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# Applications of Constraint Programming



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CRT-AI CP Week 2025

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# Applications of Constraint Programming

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# Applications are important

- Provide motivation for basic research
  - Which constraints, methods are needed
- Provide realistic benchmark problems
  - Easy to optimize for pointless results
- Shows that research has potential benefits
  - Much easier to convince funding agencies
- Typically much easier to explain than solver internals
  - Interest students, do outreach

# Main Application Areas for CP

- Scheduling
  - By far the largest application area
- Product Configuration
  - No longer much of a research focus
  - Start with Ulrich Junker's chapter in Handbook of Constraint Programming
- Rostering and Assignment
  - Propagation is very powerful
  - Start with Demirović, E., Stuckey, P.J. (2018). Constraint Programming for High School Timetabling: A Scheduling-Based Model with Hot Starts. CPAIOR 2018.
- Software/Hardware Design and Testing
  - Sometimes using specialized domains (uint32)
  - Start with Arnaud Gotlieb video  
<https://www.youtube.com/watch?v=E1Seayx3eXU>
- Transportation
  - Hybrids with other techniques
  - Start with Augustin Delecluse, Pierre Schaus, and Pascal Van Hentenryck. Sequence Variables for Routing Problems. CP 2022.

# Outline

CP and Scheduling Literature Survey

ASSISTANT SE Use Case

Outpatient Waitlist Management

Elevator Maintenance Planning and Scheduling

Other Applications

Summary

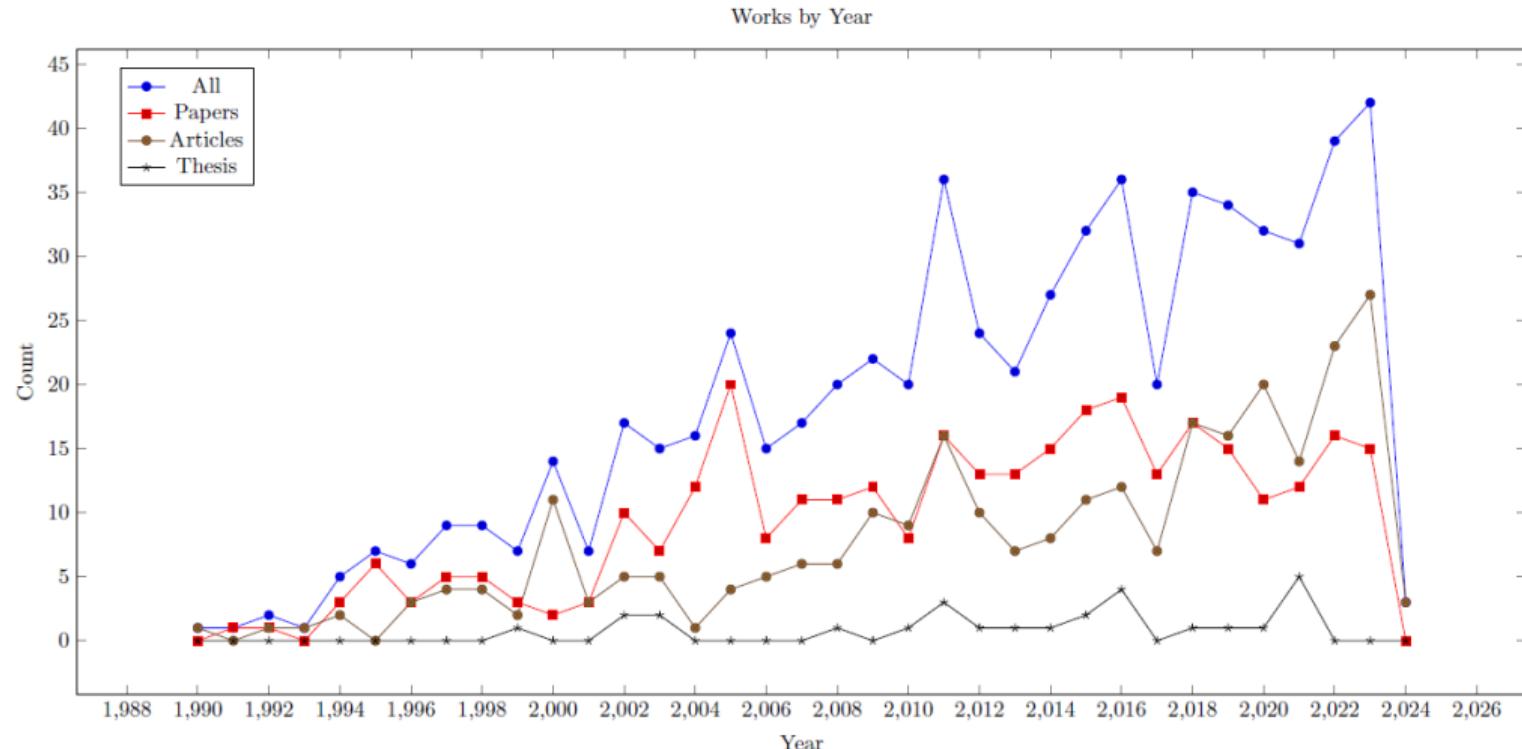
# A Survey of the Existing Literature

- Joint work with Cemalettin Oztekin, MTU
- What is out there
- Where to start
- Where to publish
- I'm interested in some specific topic, what is relevant

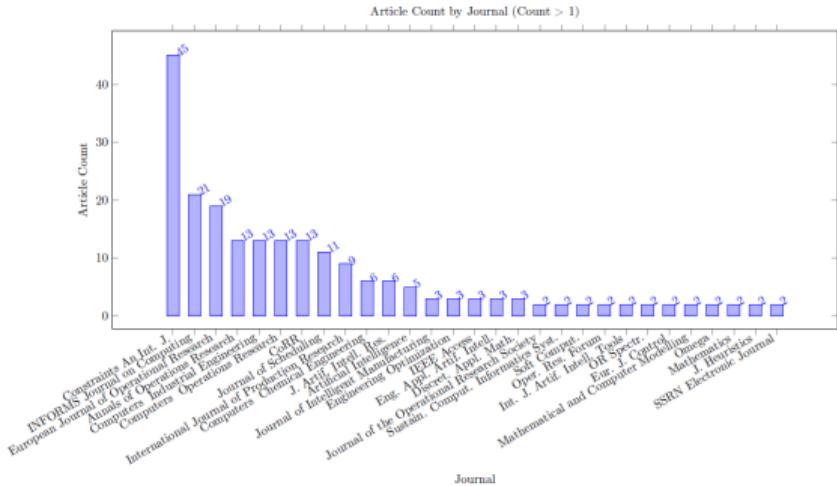
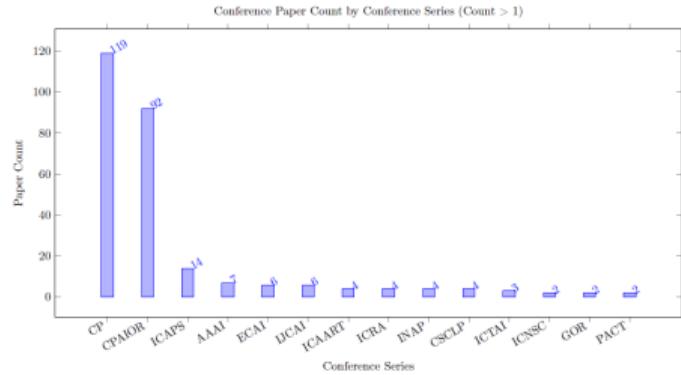
# Methodology

- Manually curated list of works, somewhat inclusive
- Starting with bibtex files
- Citation links through OpenCitations (open access)
- Content analysis on local copies of pdf files
- Closure of domain by analyzing missing cited and citing works
- Limited manual analysis of works (datasets, code)
- Results presented as LaTeX documents
- Open source analysis on git: <https://hsimonis.github.io/pthg24/>

# Overall Analysis (Based on 671 Works)



# Origin of Papers/Articles



# Most Recent Articles

Table 5: Works from bibtex (Total 274)

| Key  | Authors  | Title  | LC  | Cite | Year | Conference /Journal  | Pages | Nr Cites | Nr Refs | b    | c    |
|--|--|--|-----|------|------|--|-------|----------|---------|------|------|
| ForbesHJST24<br>ForbesHJST24               | M. Forbes, M. Harris, H. Jansen, F.A. van der Schoot, T. Taimre  | Combining optimisation and simulation using logic-based Benders decomposition  | Yes | 217  | 2024 | European Journal of Operational Research                       | 15    | 0        | 26      | 1314 | 1496 |
| PrataAN23<br>PrataAN23                     | Bruno A. Prata, Levi R. Abreu, Marcelo S. Nagano   | Applications of constraint programming in production scheduling problems: A descriptive bibliometric analysis                                | Yes | 509  | 2024 | Results in Control and Optimization                            | 17    | 0        | 0       | 1427 | 1497 |
| abs-2402-00459<br>abs-2402-00459           | S. Nguyen, Dhananjay R. Thiruvady, Y. Sun, M. Zhang  | Genetic-based Constraint Programming for Resource Constrained Job Scheduling   | Yes | 469  | 2024 | CoRR   | 21    | 0        | 0       | 1495 | 1498 |
| AbreuNP23<br>AbreuNP23                     | Levi Ribeiro de Abreu, Marcelo Seido Nagano, Bruno A. Prata  | A new two-stage constraint programming approach for open shop scheduling problem with machine blocking                                       | Yes | 168  | 2023 | International Journal of Production Research                   | 20    | 1        | 47      | 1243 | 1499 |
| AbreuPNF23<br>AbreuPNF23                   | Levi R. Abreu, Bruno A. Prata, Marcelo S. Nagano, Jose M. Framinan   | A constraint programming-based iterated greedy algorithm for the open shop with sequenc-dependent processing times and makespan minimization | Yes | 3    | 2023 | Computers Operations Research                                  | 12    | 0        | 46      | 1244 | 1500 |
| Adelgren2023<br>Adelgren2023               | N. Adelgren, Christos T. Maravelias  | On the utility of production scheduling formulations including record keeping variables  | Yes | 7    | 2023 | Computers Industrial Engineering                               | 12    | 0        | 43      | 1245 | 1501 |
| AfsarVPG23<br>AfsarVPG23                   | S. Afsar, Camino R. Vela, Juan José Palacios, I. González-Rodríguez  | Mathematical models and benchmarking for the fuzzy job shop scheduling problem   | Yes | 8    | 2023 | Computers Industrial Engineering                               | 14    | 0        | 50      | 1246 | 1502 |
| AkramNHRSA23<br>AkramNHRSA23               | Bilal Omar Akram, Nor Kamariah Noordin, F. Hashim, Mohd Fadlee A. Rasid, Mustafa Ismael Salman, Abdulrahman M. Abdughani | Joint Scheduling and Routing Optimization for Deterministic Hybrid Traffic in Time-Sensitive Networks Using Constraint Programming           | Yes | 13   | 2023 | IEEE Access  | 16    | 0        | 0       | 1248 | 1503 |
| AlfieriGPS23<br>AlfieriGPS23               | A. Alfieri, M. Garraffa, E. Pastore, F. Salassa  | Permutation flowshop problems minimizing core waiting time and core idle time  | Yes | 15   | 2023 | Computers Industrial Engineering                               | 13    | 0        | 37      | 1249 | 1504 |
| Caballero23<br>Caballero23                 | Jordi Coll Caballero   | Scheduling through logic-based tools   | Yes | 127  | 2023 | Constraints An Int. J.   | 1     | 0        | 0       | 1287 | 1505 |
| CzerniachowskaWZ23<br>CzerniachowskaWZ23   | K. Czerniachowska, R. Wiczniarek, K. Żywicki   | Constraint Programming for Flexible Flow Shop Scheduling Problem with Repeated Jobs and Repeated Operations                                  | Yes | 159  | 2023 | Advances in Science and Technology Research Journal            | 14    | 0        | 0       | 1297 | 1506 |
| FahimiQ23<br>FahimiQ23                     | H. Fahimi, C. Quimper  | Overload-Checking and Edge-Finding for Robust Cumulative Scheduling  | No  | 207  | 2023 | INFORMS Journal on Computing                                   | null  | 0        | 16      | No   | 1507 |
| Fatemi-AnarakiTFV23<br>Fatemi-AnarakiTFV23 | S. Fatemi-Anaraki, R. Tavakkoli-Moghaddam, M. Foumani, B. Vahedi-Nouri   | Scheduling of Multi-Robot Job Shop Systems in Dynamic Environments: Mixed-Integer Linear Programming and Constraint Programming Approaches   | Yes | 212  | 2023 | Omega  | 15    | 7        | 60      | 1312 | 1508 |
| GhasemiMH23<br>GhasemiMH23                 | S. Ghasemi, R. Tavakkoli-Moghaddam, M. Hamid   | Operating room scheduling by emphasising human factors and dynamic decision-making styles: a constraint programming method                   | No  | 242  | 2023 | International Journal of Systems Science: Operations Logistics | null  | 0        | 104     | No   | 1509 |
| GuoZ23<br>GuoZ23                           | P. Guo, J. Zhu   | Capacity reservation for humanitarian relief: A logic-based Benders decomposition method with subgradient cut                                | Yes | 269  | 2023 | European Journal of Operational Research                       | 29    | 0        | 112     | 1325 | 1510 |
| GurPAE23<br>GurPAE23                       | S. Gür, M. Pinarbasi, Haci Mehmet Alakas, T. Eren  | Operating room scheduling with surgical team: a new approach with constraint programming and goal programming                                | Yes | 270  | 2023 | Central Eur. J. Oper. Res.                                     | 25    | 1        | 40      | 1327 | 1511 |
| IsikYA23<br>IsikYA23                       | Eyüp Ensar Isik, Seyda Topaloglu Yıldız, Özge Satır Akpınar  | Constraint programming models for the hybrid flow shop scheduling problem and its extensions   | Yes | 321  | 2023 | Soft Comput.   | 28    | 0        | 127     | 1350 | 1512 |
| JuviniHL23a<br>JuviniHL23a                 | C. Juvini, L. Houssin, P. Lopez  | Logic-based Benders decomposition for the prver:ptv:ia flexible job-shop scheduling problem  | Yes | 331  | 2023 | Computers Operations Research                                  | 17    | 0        | 40      | 1355 | 1513 |
| LacknerMMWW23<br>LacknerMMWW23             | M. Lackner, C. Mrkvicka, N. Muslu, D. Walkertowicz, C. Winter  | Exact methods for the Oven Scheduling Problem  | Yes | 374  | 2023 | Constraints An Int. J.   | 42    | 0        | 32      | 1371 | 1514 |



