and compares more options of order delivery than what people can do manually and consistently finds cost-effective solutions for every specific situation. For example, Coca Cola Germany reduced delivery costs by up to 20% and LEGO pilot system showed possibility to reduce delivery costs by 25%.

Improved Return on Investments

If purchased as a subscription service, the System substantially reduces upfront investment and enables our clients to delay payments until they start deriving benefits from the service. One of our clients saved the initial payment for the service in ten days.

If purchased as a product under licence, typically, the investment into System can be repaid within months. To the best of our knowledge no other supply chain management tool offers such a rapid return on investment.

Improved Transparency

The System calculates costs of every single constituent supply chain transaction, which gives our customers precise costs of sourcing, producing, transporting, storing and delivering every individual item. This feature enables businesses to easily identify cost-critical links in supply chains and provides them with detailed cost analysis at all levels of operation per business unit, production line, product and customer.

Holistic View

The System considers all details and interrelations in a supply chain and provides the client with the complete picture of possibilities.

Improved Productivity

The System operates 24 hours a day, 7 days a week, continuously updating supply chain schedules in reaction to disruptive events. Whenever there is some time free from disruptions, the service autonomously analyses supply chain performance and searches for ways to improve it.

Improved Supply Chain Management

The System takes over a very large management load by making autonomously all routine scheduling decisions and thus frees managers to focus on strategic and tactical issues. It also enables managers to intervene and change decisions made by the service. Several users can collaborate on the same supply chain using user-friendly interfaces.

Why Every Business needs an Intelligent Real-Time Scheduler

Supply chains are well known to be the most difficult business processes to manage.

To manage a supply chain means to forecast correctly demand and supply, to assign resources to demands and to schedule all supply chain activities in such a way that orders are delivered in time and at minimal costs and that quality of service to customers as well as profit is maximised. Research shows that no business has managed to continuously achieve 100% of its business targets by using current supply chain management methods and tools.

The supply chain problem is one of the classical operations research problems, which has been studied extensively in literature and, which remained until recently unsolved.

Let's identify key reasons that cause the problem.

Frequent Unpredictable Disruptions

There are many unpredictable events that can disrupt smooth delivery of goods, the most important being non-arrival of an expected order, arrival of an unexpected order and cancellation or modification of a previously received order. Disruptions are caused also by cancellations or delays during transport and by failures of resources or human errors.

Every year the volatility of supply and demand increases relentlessly as more and more businesses join the Internet-based global market where million suppliers, traders, middlemen, bankers, consultants, government agencies, business customers and individual consumers are engaged in mutual transactions with unprecedented speed.

Since we now have a highly volatile global market, we cannot have stable forecasts of demand and supply and therefore we cannot have stable strategic or operational plans. Under current market conditions, our planned and actual reality will always quickly diverge unless planning is done in real time.

Large Scale

Modern supply chains tend to be very long – often stretching over two or more continents. Many use a variety of transportation modes such as road, rail, sea and air transport, as well as conveyers and trollies, with the need to unload, store and reload the cargo at intermediate distribution centres. Every large international retailer has to manage such a large-scale supply chain.

Large-scale supply chains have so many diverse variables that no current supply chain optimiser or planner based on the batch-processing principle can possibly produce an optimal solution that will last. All current ERP systems are working in batch mode, which means that their schedules are out of date as soon as produced.

Large Number of Diverse Participants

Most supply chains have a large number of diverse participants: suppliers, logistics operators, 3rd party transportation companies, warehouses, ERP system operators, dispatchers, retailers, etc., each typically under different ownership and therefore subject to different polices, rules and regulations.

Because of the high diversity of participants, activities of Collaborative Forecasting, Planning & Replenishment (CPFR) and Sales & Operations Planning (S&OP) require involvement of a wide range of participants at regular intervals, say, one or two weeks. Therefore, data on the basis of which managers make decisions are always a week or two out of date.

Increased complexity of supply chains, caused by the increased volatility of supply and demand, increased scale of supply chains and a great variety of participants, have escalated supply chain management problems to the point at which only intelligent real-time schedulers can deliver results.

How Intelligent Real-Time Scheduler Solves the Supply Chain Management Problem

Intelligent real-time scheduler is based on a completely new approach to solving the supply chain problem. It has been designed as a complex adaptive system.

It is Knowledge-Driven rather than Data-Driven

The central part of the System is a knowledgebase where we store comprehensive knowledge how to run the Client's supply chain. This is a unique feature, which enables the System to offer a rather sophisticated supply chain management service that takes into account all Client's current requirements and preferences when making decisions. Clients can access the knowledgebase and update it to always reflect current client polices, rules and regulations.

Other current supply chain systems are data driven and hard-wired or rule-based, making it difficult to keep the system up to date. Without a knowledgebase they miss a facility to record the multitude of Client's requirements and preferences.

It is Event-Driven rather than Batch

The System is so powerful and intelligent that it can rapidly identify all activities within the supply chain, which will be affected by a disruptive event a fraction of a second after it occurred, and will reschedule these activities without changing parts of the schedule that were not affected by the disruption. This unique feature ensures that any unpredictable disruption of the supply chain is dealt with before the next disruptive event occurs.

No supply chain scheduler currently on the market has this feature.

Based on initial conditions, the System produces an initial schedule and then it reacts on every disruptive event as it occurs, rescheduling the supply chain in such a way that (1) consequences of the disruption are eliminated or at least drastically reduced and (2) activities, which are not affected by the disruptive event, are not interrupted. This is the key feature – the System does not wait for a batch of data to be accumulated and then processed – it reacts rapidly on any single change of data.

Other current supply chain systems rely on batch-processing optimisation that needs typically up to 8 hours to schedule a moderately large supply chain, which is far too slow for most industries where disruptions occur with frequency of several events per hour. Batch processing schedulers cannot, by definition, take into account perpetually changing data. More importantly, batch schedulers are not capable of identifying, which parts of the schedule will be affected by a disruption and therefore they have to re-schedule the whole supply chain, which cannot be done dynamically since batch processing systems do not react to events.

The Allocation of Resources to Orders is done by Distributed Decision Making and it Involves all Stakeholders

Every stakeholder in the chain is represented by a software agent that is capable of exchanging messages with other agents and negotiating the allocation of resources to orders that satisfies current requirements and preferences of each stakeholder. Agents consult the knowledgebase before making any decision to ensure that the allocation of resources is done in accordance with Client's polices, rules and regulations.

Other current supply chain systems rely on centralised decision making, which is slow and does not take into account dynamically changing preferences of stakeholders.

It is a High-Granularity System

A very important feature of the system is its high granularity – every order and every resource available to fulfil orders is considered as a stakeholder and is represented by a software agent, which makes sure that its requirements and preferences are satisfied as much as possible, whilst at the same time ensuring that the overall enterprise value is maximised. This is the key feature because it enables the system to rapidly identify which order and which resource will be affected by a disruption. It also increases business transparency by providing to the client information on the cost of the delivery of every item to every customer. No other supply chain management system has this level of granularity.

A Testimony by a Client

When he saw Smart Supply Network, Egil Moller Nielsen, Senior Vice President of LEGO Supply Chain said: "When I heard that MAT (Multi-Agent Technology) took on the challenge of solving the general supply chain problem, I was sceptical whether they could do it. After seeing Smart Supply Network, I am happy to conclude that [the seemingly impossible optimisation challenge] finally has been solved.

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