# Automatically Extracted Article Features

Table 6: Automatically Extracted ARTICLE Properties (Requires Local Copy)

| Work                 | Pages | Concepts  | Classification                        | Constraints  | Prog Languages       | CP Systems   | Areas  | Industries   | Benchmarks  | Algorithm  | a    | c    |
|----------------------|-------|---|---------------------------------------|--|----------------------|--|--|--|---|--|------|------|
| Laborie03 [369]      | 38    | task, precedence, order, cmax, machine, job, activity, re-scheduling, setup-time, release-date, inventory, preempt, job-shop, resource, scheduling, make-span   |                                       | cycle, table constraint, cumulative, disjunctive   | C++                  | Ilog Scheduler   |  |  | benchmark   | edge-finding, not-last, energetic reasoning, not-first, time-tabling | 1201 | 1731 |
| LaborieRSV18 [372]   | 41    | release-date, job-shop, resource, activity, precedence, sequence dependent setup, earliness, scheduling, machine, inventory, transportation, manpower, due-date, setup-time, batch process, order, tardiness, flow-shop, job, make-span, re-scheduling, task, distributed | psplib, parallel machine, RCPSP       | alternative constraint, cumulative, noOverlap, disjunctive, span constraint, cycle, alwaysIn, endBeforeStart | C, Python, C++, Java | CHIP, Gecode, Ilog Solver, Cplex, Ilog Scheduler, OPL, Choco Solver, CPO | semiconductor railway, container terminal, satellite, robot, pipeline, aircraft, shipping line | chemical industry, petro-chemical industry                   | real-world, CSPlib, benchmark   | edge-finding   | 1080 | 1610 |
| LacknerMMWW23 [374]  | 42    | release-date, batch process, setup-time, job, order, due-date, tardiness, scheduling, make-span, machine, task, lateness, job-shop, earliness   | parallel machine, OSP, single machine | alternative constraint, disjunctive, bin-packing, noOverlap, cumulative, endBeforeStart                      |                      | Chuffed, Cplex, OPL, CPO, OR-Tools, MiniZinc, Gurobi                     | semiconductor oven scheduling  | electronics industry, steel industry, manufacturing industry | random instance, industrial partner, benchmark, instance generator, zenodo, real-life | time-tabling   | 984  | 1514 |
| LammaMM97 [377]      | 15    | job-shop, resource, scheduling, precedence, order, task, job, distributed, no-wait  |                                       | circuit, disjunctive   | C++, Prolog          | ECLiPSe, OPL, CHIP   | railway  |  |   |  | 1230 | 1760 |
| LetortCB15 [385]     | 52    | machine, make-span, job, precedence, resource, scheduling, task, order  | psplib                                | cumulative, cycle, bin-packing   | Java, Prolog         | Choco Solver, CHIP, SICStus  |  |  | generated instance, Roadef, benchmark, random instance                                | energetic reasoning, sweep, edge-finding                             | 1110 | 1640 |
| LiW08 [386]          | 18    | precedence, activity, resource, completion-time, setup-time, make-span, scheduling, machine, preempt, job-shop, no preempt, job, re-scheduling, open-shop, due-date, task, order  | RCPSP                                 | disjunctive, cycle, bin-packing  |                      | Ilog Solver, OZ, Cplex, ECLiPSe, OPL, CHIP                               |  |  | real-world  |  | 1178 | 1708 |
| LiessM08 [388]       | 12    | preempt, resource, scheduling, machine, job, activity, precedence, job-shop, task, make-span, order, cmax   | RCPSP, psplib                         | disjunctive, cumulative  | C++                  | OZ   |  |  | benchmark   | edge-finding   | 1179 | 1709 |
| LimtanyakulS12 [393] | 32    | release-date, scheduling, order, completion-time, job, resource, activity, tardiness, machine, due-date, precedence   |                                       | table constraint, disjunctive, bin-packing, cumulative   |                      | OZ, Ilog Scheduler, Cplex  | robot, automotive  | automotive industry  | random instance, real-life, generated instance, industrial partner, benchmark         | not-last, energetic reasoning, not-first, edge-finding               | 1133 | 1663 |
| LombardiM10a [402]   | 30    | due-date, distributed, order, job, make-span, release-date, re-scheduling, task, completion-time, resource, activities, precedence, preempt   | TCSP                                  | cycle, span constraint, cumulative, disjunctive, table constraint  | C                    | Cplex  |  |  | real-world, benchmark, real-life  | sweep  | 1160 | 1690 |



# Manually Extracted Article Features

Table 4: Manually Defined PAPER Properties

| Key  | Title (Local Copy)  | CP System  | Bench   | Links | Data Avail           | Sol Avail | Code Avail | Related To | Classification               | Constraints                                 | a  | b   |
|--|---|--|---|-------|----------------------|-----------|------------|------------|------------------------------|---|----|-----|
| AalianPG23<br>AalianPG23 [1]                       | Optimization of Short-Term Underground Mine Planning Using Constraint Programming   | CP Opt   | real-world  | 1     | n                    | n         | -          | -          | -                            | ?   | 1  | 325 |
| Bit-Monnot23<br>Bit-Monnot23 [96]                  | Enhancing Hybrid CP-SAT Search for Disjunctive Scheduling   | ARIES<br>CP Opt<br>OR-Tools<br>Mistral<br>OR-Tools | real-world,<br>github, bench-<br>mark   | 1     | y                    | y         | -          | -          | JSSP<br>OSSP                 | -   | 2  | 371 |
| EfthymiouY23<br>EfthymiouY23 [124]                 | Predicting the Optimal Period for Cyclic Hoist Scheduling Problems  | Mistral<br>OR-Tools                                | benchmark, ran-<br>dom instance,<br>generated in-<br>stance, real-life,<br>industrial in-<br>stance | 3     | n                    | n         | -          | -          | CHSP                         | -   | 3  | 415 |
| JuvinHHL23<br>JuvinHHL23 [328]                     | An Efficient Constraint Programming Approach to Preemptive Job Shop Scheduling  | CP Opt<br>Mistral                                  | supplementary<br>material,<br>github, bench-<br>mark  | 6     | ref                  | y         | -          | -          | PJSSP                        | endBeforeStart<br>span<br>noOverlap         | 4  | 476 |
| JuvinHL23<br>JuvinHL23 [330]                       | Constraint Programming for the Robust Two-Machine Flow-Shop Scheduling Problem with Budgeted Uncertainty                          | CP Opt<br>Cplex                                    | real-world  | 0     | ref                  | n         | -          | -          | Perm FSSP                    | endBeforeStart<br>noOverlap<br>sameSequence | 5  | 477 |
| KameugneFND23<br>KameugneFND23 [336]               | Horizontally Elastic Edge Finder Rule for Cumulative Constraint Based on Slack and Density  | ?  | benchmark   | 5     | BL<br>PSplib         | n         | -          | -          | RCPPSPs                      | cumulative                                  | 6  | 480 |
| KimCMILLP23<br>KimCMILLP23 [345]                   | Iterated Greedy Constraint Programming for Scheduling Steelmaking Continuous Casting  | Gurobi<br>OR-Tools                                 | real-world,<br>benchmark,<br>zenodo   | 0     | y                    | n         | -          | -          | SCC                          | alternative<br>noOverlap                    | 7  | 485 |
| Mehdizadeh-Somarin23<br>Mehdizadeh-Somarin23 [430] | A Constraint Programming Model for a Reconfigurable Job Shop Scheduling Problem with Machine Availability                         | CP Opt   | random instance   | 0     | n                    | n         | -          | -          | JSSP<br>RMS                  | alternative<br>endBeforeStart<br>noOverlap  | 8  | 529 |
| PerezGSL23<br>PerezGSL23 [498]                     | A Constraint Programming Model for Scheduling the Unloading of Trucks in Ports  | custom   | real-world, gen-<br>erated instance   | 0     | n                    | n         | -          | -          | SUTP                         | table                                       | 9  | 553 |
| PovedaAA23<br>PovedaAA23 [506]                     | Partially Preemptive Multi Skill/Mode Resource-Constrained Project Scheduling with Generalized Precedence Relations and Calendars | CP Opt<br>MiniZinc<br>Chuffed                      | real-world,<br>github, bench-<br>mark, industrial<br>instance, real-<br>life                        | 4     | y                    | y         | -          | -          | PP-MS-<br>MMRCPP/max-<br>cal | disjunctive                                 | 10 | 557 |
| SquillaciPR23<br>SquillaciPR23 [564]               | Scheduling Complex Observation Requests for a Constellation of Satellites: Large Neighborhood Search Approaches                   | Cplex Studio                                       | github, bench-<br>mark  | 2     | y                    | n         | -          | -          | EOSP                         | ?   | 11 | 584 |
| TardivoDFMP23<br>TardivoDFMP23 [575]               | Constraint Propagation on GPU: A Case Study for the Cumulative Constraint   | MiniCPP<br>MiniZinc                                | bitbucket,<br>github, bench-<br>mark, real-<br>world  | 9     | PSPLib<br>BL<br>Pack | y         | -          | -          | RCPPSP                       | cumulative                                  | 12 | 590 |
| TasselGS23<br>TasselGS23 [576]                     | An End-to-End Reinforcement Learning Approach for Job-Shop Scheduling Problems Based on Constraint Programming                    | custom<br>Choco                                    | industrial<br>instance, real-<br>world, supple-<br>mentary mat-<br>erial, github,<br>benchmark      | 0     | ref                  | y         | -          | -          | JSSP                         | noOverlap                                   | 13 | 591 |
| WangB23<br>WangB23 [629]                           | Dynamic All-Different and Maximal Cliques Constraints for Fixed Job Scheduling  | FCile  | related Software Generation Survey (y)  | n     | 628                  | FJS       | -          | -          | -                            | -   | 14 | 620 |
| YuraszeczkMC23                                     | A competitive constraint programming approach   | CP Opt   | github, bench-<br>mark  | 0     | ref                  | n         | -          | -          | GSSP                         | noOverlap                                   | 15 | 633 |



# Extracted Features: Application Areas

Table 16: Works for Concepts of Type ApplicationAreas

| Type             | Keyword            | High  | Medium  | Low   |
|------------------|--------------------|---|---|---|
| ApplicationAreas | COVID              | GuoZ23 [269]  | GeibingerKKMMW21 [234]  | Fatemi-AnarakiTFV23 [212], Mehdizadeh-Somarin23 [430], GurPAE23 [270], JuvivHL23a [331], OujanaAYB22 [487], Lemos21 [381]   |
| ApplicationAreas | HVAC               | LimHTB16 [390], LimBTBB15 [391], GrimesIOS14 [260]  |   |   |
| ApplicationAreas | agriculture        |   |   | AkramNHRSA23 [13], BenderWS21 [84], HamPK21 [275], Astrand21 [35], QinWLSL21 [511], Astrand0F21 [36], MejiaY20 [431]  |
| ApplicationAreas | aircraft           | PohlAK22 [502], WangB20 [628], TranDRFWOVBl6 [596], FahimI16 [205], BajestaniB13 [42], LombardiM12 [405], BajestaniB11 [41], FrankK05 [219], ArtiouchineB05 [34], Simonis99 [558] | WangB23 [629], GombolayWS18 [253], Ham18 [273], Simonis07 [559], SakkoutW00 [529], Simonis95a [556]   | PrataAN23 [509], PovedaAA23 [506], Adelgren2023 [7], EttmianiesfahaniGNMS22 [202], EleOH22 [195], ZarandiASC20 [654], HauderBRPA20 [283], abs-1902-09244 [282], Hooker19 [312], LaborieRSV18 [372], HookerH17 [314], TranAB16 [594], LombardI10 [398], Laboriet09 [370], KovacsB08 [355], KrogLPHJ07 [608], MartinPY01 [427], SimonisCK00 [560], GruianK98 [264], Darby-DownmanLMZ97 [163], Wallace96 [625], Simonis05 [557], Simonis95 [561]   |
| ApplicationAreas | automotive         |   | GuoZ23 [269], YuraszeczkMPV22 [650], EmdeZD22 [199], Grolearz1 [261], LimtanyakulS12 [363], SunLYL10 [567], LombardI10 [398], BarlattCG08 [52], SchildW00 [532] | PovedaAA23 [506], NaderiRR23 [460], CzerniawskiWZ23 [159], NaderiBZ22 [457], NaderiBZ22a [456], AntuoriHHEN21 [22], HubnerGSV21 [318], AbreuAPNM21 [166], KoehlerBFFHPSSS21 [348], VlkH121 [623], BarzegaranZP20 [61], GeibingerMM19 [236], abs-1911-04766 [231], BonfettiZLM16 [113], Sialai5a [552], SchnellH15 [533], AlecioNGC14 [181], HarjunkoskiMBC14 [279], BeniniBGM06 [88], KovacsV06 [360], Wallace96 [625]  |
| ApplicationAreas | cable tree         | KoehlerBFFHPSSS21 [348]   |   | BeldiceanuC94 [78], abs-2312-13682 [497], PerezGSL23 [496], TouatBT22 [592], CauwelaertDS20 [142], WallaceY20 [627], ZarandiASC20 [654], FallahiAC20 [209], Hooker19 [312], CauwelaertDMS16 [140], Dejemeppe16 [172], DejemeppeCS15 [173], Novash12 [476], CorreaLR07 [158], LimRXP04 [389], NaderiHR23 [460], WangB23 [629], Adelgren2023 [7], EttmianiesfahaniGNMS22 [202], NaderiBZ22a [456], NaderiBZ22 [457], HeinzNVH22 [295], EleOH22 [195], Lemos21 [381], MokhtarzadehTIN20 [443], TangLWSK18 [574], HookerH17 [314], DoulaibiRP16 [190], LipovetzkyBPS14 [394], HachemiGR11 [278], MilanoW09 [441], WuB309 [643], MilanoW06 [340], BeldiceanuC02 [79], JainG01 [323], SimonisCK00 [560] |
| ApplicationAreas | car manufacturing  |   |   | Bartak02 [64], Bartak02a [53], Grolearz1 [261]  |
| ApplicationAreas | container terminal | QinDCS20 [512], SacramentoSP20 [526]  | AntuoriHHEN21 [22], LaborieRSV18 [372]  | Zahoui21 [652], GalleguillosKSB19 [225], Madl-WambaLOBM17 [418], Letort13 [382], IfrimOS12 [320], LetortBC12 [383]  |
| ApplicationAreas | crew-scheduling    | ZarandiASC20 [654], PourDERB18 [505]  | BourreauGGLT22 [118], Zahoui21 [652], GombolayWS18 [253], Mason01 [429], Touraivane93 [593]   | NaderiHR23 [460], WangB23 [629], Adelgren2023 [7], EttmianiesfahaniGNMS22 [202], NaderiBZ22a [456], NaderiBZ22 [457], HeinzNVH22 [295], EleOH22 [195], Lemos21 [381], MokhtarzadehTIN20 [443], TangLWSK18 [574], HookerH17 [314], DoulaibiRP16 [190], LipovetzkyBPS14 [394], HachemiGR11 [278], MilanoW09 [441], WuB309 [643], MilanoW06 [340], BeldiceanuC02 [79], JainG01 [323], SimonisCK00 [560]  |
| ApplicationAreas | dairies            |   |   | Bartak02 [64], Bartak02a [53]   |
| ApplicationAreas | dairy              | EscobetPQPR19 [201]   | PrataAN23 [509], HarjunkoskiMBC14 [279]   | Grolearz1 [261]   |
| ApplicationAreas | datacenter         | HermenierDL11 [300]   |   | Zahoui21 [652], GalleguillosKSB19 [225], Madl-WambaLOBM17 [418], Letort13 [382], IfrimOS12 [320], LetortBC12 [383]  |
| ApplicationAreas | datacentre         |   | HurleyOS16 [319]  | HebrardALLCMR22 [285]   |
| ApplicationAreas | day-ahead market   |   |   | GuoZ23 [269], JuvivHL23a [331], Adelgren2023 [7]  |
| ApplicationAreas | deep space         | MontemannD23a [446], MontemannD23 [447], Ham18 [273]  |   | ShaikhK23 [547], EmdeZD22 [199], Astrand21 [35], Astrand0F21 [36], AntuoriHHEN21 [22], ZarandiASC20 [654], Ham18a [274]   |
| ApplicationAreas | drone              |   |   |   |



# Prolific Authors

Table 8: Co-Authors of Articles/Papers

| Author              | Nr Works | Nr Cites | Entries   |
|---------------------|----------|----------|---|
| J. Christopher Beck | 49       | 701      | LuoB22 [416], ZhangBB22 [658], TangB20 [573], RoshanaeiBAUB20 [521], TranPZLDB18 [597], TranVNB17 [599], TranVNB17a [600], CohenHB17 [154], BoothNB16 [114], KuB16 [365], TranAB16 [594], TranRFOVB16 [601], LuovLBM16 [415], TranDRFWOVB16 [596], BajestaniB15 [43], KoschB14 [353], TerekhovTDB14 [581], LouieVNB14 [412], HeinzSB13 [294], HeinzKB13 [291], BajestaniB13 [42], TranTDB13 [598], HeinzB12 [290], TerekhovDOB12 [580], TranB12 [595], ZarandiB12 [213], KovacsB11 [356], BeckFW11 [66], HeckmanB11 [289], BajestaniB11 [41], WuBB09 [643], BidotVLOB09 [94], CarchraeB09 [131], WatsonB08 [632], KovacsB08 [355], BeckW07 [73], Beck07 [64], KovacsB07 [354], Beck06 [63], CarchraeBF05 [132], WuBB05 [642], BeckW05 [72], BeckW04 [71], BeckR03 [70], BeckPS03 [69], BeckF00 [68], Beck99 [62], BeckF98 [67], BeckDF97 [65] |
| Michela Milano      | 31       | 297      | BorghesiBLMB18 [115], BonfiettiZLM16 [113], BridiBLMB16 [120], BridiLBBM16 [121], LombardiBM15 [399], BartoliniBBLM14 [60], BonfiettiILM14 [111], BonfiettiLBM14 [109], BonfiettiLM13 [110], LombardiM13 [406], LombardiMB13 [407], LombardiM12 [405], BonfiettiLBM12 [108], LombardiM12a [404], BonfiettiM12 [112], BonfiettiLBM11 [107], LombardiBMB11 [400], BeniniLMR11 [90], Milano11 [438], LombardiM10 [403], LombardiM10a [402], LombardiMRB10 [408], LombardiM09 [401], RuggieroBBMA09 [525], MilanoW09 [441], BeniniLMR08 [89], BeniniBGM06 [88], MilanoW06 [440], MilanoORT02 [439], LammaMM97 [377], BrusoniCLMT19 [123]  |
| Andreas Schutt      | 27       | 322      | YangSS19 [644], KreterSSZ18 [364], GoldwaserS18 [251], MushiSS18 [455], KreterSS17 [363], YoungFS17 [646], GoldwaserS17 [250], SchuttS16 [543], SzorediS16 [570], KreterSS15 [362], EvenSH15a [203], EvenSH15a [204], SchuttFSW15 [542], ThiruvadyWGS14 [555], GuSSWC14 [266], Schut-tFSI13 [537], SchuttFSI13a [536], GuS13 [265], SchuttFSW13 [541], ChugNSW13 [147], SchuttCSW12 [535], SchuttFSW11 [540], Schutt11 [534], SchuttW10 [544], abs-1009-0347 [539], SchuttFSW09 [538], SchuttWS05 [545]   |
| Michele Lombardi    | 25       | 194      | BorghesiBLMB18 [115], CauwelaertLS18 [141], BonfiettiZLM16 [113], BridiBLMB16 [120], BridiLBBM16 [121], LombardiBM15 [399], BartoliniB-BLM14 [60], BonfiettiLM14 [111], BonfiettiLBM14 [109], BonfiettiLM13 [110], LombardiM13 [406], LombardiMB13 [407], LombardiM12 [405], BonfiettiLBM12 [108], LombardiM12a [404], BonfiettiLBM11 [107], LombardiBMB11 [400], BeniniLMR11 [90], LombardiM10 [403], LombardiM10a [402], LombardiMRB10 [408], LombardiM09 [401], BeniniLMR08 [89], HoeveGLS07 [609]   |
| Peter J. Stuckey    | 24       | 453      | YangSS19 [644], DemirovicS18 [177], KreterSSZ18 [364], MushiSS18 [455], KreterSS17 [363], SchuttS16 [543], BlompS16 [100], KreterSS15 [362], BurtLPS15 [124], SchuttFSW15 [542], BlomBPS14 [99], LipovetskyBPS14 [394], GuSSWC14 [266], SchuttFSI13 [537], SchuttFSI13a [536], GuS13 [265], SchuttFSW13 [541], SchuttCSW12 [535], GuSW12 [267], SchuttFSW11 [540], BandaSC11 [170], abs-1009-0347 [539], Schut-tFSW09 [538], OhrimenkoSK09 [483]  |
| John N. Hooker      | 19       | 1316     | EliCIH22 [195], Hooker19 [312], Hooker17 [311], HookerH17 [314], HechingH16 [288], CireCH16 [150], HarjunkoskiMBC14 [279], CireCH13 [149], CobanH11 [153], CobanH10 [152], Hooker10 [310], Hooker07 [309], Hooker06 [308], Hooker05 [306], Hooker05a [307], Hooker04 [305], Hooker003 [313], HookerY02 [315], Hooker00 [304]  |
| Emmanuel Hebrard    | 17       | 71       | JuvinHH23 [323], HebrardALLCMR22 [285], AntuoriHHEN21 [22], ArtiguesHQ21 [32], GodetLHS20 [247], AntuoriHHEN20 [21], Hebrard-HJMPV16 [286], SimoninAHL15 [555], SialaAH15 [553], GrimesH15 [258], BessiereHMQW14 [93], SimoninAHL12 [554], BillautHL12 [95], GrimesH11 [257], GrimesH10 [256], GrimesHM09 [259], HebrardTW05 [287]  |
| Pierre Lopez        | 17       | 90       | JuvinHH23 [328], JuvinHL23a [331], JuvinHL23 [330], HebrardALLCMR22 [285], JuvinHL22 [329], Polo-MejiaALB20 [503], NattafHKAL19 [466], NattafAL17 [463], NattafALR16 [464], SimoninAHL15 [555], NattafAL15 [462], SimoninAHL12 [554], BillautHL12 [95], LahimerLH11 [375], Tro-letHL11 [602], LopezAKYG001 [410], TorresL00 [591]   |
| Christian Artigues  | 16       | 203      | PovedaAA23 [506], PohlAK22 [502], HebrardALLCMR22 [285], ArtiguesHQ21 [32], Polo-MejiaALB20 [503], NattafHKAL19 [466], NattafAL17 [463], NattafALR16 [464], SimoninAHL15 [555], NattafAL15 [462], SialaAH15 [553], SimoninAHL12 [554], NeronABCDD06 [481], DemasseyAO05 [176], ArtiguesBF04 [30], ArtiguesR00 [33]  |
| Pierre Schaus       | 15       | 79       | CauwelaertDS20 [142], ThomasK20 [586], HoundJSW19 [316], CapartTSR18 [130], CauwelaertLS18 [141], CapartS17 [129], Cauwelaert-DMS16 [140], DejemeppeCS15 [173], GayHLS15 [220], GayHS15 [230], GayHS15a [231], HoundJSW14 [314], GaySS14 [232], SchausHM-CMD11 [521], SchausD08 [530]   |
| Helmut Simonis      | 15       | 154      | ArmstrongGOS22 [27], ArmstrongGOS21 [26], AntunesABD20 [20], AntunesABD18 [19], HurleyOS16 [319], GrimesIOS14 [260], IfrimOS12 [320], SimonisH11 [562], Simonis07 [559], SimonisCK00 [560], Simonis99 [558], SimonisC95 [561], Simonisfa [556], DincbasSH90 [184]   |
| Nicolas Beldiceanu  | 13       | 274      | Madi-WambaLOBM17 [418], Madi-WambaB16 [417], LetortCBI15 [385], LetortCBI13 [384], LetortBCI2 [383], ClercqPB11 [151], BeldiceanuCDP11 [80], BeldiceanuCP08 [81], PoderBS08 [500], BeldiceanuP07 [82], PoderBS04 [501], BeldiceanuC02 [79], AggounB93 [9]   |
| Luca Benini         | 13       | 146      | BorghesiBLMB18 [115], BridiBLMB16 [120], BridiLBBM16 [121], BonfiettiLBM14 [109], LombardiBMB13 [407], BonfiettiLBM12 [108], BonfiettiLBM11 [107], LombardiMB11 [408], RuggieroBBMA09 [525], BeniniLMR08 [89], BeniniBGM06 [88]   |
| Philippe Laborie    | 12       | 513      | LunardiBLRV20 [413], LaborieRSV18 [372], Laborie18a [371], MelgaroleS15 [11], VilimLS15 [621], Laborie09 [370], BidotVLB09 [94], Baptis-  |



# Limitations

- Limited coverage by OpenCitations
- Difficult to have local access to some publication types (book, incollection)
- Heavily biased towards publications in English
- More powerful NLP analysis of works possible?

# Problem: Count for Most Cited Papers

Table 9: Works from bibtex (Total 30)

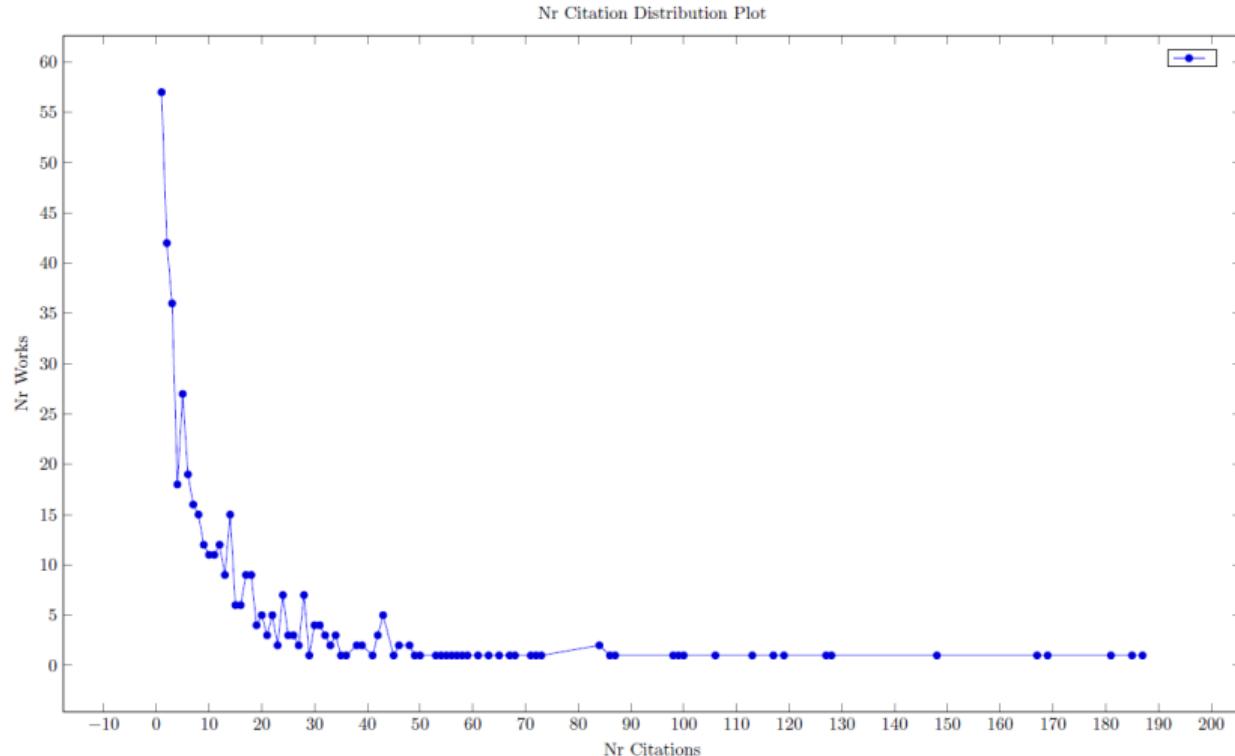
| Key                                 | Authors   | Title   | LC  | Cite | Year | Conference /Journal                            | Pages | Nr Cites | Nr Refs | b    | c    |
|-------------------------------------|---|---|-----|------|------|--|-------|----------|---------|------|------|
| JainM99 [JainM99]                   | A. Jain   S. Meeran   | Deterministic job-shop scheduling: Past, present and future   | Yes | 322  | 1999 | European Journal of Operational Research       | 45    | 490      | 150     | 1352 | 1753 |
| HarjunkoskiMBC14 [HarjunkoskiMBC14] | I. Harjunkoski   Christos T. Maravelias   P. Bongers   Pedro M. Castro   S. Engell   Ignacio E. Grossmann   John N. Hooker   C. Méndez   G. Sand   J. Wassick | Scope for industrial applications of production scheduling models and solution methods  | Yes | 279  | 2014 | Computers Chemical Engineering                 | 33    | 381      | 176     | 1335 | 1649 |
| BlazewiczDP96 [BlazewiczDP96]       | J. Blazewicz   W. Domschke   E. Pesch   | The job shop scheduling problem: Conventional and new solution techniques   | Yes | 125  | 1996 | European Journal of Operational Research       | 33    | 344      | 127     | 1278 | 1762 |
| HookerO03 [HookerO03]               | John N. Hooker   G. Ottosson  | Logic-based Benders decomposition   | Yes | 313  | 2003 | Mathematical Programming                       | 28    | 317      | 0       | 1347 | 1729 |
| BaptistePN01 [BaptistePN01]         | P. Baptiste   Claude Le Pape   W. Nuijten   | Constraint-Based Scheduling   | No  | 50   | 2001 | Book   | null  | 296      | 0       | No   | n/a  |
| JainG01 [JainG01]                   | V. Jain   Ignacio E. Grossmann  | Algorithms for Hybrid MILP/CP Models for a Class of Optimization Problems   | Yes | 323  | 2001 | INFORMS Journal on Computing                   | 19    | 279      | 23      | 1351 | 1738 |
| AggounB93 [AggounB93]               | A. Aggoun   N. Beldiceanu   | Extending CHIP in order to solve complex scheduling and placement problems  | Yes | 9    | 1993 | Mathematical and Computer Modelling            | 17    | 187      | 11      | 1247 | 1767 |
| Hooker00 [Hooker00]                 | John N. Hooker  | Logic Based Methods for Optimization: Combining Optimization and Constraint Satisfaction  | No  | 304  | 2000 | Book   | null  | 185      | 0       | No   | n/a  |
| Hooker07 [Hooker07]                 | John N. Hooker  | Planning and Scheduling by Logic-Based Benders Decomposition  | Yes | 309  | 2007 | Operations Research                            | 29    | 181      | 19      | 1345 | 1715 |
| HarjunkoskiG02 [HarjunkoskiG02]     | I. Harjunkoski   Ignacio E. Grossmann   | Decomposition techniques for multistage scheduling problems using mixed-integer and constraint programming methods                    | Yes | 278  | 2002 | Computers Chemical Engineering                 | 20    | 169      | 11      | 1334 | 1733 |
| BeldiceanuC94 [BeldiceanuC94]       | N. Beldiceanu   E. Contejean  | Introducing Global Constraints in CHIP  | Yes | 78   | 1994 | Mathematical and Computer Modelling            | 27    | 167      | 8       | 1271 | 1765 |
| LaborieRSV18 [LaborieRSV18]         | P. Laborie   J. Rogerie   P. Shaw   P. Vilim  | IBM ILOG CP optimizer for scheduling - 20+ years of scheduling with constraints at IBM/ILOG   | Yes | 372  | 2018 | Constraints An Int. J.                         | 41    | 148      | 35      | 1370 | 1610 |
| Laborie03 [Laborie03]               | P. Laborie  | Algorithms for propagating resource constraints in AI planning and scheduling: Existing approaches and new results                    | Yes | 369  | 2003 | Artificial Intelligence                        | 38    | 128      | 10      | 1369 | 1731 |
| OhrimenkoSC09 [OhrimenkoSC09]       | O. Ohrimenko   Peter J. Stuckey   M. Codish   | Propagation via lazy clause generation  | Yes | 483  | 2009 | Constraints An Int. J.                         | 35    | 127      | 15      | 1417 | 1702 |
| KuB16 [KuB16]                       | W. Ku   J. Christopher Beck   | Mixed Integer Programming models for job shop scheduling: A computational analysis  | Yes | 465  | 2016 | Computers Operations Research                  | 9     | 119      | 17      | 1367 | 1630 |
| Rodriguez07 [Rodriguez07]           | J. Rodriguez  | A constraint programming model for real-time train scheduling at junctions  | Yes | 520  | 2007 | Transportation Research Part B: Methodological | 15    | 117      | 6       | 1430 | 1716 |
| LiW08 [LiW08]                       | H. Li   K. Womer  | Scheduling projects with multi-skilled personnel by a hybrid MILP/CP benders decomposition algorithm                                  | Yes | 386  | 2008 | Journal of Scheduling                          | 18    | 113      | 31      | 1374 | 1708 |
| CorrealLR07 [CorrealLR07]           | Ayoub Insa Correal   A. Langevin   L. Rousseau  | Scheduling and routing of automated guided vehicles: A hybrid approach  | Yes | 158  | 2007 | Computers Operations Research                  | 20    | 106      | 20      | 1296 | 1714 |
| MengZRZL20 [MengZRZL20]             | L. Meng   C. Zhang   Y. Ren   B. Zhang   C. Lv  | Mixed-Integer linear programming and constraint programming formulations for solving distributed flexible job shop scheduling problem | Yes | 435  | 2020 | Computers Industrial Engineering               | 13    | 100      | 62      | 1393 | 1574 |
| BensanaLV99 [BensanaLV99]           | E. Bensana   M. Lemaître   G. Verfaillie  | Earth Observation Satellite Management  | Yes | 91   | 1999 | Constraints An Int. J.                         | 7     | 99       | 0       | 1276 | 1752 |



## OpenCitation Count Compared to Google Scholar

| Key              | Type    | Google | OC  | Ratio |
|------------------|---------|--------|-----|-------|
| JainM99          | article | 1116   | 490 | 2.28  |
| HarjunkoskiMBC14 | article | 588    | 381 | 1.54  |
| BlazewiczDP96    | article | 796    | 344 | 2.31  |
| BaptistePN01     | book    | 1039   | 296 | 3.51  |
| AggounB93        | article | 502    | 187 | 2.68  |
| LaborieRSV18     | article | 309    | 148 | 2.09  |
| BensanaLV99      | article | 251    | 99  | 2.54  |
| DincbasSH90      | article | 271    | 86  | 3.15  |
| Thorsteinsson01  | paper   | 205    | 67  | 3.06  |
| DincbasSH88      | paper   | 287    | 0   | ∞     |

# Problem: Citation Count Distribution



# Reuse Example: Survey of Car Sequencing

Table 9: Works from bibtex (Total 29)

| Key                         | Authors  | Title   | LC  | Cite | Year | Conference /Journal                                       | Pages | Nr Cites | Nr Refs | b   | c   |
|-----------------------------|--|---|-----|------|------|---|-------|----------|---------|-----|-----|
|                             |  |   |     |      |      |   |       |          |         |     |     |
| BoysenFS09                  | N. Boysen, M. Fliedner, A. Scholl                                | Sequencing mixed-model assembly lines: Survey, classification and model critique  | No  | 2    | 2009 | European Journal of Operational Research                  | null  | 308      | 167     | No  | 58  |
| BoysenFS09                  |  |   |     |      |      |   |       |          |         |     |     |
| SolnonCNA08                 | C. Solnon, V. Cung, A. Nguyen, C. Artigues                       | The car sequencing problem: Overview of state-of-the-art methods and industrial case-study of the ROADEF'2005 challenge problem   | No  | 21   | 2008 | European Journal of Operational Research                  | 16    | 146      | 22      | No  | 61  |
| SolnonCNA08                 |  |   |     |      |      |   |       |          |         |     |     |
| ParrelloK86                 | Bruce D. Parrello, Waldo C. Kabat                                | Job-Shop Scheduling Using Automated Reasoning: A Case Study of the Car-Sequencing Problem   | Yes | 14   | 1986 | J. Autom. Reason.   | 42    | 74       | 0       | 46  | 66  |
| ParrelloK86                 |  | On the complexity of the car sequencing problem   | No  | 9    | 2004 | Operations Research Letters                               | null  | 69       | 3       | No  | 62  |
| Kis04 Kis04                 | T. Kis   |   |     |      |      |   |       |          |         |     |     |
| ReginP97 ReginP97           | J. Régin, J. Puget   | A Filtering Algorithm for Global Sequencing Constraints   | Yes | 16   | 1997 | CP 1997   | 15    | 53       | 3       | 17  | 25  |
| GottliebPS03                | J. Gottlieb, M. Puchta, C. Solnon                                | A Study of Greedy, Local Search, and Ant Colony Optimization Approaches for Car Sequencing Problems   | Yes | 7    | 2003 | EvoWorkshop 2003  | 12    | 46       | 5       | 13  | 24  |
| GottliebPS03                |  |   |     |      |      |   |       |          |         |     |     |
| HoevePRS06                  | Willem Jan van Hoeve, G. Pesant, L. Rousseau                     | Revisiting the Sequence Constraint  | Yes | 23   | 2006 | CP 2006   | 15    | 33       | 7       | 14  | 21  |
| HoevePRS06                  | A. Sabharwal   |   |     |      |      |   |       |          |         |     |     |
| OzturkTHO13                 | C. Ozturk, S. Tunali, B. Hnich, M. Arslan Ornek                  | Balancing and scheduling of flexible mixed model assembly lines   | No  | 13   | 2013 | Constraints An Int. J.                                    | 36    | 31       | 44      | No  | 57  |
| OzturkTHO13                 |  | Tackling Car Sequencing Problems Using a Generic Genetic Algorithm  | No  | 25   | 1995 | Evolutionary Computation                                  | null  | 28       | 0       | No  | 64  |
| WarwickT95                  | T. Warwick, Edward P. K. Tsang                                   | Formulation and solution of a selection and sequencing problem in car manufacture   | No  | 8    | 1994 | Computers Industrial Engineering CPAIOR 2004              | null  | 24       | 4       | No  | 65  |
| WarwickT95                  |  | Combining Forces to Solve the Car Sequencing Problem  | Yes | 15   | 2004 | CPAIOR 2004   | 15    | 17       | 9       | 16  | 23  |
| HindiP94 HindiP94           | Khalil S. Hindi, G. Płoszajski                                   | A study of constraint programming heuristics for the car-sequencing problem   | No  | 20   | 2015 | Eng. Appl. Artif. Intell.                                 | 11    | 15       | 10      | No  | 54  |
| PerronS04 PerronS04         | L. Perron, P. Shaw   | Iterative beam search for car sequencing  | No  | 6    | 2014 | Annals of Operations Research                             | null  | 15       | 15      | No  | 55  |
| SialaHH155 SialaHH155       | M. Siala, E. Hebrard, M. Huguet                                  | New filtering algorithms for combinations of among constraints  | No  | 24   | 2009 | Constraints An Int. J.                                    | null  | 13       | 8       | No  | 59  |
| GolleRB14 GolleRB14         | U. Golle, F. Rothlauf, N. Boysen                                 | Constructive metaheuristics for solving the Car Sequencing Problem under uncertain partial demand   | No  | 12   | 2019 | Computers Industrial Engineering                          | 1     | 8        | 44      | No  | 50  |
| HoevePRS09                  | Willem-Jan van Hoeve, G. Pesant, L. Rousseau                     | An optimal arc consistency algorithm for a particular case of sequence constraint   | Yes | 19   | 2014 | Constraints An Int. J.                                    | 27    | 3        | 14      | 47  | 56  |
| HoevePRS09                  | A. Sabharwal   | Parallel Construction Heuristic Combined with Constraint Propagation for the Car Sequencing Problem   | No  | 29   | 2017 | Chinese Journal of Mechanical Engineering CPAIOR 2014     | null  | 3        | 32      | No  | 52  |
| MoyaCB19 MoyaCB19           | I. Moya, M. Chica, J. Bautista                                   | SAT and Hybrid Models of the Car Sequencing Problem   | Yes | 11   | 2014 | ECAI 1988   | 16    | 2        | 16      | 10  | 18  |
| SialaHH14 SialaHH14         | M. Siala, E. Hebrard, M. Huguet                                  | Heuristic approaches for the car sequencing problems with block batches   | No  | 28   | 2022 | EURASIP Journal on Wireless Communications and Networking | null  | 2        | 37      | No  | 48  |
| ZhangGWH17 ZhangGWH17       | X. ZHANG, L. GAO, L. WEN, Z. HUANG                               |   |     |      |      |   |       |          |         |     |     |
| ArtiguesHMO14 ArtiguesHMO14 | C. Artigues, E. Hebrard, V. Mayer-Eichberger, M. Siala, T. Walsh |   |     |      |      |   |       |          |         |     |     |
| YuLZCLW22 YuLZCLW22         | Y. Yu, X. Lu, T. Zhao, M. Cheng, L. Liu, W. Wei                  |   |     |      |      |   |       |          |         |     |     |
| DincbasSH88                 | M. Dincbas, H. Simonis, Pascal Van Hentenryck                    | Solving the Car-Sequencing Problem in Constraint Logic Programming  | Yes | 4    | 1988 | INSA Toulouse, France                                     | 6     | 0        | 0       | 12  | 26  |
| DincbasSH88                 |  |   |     |      |      |   |       |          |         |     |     |
| Siala15 Siala15             | M. Siala   | Search, propagation, and learning in sequencing and scheduling problems. (Recherche, propagation et apprentissage dans les problèmes de séquencement et d'ordonnancement) | Yes | 18   | 2015 | n/a   | 200   | 0        | 0       | 134 | n/a |



# More Detailed Example Applications

- Production Planning and Scheduling
  - Siemens Energy, part of ASSISTANT project
- Outpatient Waitlist Management
  - Working within health service
- Elevator Maintenance Planning and Scheduling
  - Combination with simulation
- Selection of other problem types
  - Only summary slide shown

# Outline

CP and Scheduling Literature Survey

**ASSISTANT SE Use Case**

Outpatient Waitlist Management

Elevator Maintenance Planning and Scheduling

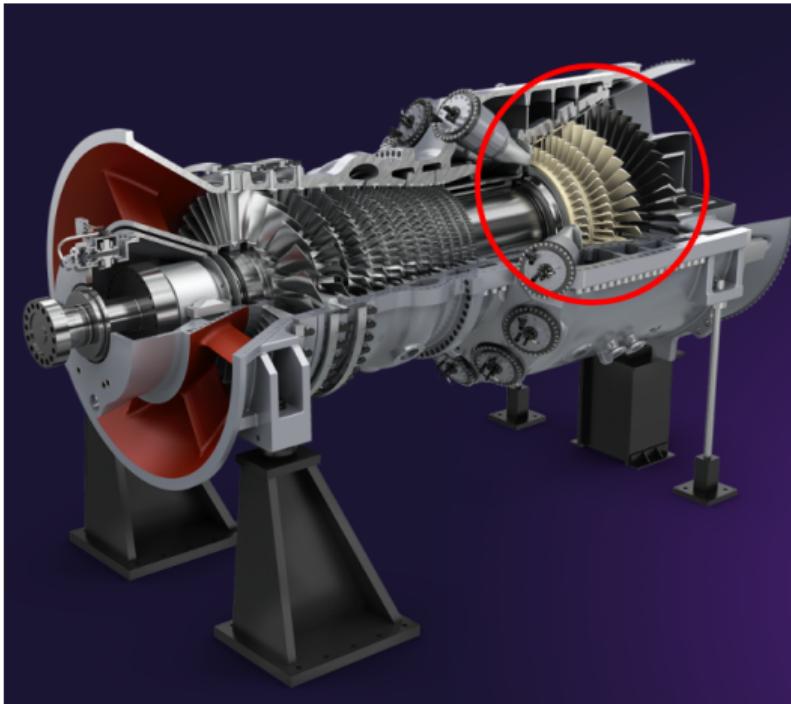
Other Applications

Summary

## An Industrial Example

- ASSISTANT project Siemens Energy use case
- Mid/Long-term scheduling/production planning
- Realistic/not real data
- Rather complex constraint model
  - Multi-stage BOM
  - Alternative Process Paths
  - Alternative machines
  - Quality/cost based routing preferences
  - Potential outsourcing of certain steps
  - Machine specific calendars
  - Infeasible release/due date pairs
  - Calendar dependent speed reduction
  - Complex manpower constraints

# Assistant Siemens Energy Use Case



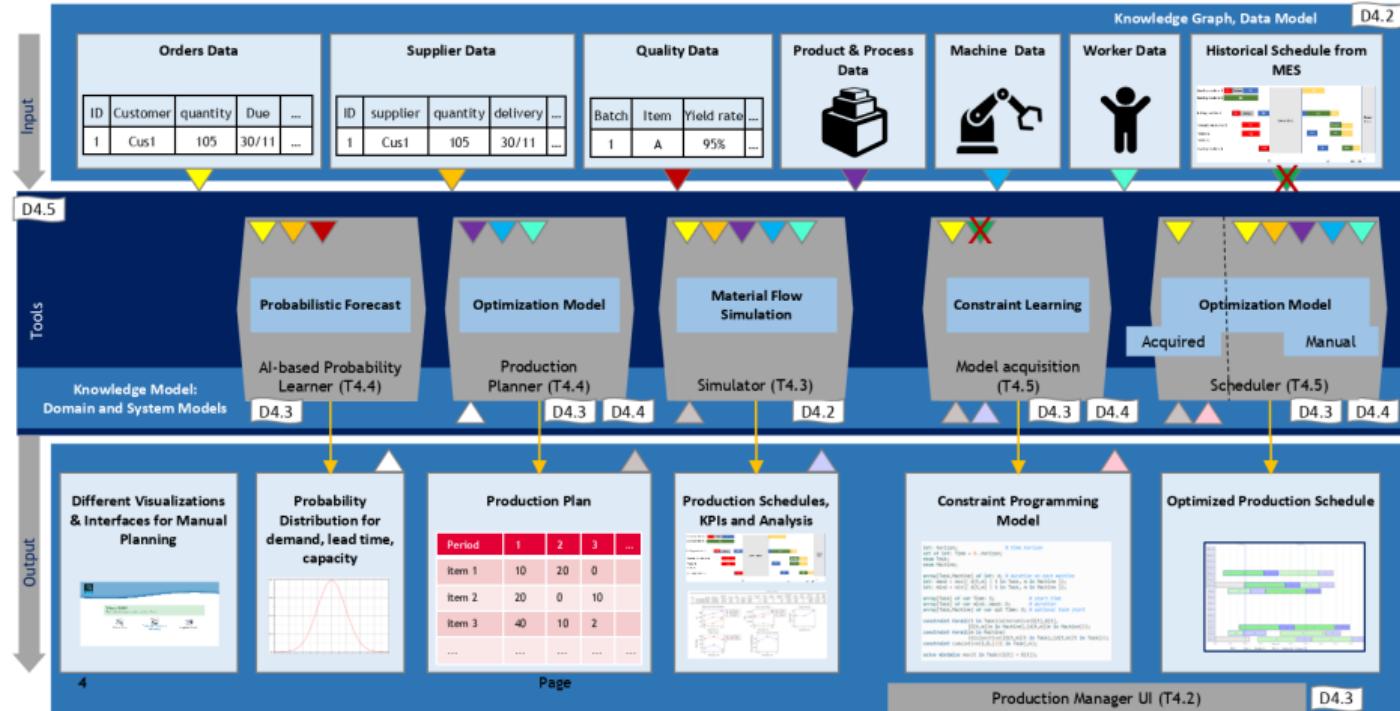
## Use Case Scenarios

- Schedule *validation* of gas turbine blades and vanes manufacturing operations in Berlin plant
- Schedule *optimization* to manage short-term, mid-term and long-term load fluctuations
- Generate *Make-or-Buy proposals* for workload balancing within the manufacturing network

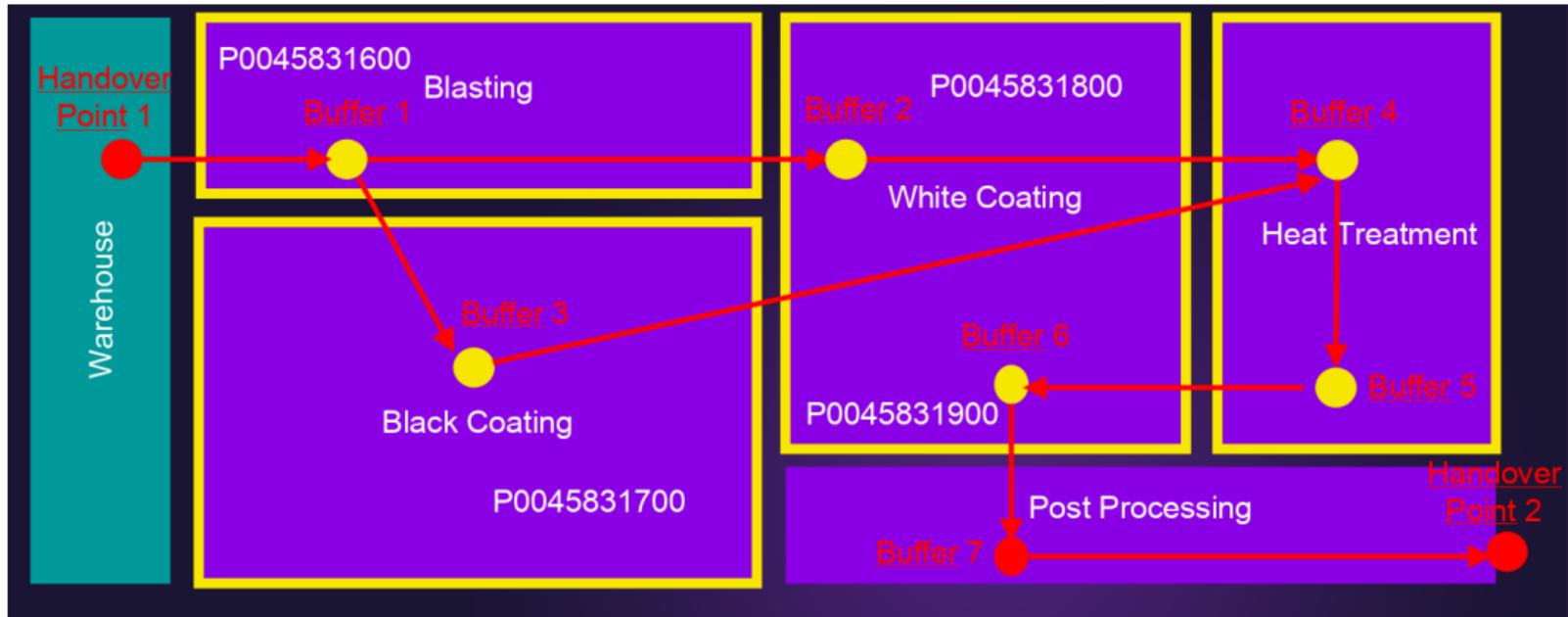
# Digital Twin

## Intelligent digital twin for process planning and scheduling

ASSISTANT



# SE Product Routing



# Datasets

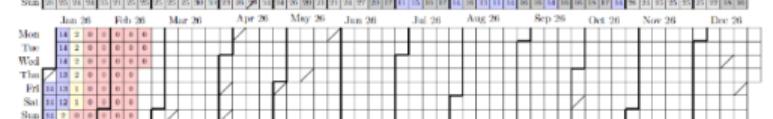
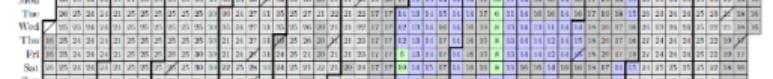
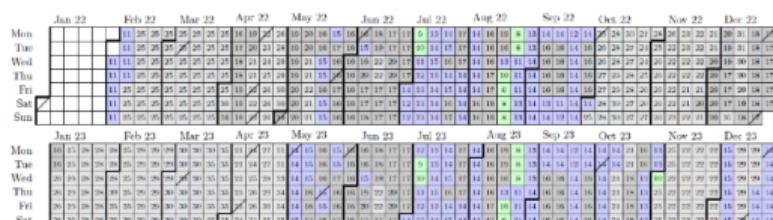
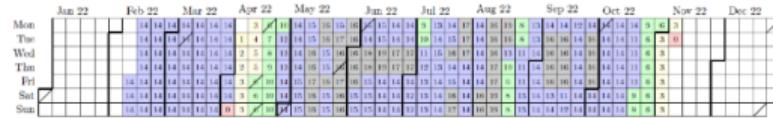
## Full Scale Datasets

Berlin06: 96 orders, 9 months horizon, previous review

Berlin07: 450 orders, 4 years horizon

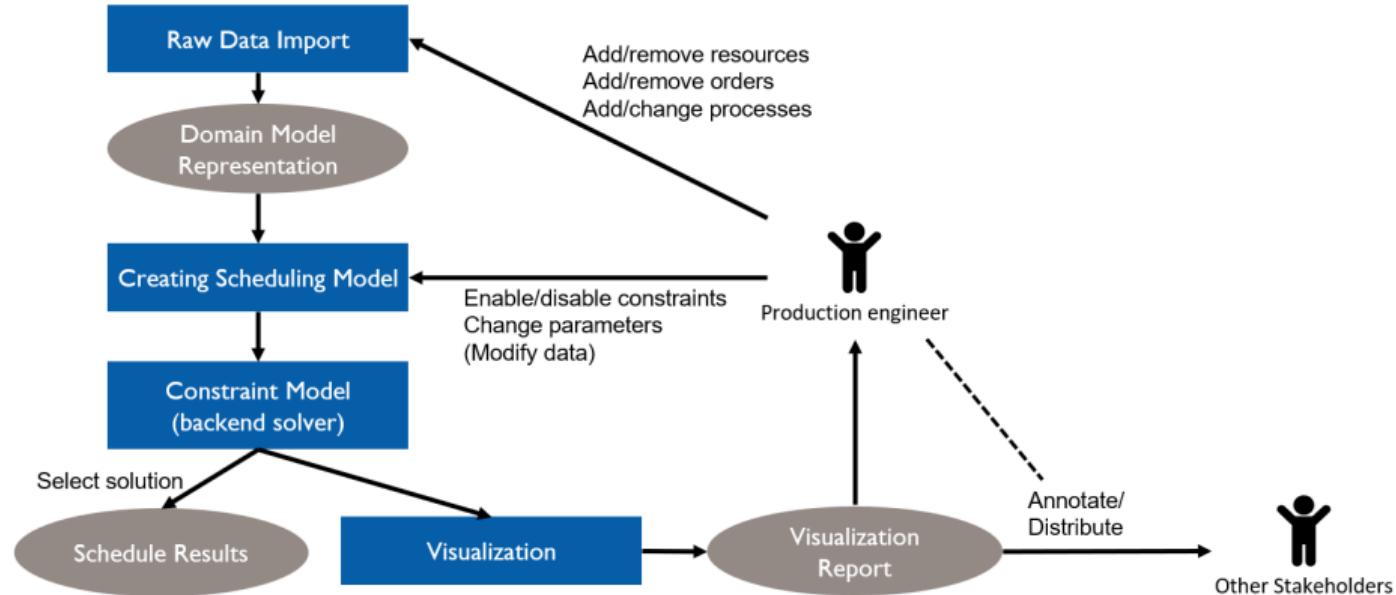
Berlin08: 559 orders, Christmas gap added

Berlin08a: 670 orders, filling gaps



Value in cell indicates active orders  
Yellow and red colors indicate low order volume

# Optimizer High Level Structure

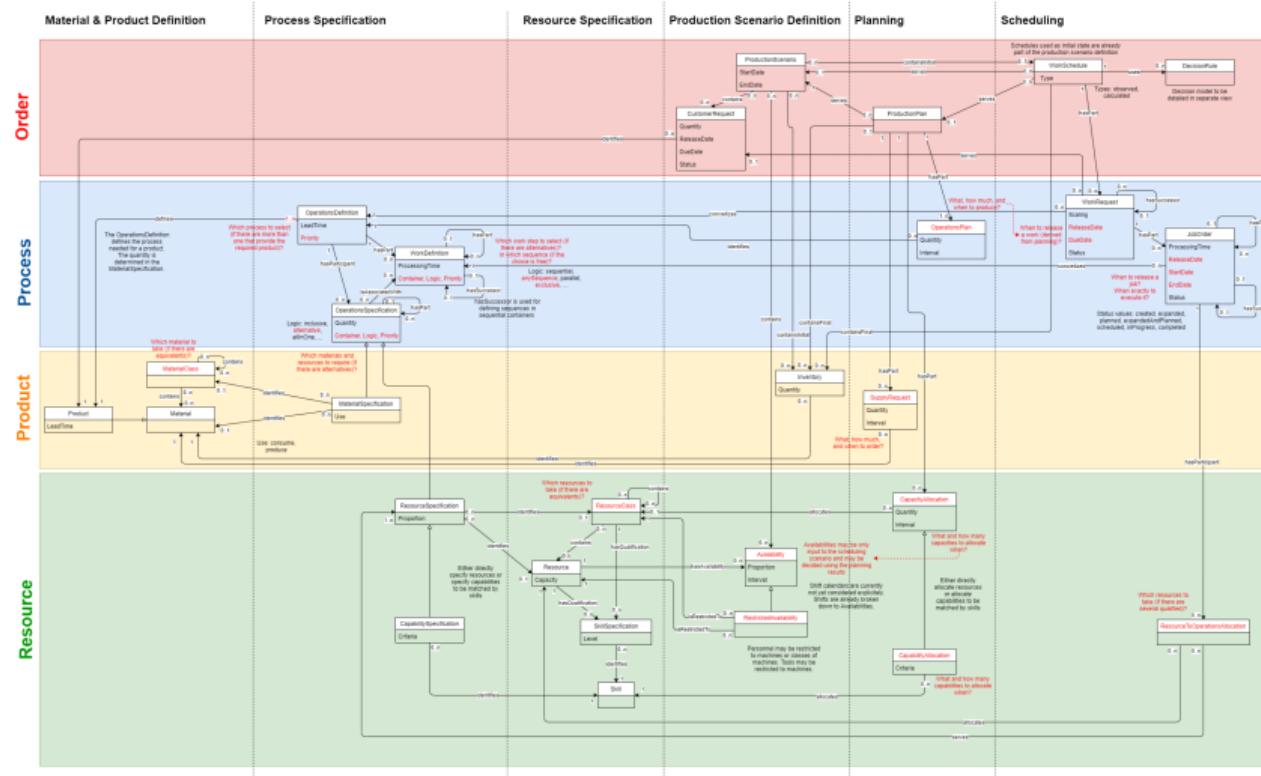


# Raw Data - Manual Data Entry Causes Problems

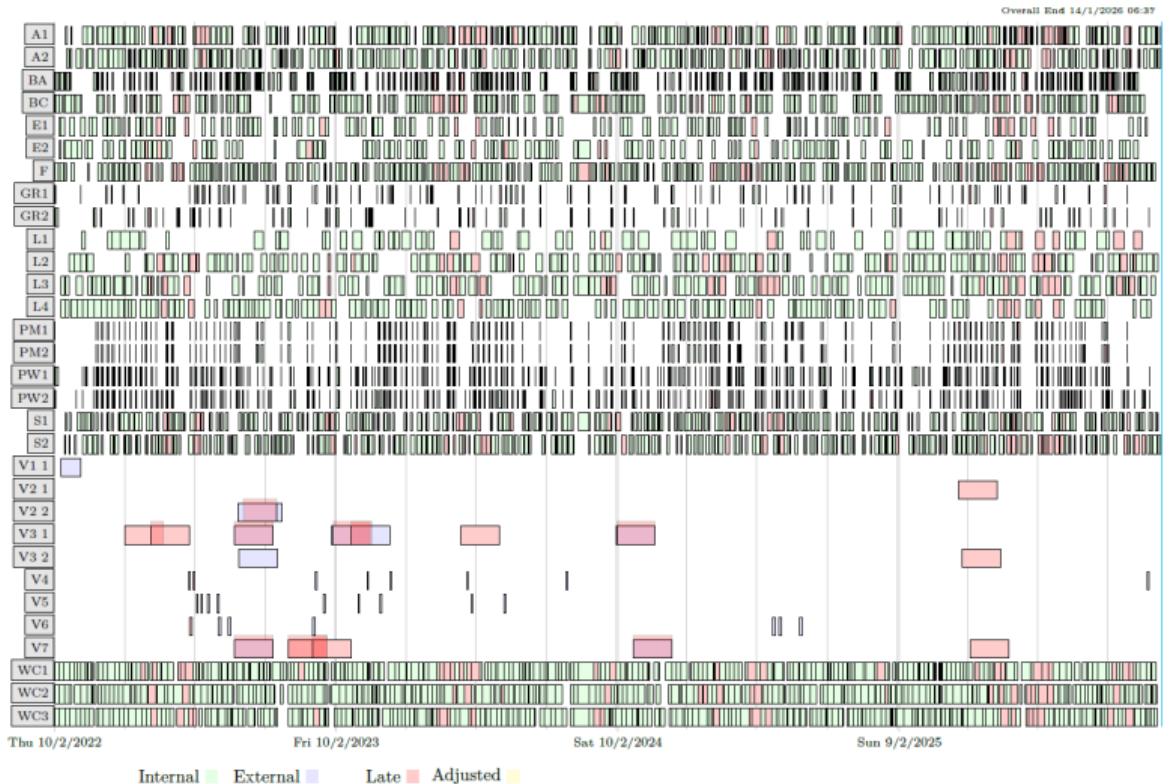
- Raw data come from spreadsheet
  - 20 tabs
- Excel is a particularly bad input data format
- Realistic, not real data
- Created by hand/automatically from existing test scenarios
- Series of files Berlin01 - Berlin05 were too inconsistent to run
- Berlin06 still contains some errors
- Optimizer explains all issues that it finds

| Name    | Severity | Sheet              | RowNr | ColNr | Description   |
|---------|----------|--------------------|-------|-------|---|
| Issue1  | Major    | t_Load             | 129   | 11    | Date/Time not formatted correctly, found 2022-02-280000:00 format yyyy-MM-dd'T'HHmmss |
| Issue2  | Minor    | t_Products         | 1     | 15    | Extra Empty Header  |
| Issue3  | Minor    | t_Availabilities   | 1     | 8     | Extra Empty Header  |
| Issue4  | Minor    | t_Unavailabilities | 1     | 8     | Extra Empty Header  |
| Issue5  | Minor    | t_Shift_Segments   | 1     | 6     | Extra Empty Header  |
| Issue6  | Major    | t_Shift_Segments   | 1     | 1     | TimeOnly not formatted correctly, found 0.250000, format HHmmss                       |
| Issue7  | Major    | t_Shift_Segments   | 1     | 2     | TimeOnly not formatted correctly, found 0.583333, format HHmmss                       |
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| Issue11 | Major    | t_Shift_Segments   | 3     | 2     | TimeOnly not formatted correctly, found 0.479167, format HHmmss                       |
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| Issue15 | Major    | t_Shift_Segments   | 5     | 2     | TimeOnly not formatted correctly, found 0.677083, format HHmmss                       |
| Issue16 | Major    | t_Shift_Segments   | 6     | 1     | TimeOnly not formatted correctly, found 0.770833, format HHmmss                       |
| Issue17 | Major    | t_Shift_Segments   | 6     | 2     | TimeOnly not formatted correctly, found 0.791667, format HHmmss                       |
| Issue18 | Major    | t_Shift_Segments   | 7     | 1     | TimeOnly not formatted correctly, found 0.916667, format HHmmss                       |
| Issue19 | Major    | t_Shift_Segments   | 7     | 2     | TimeOnly not formatted correctly, found 0.250000, format HHmmss                       |
| Issue20 | Major    | t_Shift_Segments   | 8     | 1     | TimeOnly not formatted correctly, found 0.000000, format HHmmss                       |
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| Issue22 | Major    | t_Shift_Segments   | 9     | 1     | TimeOnly not formatted correctly, found 0.083333, format HHmmss                       |
| Issue23 | Major    | t_Shift_Segments   | 9     | 2     | TimeOnly not formatted correctly, found 0.104167, format HHmmss                       |
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| Issue25 | Minor    | t_Shift_Segments   | 11    | 0     | First Column Empty  |
| Issue26 | Minor    | t_Shift_Segments   | 12    | 0     | First Column Empty  |
| Issue27 | Minor    | t_Shift_Segments   | 13    | 0     | First Column Empty  |
| Issue28 | Minor    | t_Shift_Segments   | 14    | 0     | First Column Empty  |
| Issue29 | Minor    | t_Shift_Segments   | 15    | 0     | First Column Empty  |
| Issue30 | Minor    | t_Shift_Segments   | 16    | 0     | First Column Empty  |
| Issue31 | Minor    | t_Shift_Segments   | 17    | 0     | First Column Empty  |
| Issue32 | Minor    | t_Shift_Segments   | 18    | 0     | First Column Empty  |
| Issue33 | Minor    | t_Shift_Patterns   | 1     | 9     | Extra Empty Header  |
| Issue34 | Minor    | t_Shift_Patterns   | 7     | 0     | First Column Empty  |
| Issue35 | Minor    | t_Shift_Patterns   | 8     | 0     | First Column Empty  |

# Domain Model - Knowledge Graph



# Single Solution for Berlin 08a - Shows Only 20% of Tasks in Model

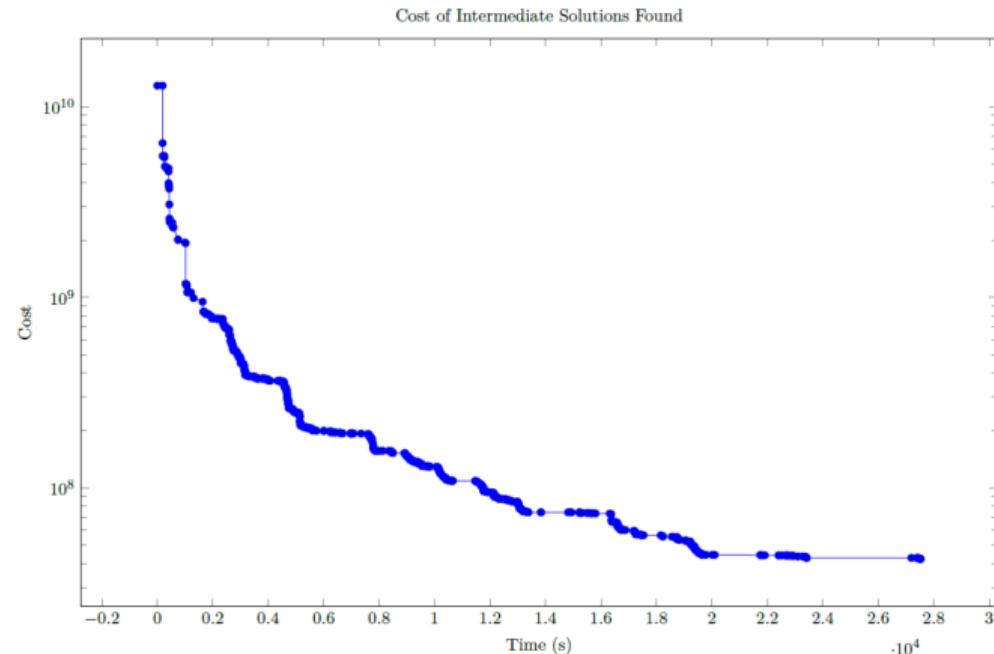


# Implementation

- Requirement capture done inside project
- Data checking/cleaning most time consuming aspect
- Some specified functionality was rejected by Betriebsrat
- Built in Java
- Uses IBM's CPO back-end
- 120k LoC, 110k generated, 3k solver
- Outperforms both
  - Current in-house tool
  - Simulation based tool based on commercial simulator
- System installed at SE site, but not in daily use

# CPO Keeps on Trucking

Figure 23: Evolution of Intermediate Solution Cost over Time, Dataset08, Pref 2 Options, time limit 8 hours



# Conclusion

*“Within less than eight hours the ASSISTANT tools provided us thousands of manufacturing scenarios including different make-or-buy recommendations for making deliberate decisions on the way to proceed for strategic planning.”*

Siemens SE final project review assessment

# Outline

CP and Scheduling Literature Survey

ASSISTANT SE Use Case

## Outpatient Waitlist Management

Introduction

Solution Approach

Results

Summary

Elevator Maintenance Planning and Scheduling

Other Applications

## Joint work with...

- Mike O'Keefe
- Adrian O'Leary
- Barry O'Sullivan
- At Insight Centre for Data Analytics, University College Cork

# Real-World Problem

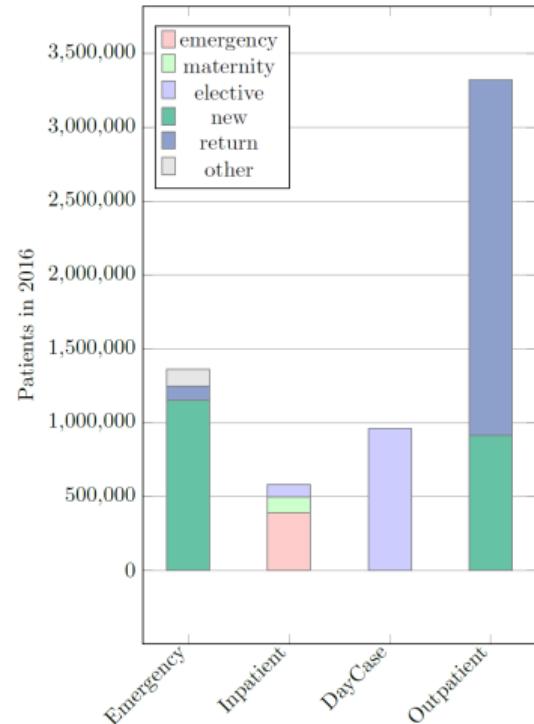
- Healthcare in Ireland
- Wait times for patients are out of control, even before Covid-19
- Longer wait times, poorer patient outcomes
- Critical to understand where to invest
- Currently: no tools to understand how changes affect performance

# Research Challenges

- How to model hospital environment, many independent actors
- Deal with uncertain demand, and uncertain outcomes
- Understand where capacity is lost/not used

# Hospital Services Overview

National Total Patients Seen for 2016



Data: HSE Management Data Report, Dec 2016

# Outpatient Types

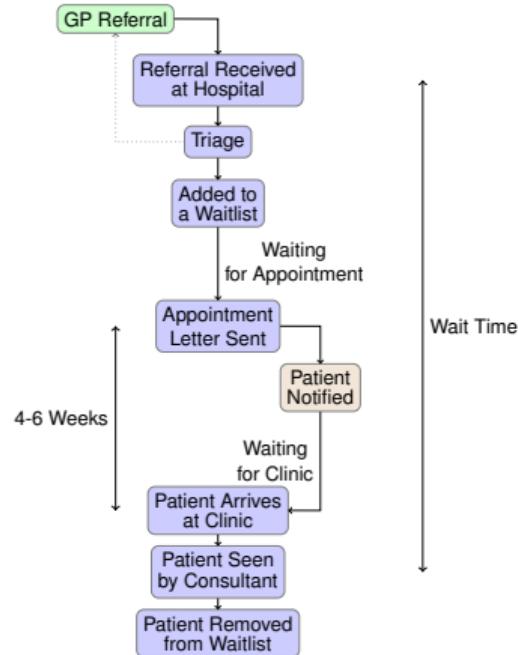
Rapid access seen within 14 days

Urgent seen within 28 days

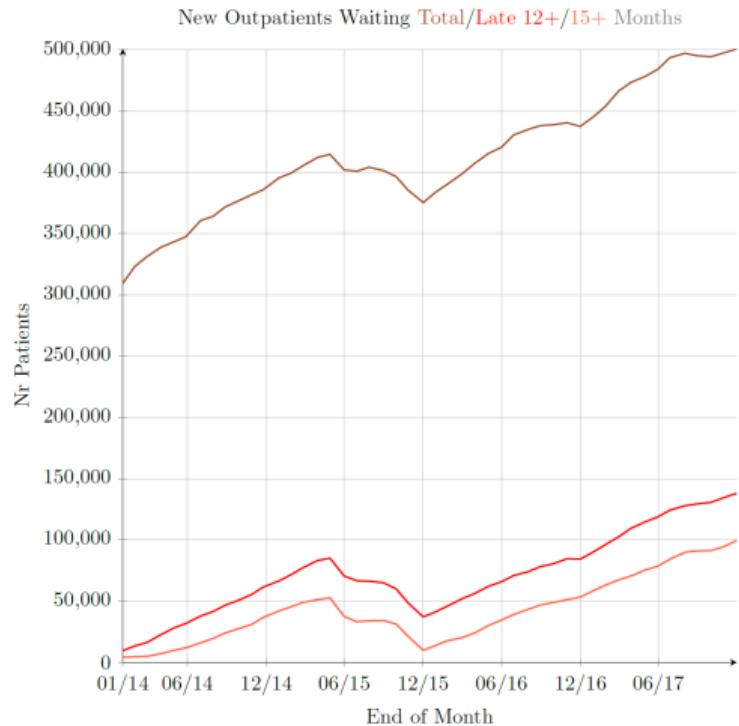
Soon seen within 3 months

Routine seen within 12 months (13 weeks, 15 months, 18 months?)

# Outpatient Waitlist Management Process (Simplified)



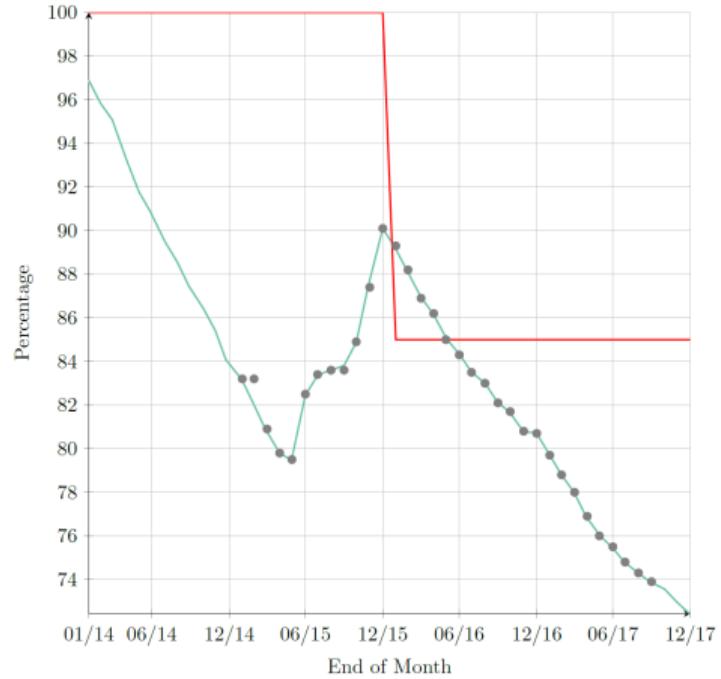
# The Bad News



Data: NTPF

# KPI: Waiting Time Percentage

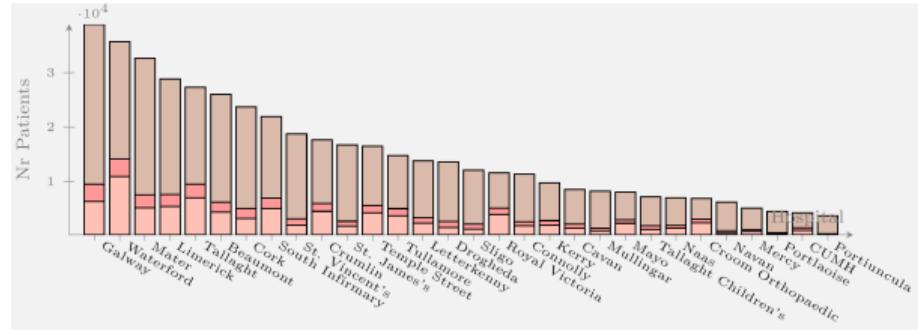
Percentage of New Outpatients Waiting Less Than 12 Months (Target, Actual, KPI)



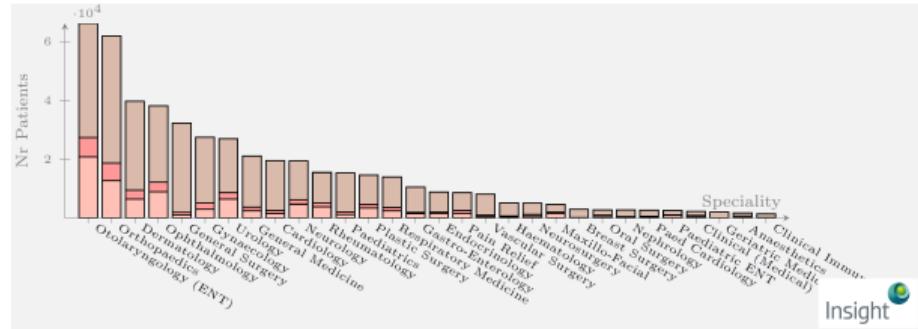
Data: HSE

# A Near Universal Problem in Ireland

By Hospital



By Speciality



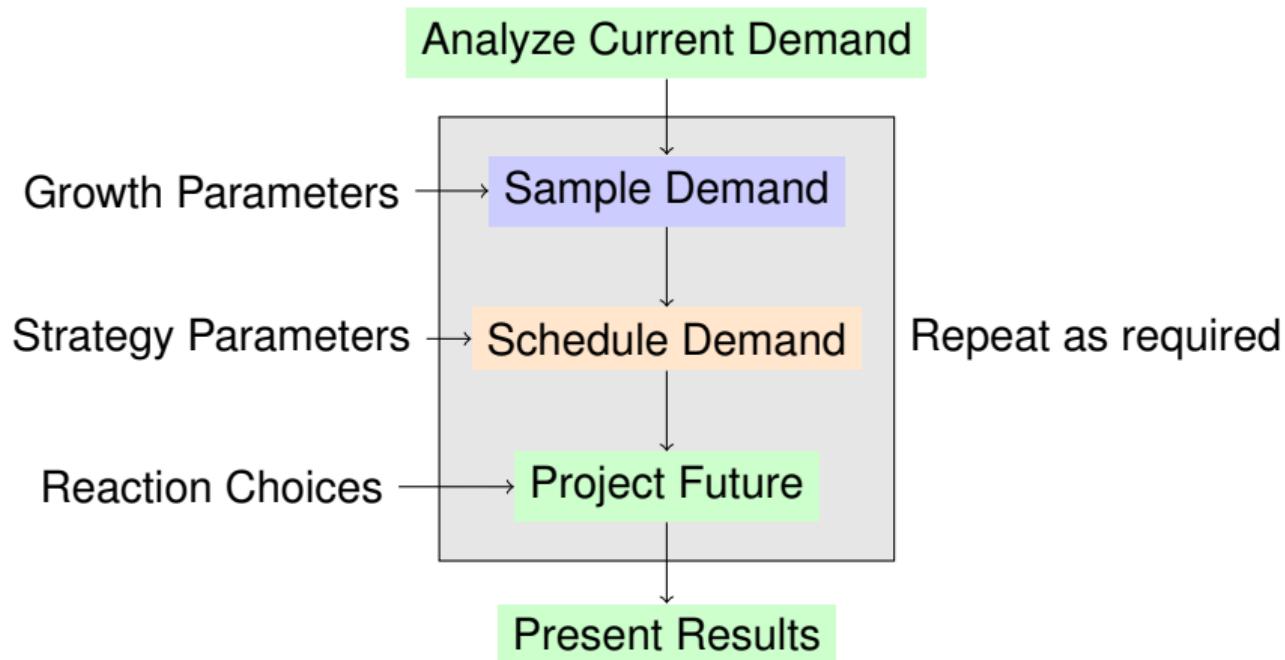
# Our Brief

- Concentrate on Outpatients
- Develop strategy for appointment decision making
- What-if tool to understand the impact of decisions
- Support current stakeholders
- Not: Build automated appointment scheduling tool

# The Appointment Conundrum

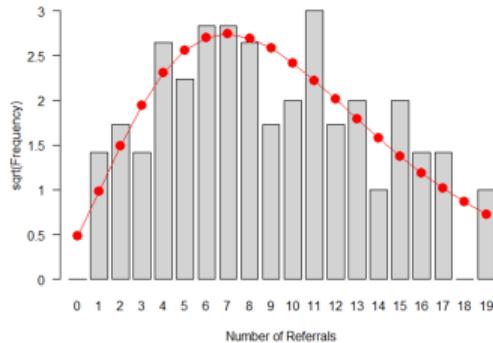
- We have to give “routine” appointment before knowing “urgent” demand
- There is limited capacity
- No overtime allowed (Croke Park agreement)
- How much capacity to set aside for urgent cases?
- How much overbooking is possible?

# Methodology

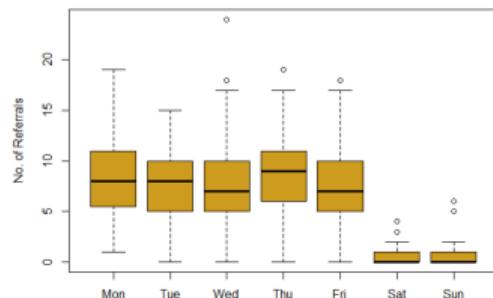


# Demand Data (Not Public)

Received  
Per Day



Received  
Per Day of Week



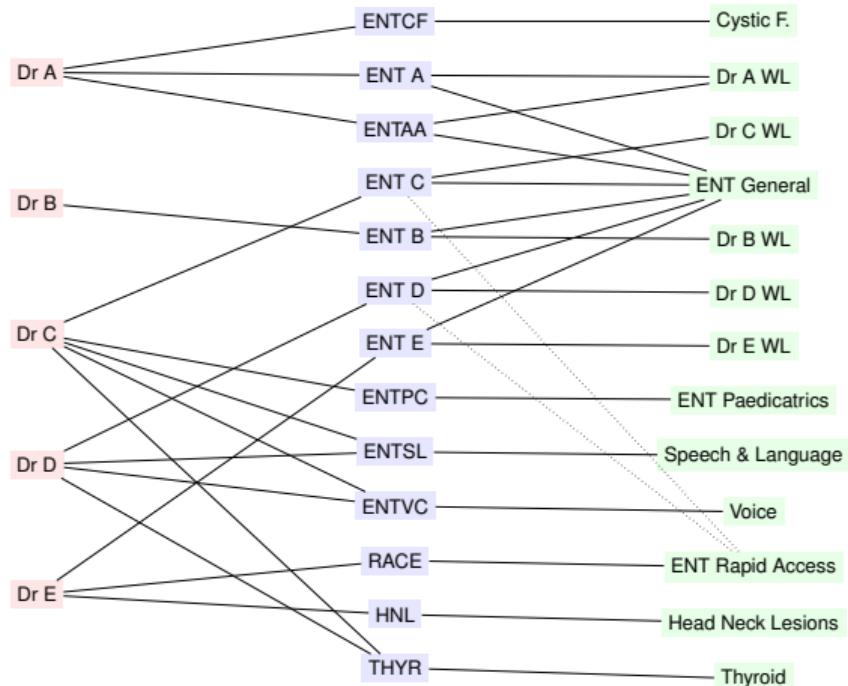
- Fitting distributions
  - Poisson, not good fit
  - Negative Binomial
- Limited Seasonality (unlike Emergency Department)

# Waitlist/Clinic Model

Clinicians

Clinic

Waitlist



# Learning Capacity from Historical Data

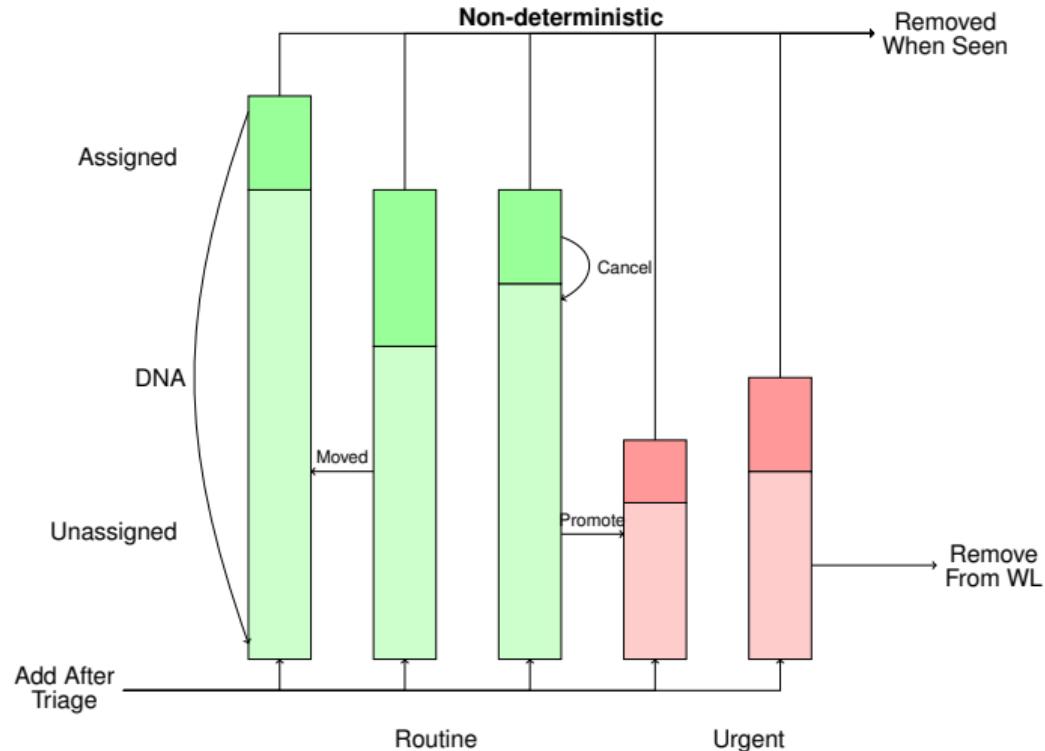
|   | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |   |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---|
| S | .   | .   | .   | .   | E   | E   | .   | E   | .   | .   | E   | .   | C |
| M | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| T | E   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| W | C   | C   | C   | C   | C   | C   | C   | C   | C   | C   | C   | C   | B |
| T | T   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | B |
| F | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| S | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| S | .   | .   | .   | .   | E   | .   | E   | E   | .   | .   | E   | .   |   |
| M | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| T | T   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| W | E   | C   | C   | C   | C   | C   | C   | C   | C   | C   | C   | C   | B |
| T | T   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | B |
| F | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| S | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| S | .   | .   | .   | .   | E   | .   | E   | E   | .   | .   | E   | .   |   |
| M | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| T | T   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| W | C   | C   | C   | C   | C   | C   | C   | C   | C   | C   | C   | C   | B |
| T | E   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | B |
| F | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| S | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| S | .   | .   | .   | .   | E   | .   | E   | E   | .   | .   | E   | .   |   |
| M | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| T | T   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| W | .   | C   | E   | .   | .   | C   | .   | C   | .   | .   | .   | .   |   |
| T | T   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| F | E   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |
| S | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |   |

- Repeat frequency
- Capacity
- Cancellation frequency
- Replacement clinics

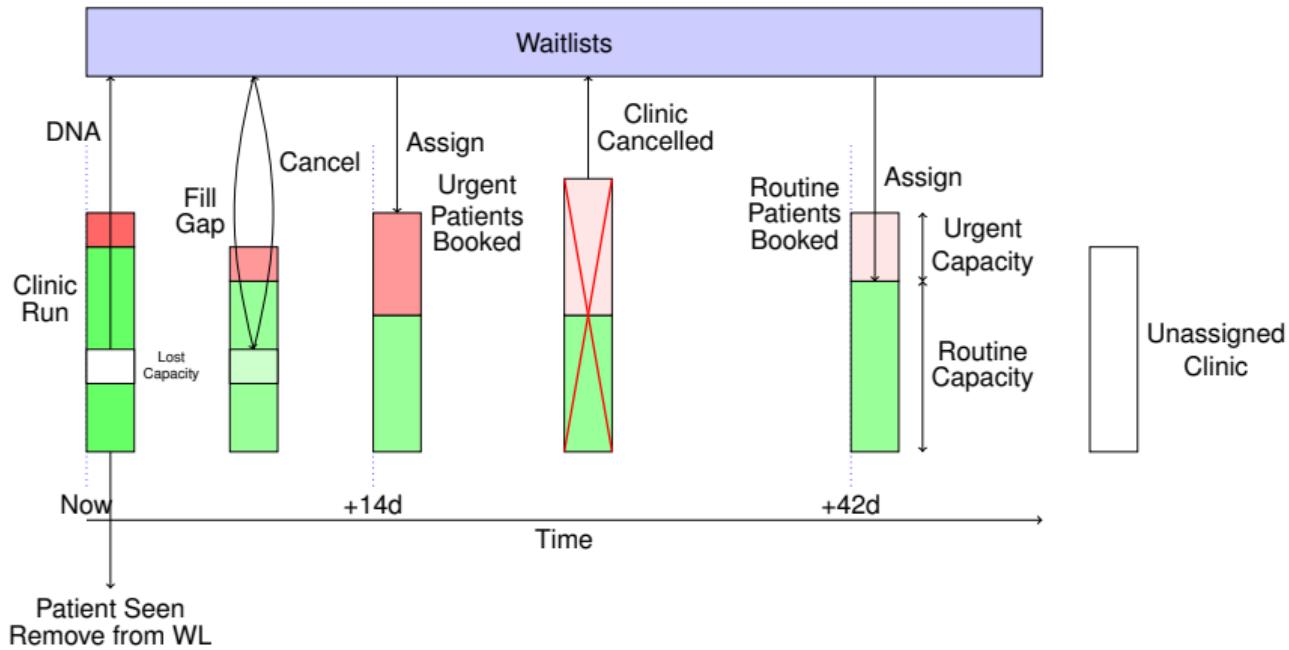
# Optimization Problem

- Assign waiting patients to slots in clinics
- Use appropriate clinic for given patient
- Make appointments  $k_p$  days in advance
- Free and reuse slots when patients cancel
- Reschedule patients when clinic cancelled
- Do not change appointments otherwise
- Reserve  $u$  slots for urgent cases
- Solved for each day

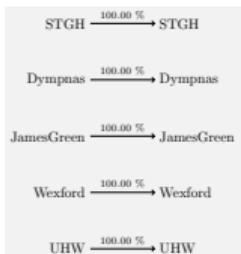
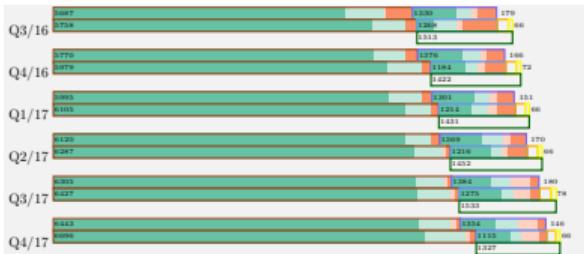
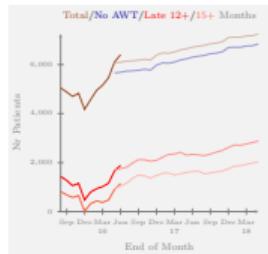
# Waitlist Actions



# Clinic Allocation



# Baseline Analysis, Management View

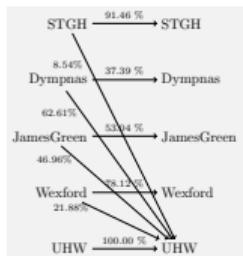
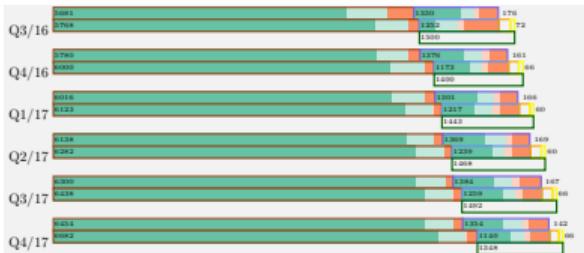


| List/Category | Date          | Patients Waiting | Breaching | Patients in Breach | Avg    | 90%  | Max  | Waiting Time Distribution |
|---------------|---------------|------------------|-----------|--------------------|--------|------|------|---------------------------|
|               |               |                  | on Date   |                    |        |      |      |                           |
| All Urgent    | One Month Ago | 596              | 464       | 584                | 142.84 | 250  | 515  |                           |
|               | Now           | 432              | 302       | 428                | 90.72  | 128  | 228  |                           |
|               | In One Month  | 352              | 227       | 343                | 73.50  | 115  | 228  |                           |
|               | In Six Months | 150              | 38        | 147                | 45.45  | 63   | 228  |                           |
|               | In One Year   | 109              | 11        | 51                 | 33.19  | 56   | 70   |                           |
| Routine       | One Month Ago | 5080             | 1635      | 4514               | 682.66 | 1215 | 1512 |                           |
|               | Now           | 5255             | 1737      | 4613               | 686.44 | 1219 | 1554 |                           |
|               | In One Month  | 5390             | 1801      | 4687               | 696.07 | 1226 | 1623 |                           |
|               | In Six Months | 5845             | 2090      | 5315               | 743.39 | 1293 | 1718 |                           |
|               | In One Year   | 6196             | 2317      | 5737               | 787.76 | 1505 | 1835 |                           |

OWL2 (baseline): Thursday 4<sup>th</sup> August, 2016, at 22:58

Insight

# Scenario: Balance Patients Between Hospitals

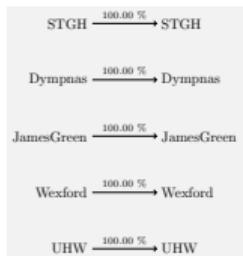
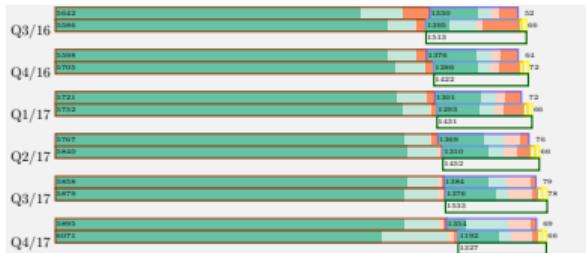
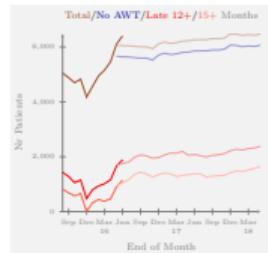


| List/Category | Date          | Patients Waiting | Breaching on Date | Patients in Breach | Avg    | 90% | Max | Waiting Time Distribution |
|---------------|---------------|------------------|-------------------|--------------------|--------|-----|-----|---------------------------|
| All Urgent    | One Month Ago | 596              | 464               | 584                | 140.17 | 250 | 515 |                           |
|               | Now           | 412              | 281               | 408                | 84.85  | 106 | 200 |                           |
|               | In One Month  | 339              | 217               | 330                | 69.21  | 92  | 200 |                           |
|               | In Six Months | 146              | 36                | 143                | 36.86  | 42  | 46  |                           |
|               | In One Year   | 112              | 15                | 109                | 33.42  | 37  | 41  |                           |
| Routine       | One Month Ago | 5080             | 1635              | 4511               | 608.66 | 718 | 796 |                           |
|               | Now           | 5269             | 1758              | 4629               | 609.15 | 743 | 797 |                           |
|               | In One Month  | 5390             | 1784              | 4661               | 612.68 | 757 | 798 |                           |
|               | In Six Months | 5870             | 2111              | 5326               | 632.37 | 781 | 803 |                           |
|               | In One Year   | 6188             | 2325              | 5726               | 632.10 | 780 | 803 |                           |

OWL2 (balanced; ENTMH can serve all hospitals with overall capacity): Thursday 4<sup>th</sup> August, 2016, at 17:02



# Scenario: Reduce DNA (Did not attend) to 5%

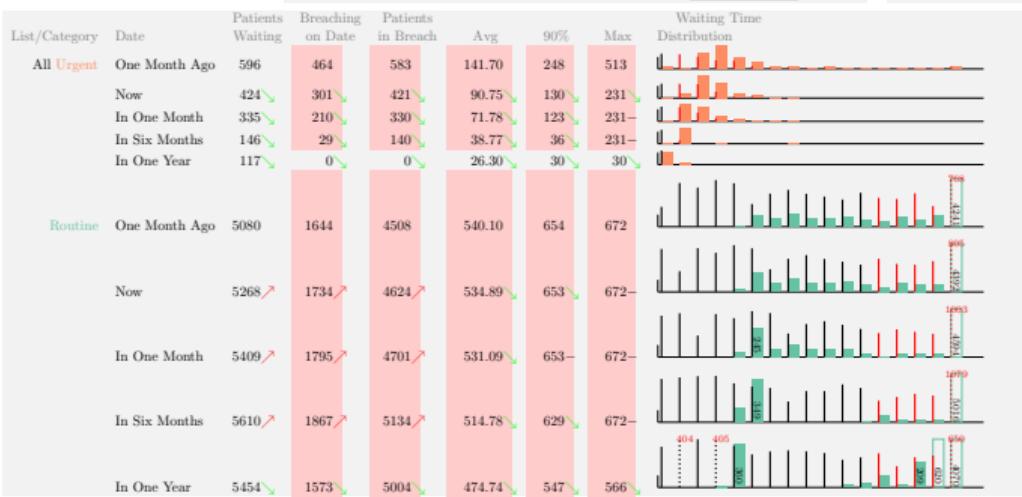
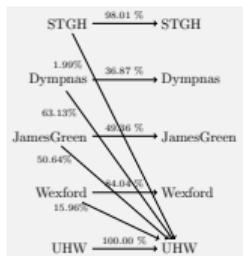
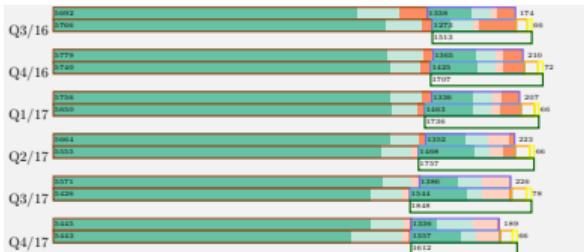
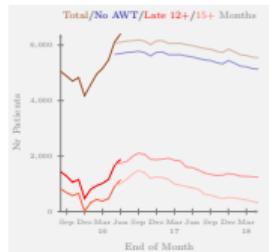


| List/Category | Date          | Patients Waiting | Breaching | Patients in Breach | Avg    | 90%  | Max  | Waiting Time Distribution |
|---------------|---------------|------------------|-----------|--------------------|--------|------|------|---------------------------|
|               |               |                  | on Date   |                    |        |      |      |                           |
| All Urgent    | One Month Ago | 596              | 464       | 584                | 142.64 | 250  | 515  |                           |
|               | Now           | 404              | 300       | 401                | 91.83  | 128  | 228  |                           |
|               | In One Month  | 301              | 199       | 293                | 74.12  | 120  | 228  |                           |
|               | In Six Months | 130              | 27        | 127                | 42.88  | 56   | 228  |                           |
|               | In One Year   | 92               | 8         | 21                 | 30.87  | 47   | 64   |                           |
| Routine       | One Month Ago | 5080             | 1635      | 4509               | 655.06 | 1154 | 1473 |                           |
|               | Now           | 5238             | 1735      | 4606               | 658.91 | 1161 | 1490 |                           |
|               | In One Month  | 5346             | 1796      | 4678               | 668.77 | 1166 | 1540 |                           |
|               | In Six Months | 5591             | 1968      | 5145               | 714.68 | 1277 | 1669 |                           |
|               | In One Year   | 5766             | 2061      | 5314               | 757.54 | 1471 | 1779 |                           |

OWL2 (DNA 5 percent for routine patients): Thursday 4<sup>th</sup> August, 2016, at 16:59



# Scenario: Add Capacity



OWL2 (25 New Patients per Week from 1/10/2016): Thursday 4<sup>th</sup> August, 2016, at 17:06

Insight

# Summary

- Presented case study from Irish health system
- Strategy for outpatient appointments
- Mix of analytics, simulation, and optimization
- Nation-wide analysis of available data
- What-if tool for selected departments

# Outline

CP and Scheduling Literature Survey

ASSISTANT SE Use Case

Outpatient Waitlist Management

## Elevator Maintenance Planning and Scheduling

Introduction

Our Contribution

Evaluation

Challenges

Other Applications

## Joint work with...

- Mark Antunes, Vincent Armant, Kenneth N. Brown, Gabriel G. Castane, Daniel Desmond, Guillaume Escamocher, Michele Garraffa, Anne-Marie George, Diarmuid Grimes, Mike O'Keefe, Yiqing Lin, Barry O'Sullivan, Cemalettin Ozturk, Luis Quesada, Mohamed Siala, Helmut Simonis and Nic Wilson

# Real World Problem

- Manufacturing Industry, after sales support
- Maintenance is crucial for safety/availability of product
- Preventive/Predictive/Reactive Maintenance influence each other
- How to organize service, what to do?

# Research Challenge

- How to plan/schedule if events interrupt planned work
- How to use predictive maintenance to avoid problems before they occur
- What is the right problem decomposition?

## Travelling Repair Person (TRP)

- Providing service for devices at customer premises
- Planned preventive maintenance and testing, regular visits
- Technicians travel to multiple, but few customers per day
- Unplanned repair work after faults, response-time critical
- Service times quite variable
- Impact of skills and local knowledge

# Why is this important? (1)



South China Morning Post

Connecting quality brands in **different industries** with educated and affluent readers.

Law and Crime

## Lift firm Otis fined HK\$320,000 over Hong Kong mall escalator accident that injured 18

Company, which pleaded guilty to four summonses, could have discovered safety issues with escalator three months before malfunction, court told



Jasmine Siu

Published: 8:15pm, 9 Mar, 2018 ▾

# Why is this important? (2)

BIG STORY 10 APRIL 5, 2016 / 6:40 AM / 3 YEARS AGO

## Schindler sells Japanese business to Otis after accident

2 MIN READ



---

ZURICH (Reuters) - Elevator maker Schindler is selling its Japanese business to United Technologies' Otis unit after its new installations in the country were halted following a 2006 accident.

Source:  REUTERS

## Why is this important? (3)

**Elevator at one of Chicago's tallest skyscrapers plunges 84 floors after hoist rope breaks**

NOVEMBER 19, 2018 / 10:47 AM / CBS NEWS

f t g



Source: By Chris6d - Own work, CC BY-SA 4.0, <https://commons.wikimedia.org/w/index.php?curid=78201640>

# High-level View

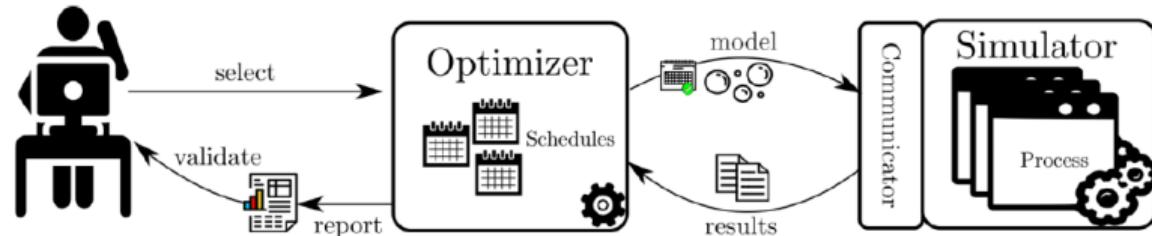


Figure 1 High level overview of the framework

- Optimizer deals with planning, load balancing, efficient schedules
- Simulator explores how to react to changes
- Simulator also provides one result as assumed reality

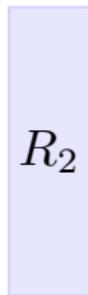
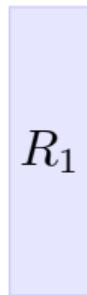
# Optimizer Design

- Infeasible to build homogenous model for complete problem
- Added business process constraint
  - Technicians should be responsible for “their” buildings
  - Improves service quality
  - Customers see familiar face
- All work in one building should be performed by the same engineer, if possible
- Engineers should be assigned compact areas of work
- Balanced workload within the same depot

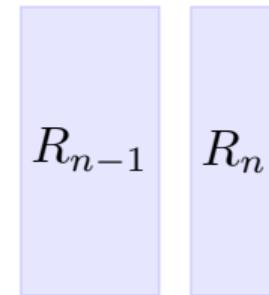
# Optimizer Decomposition

Clustering

Route Generation

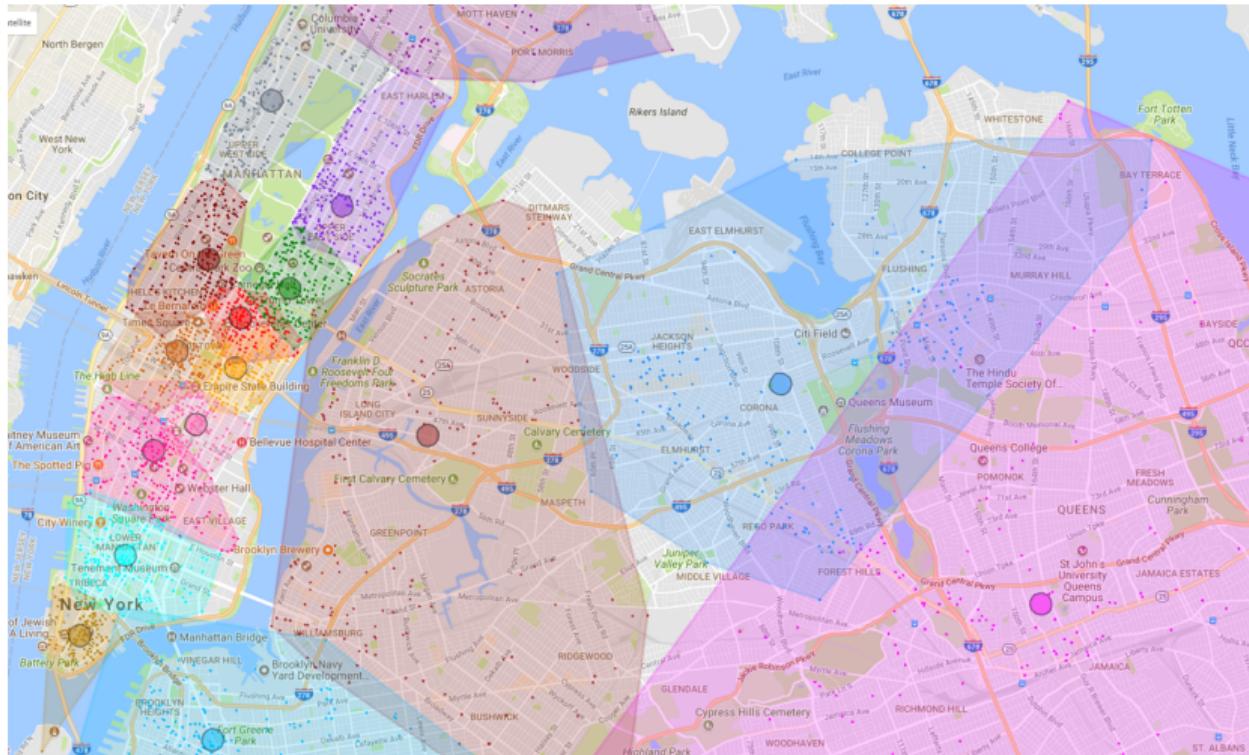


Monthly  
Schedule



Daily Schedule

# Clustering and Depot Assignment



# Scheduling: One Day of Monthly Plan



# Methods Used

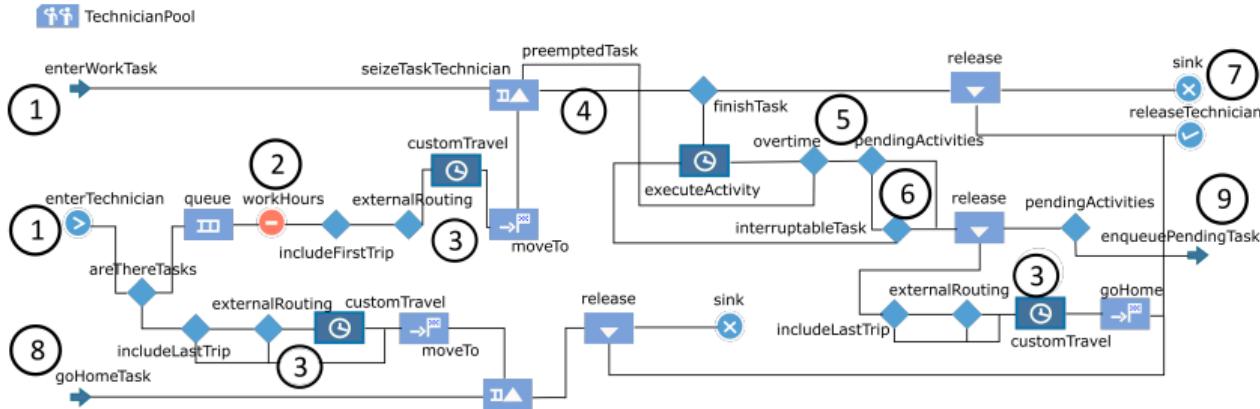
**Clustering** Connected components on generated graph

**Routing** Which places to visit in one trip

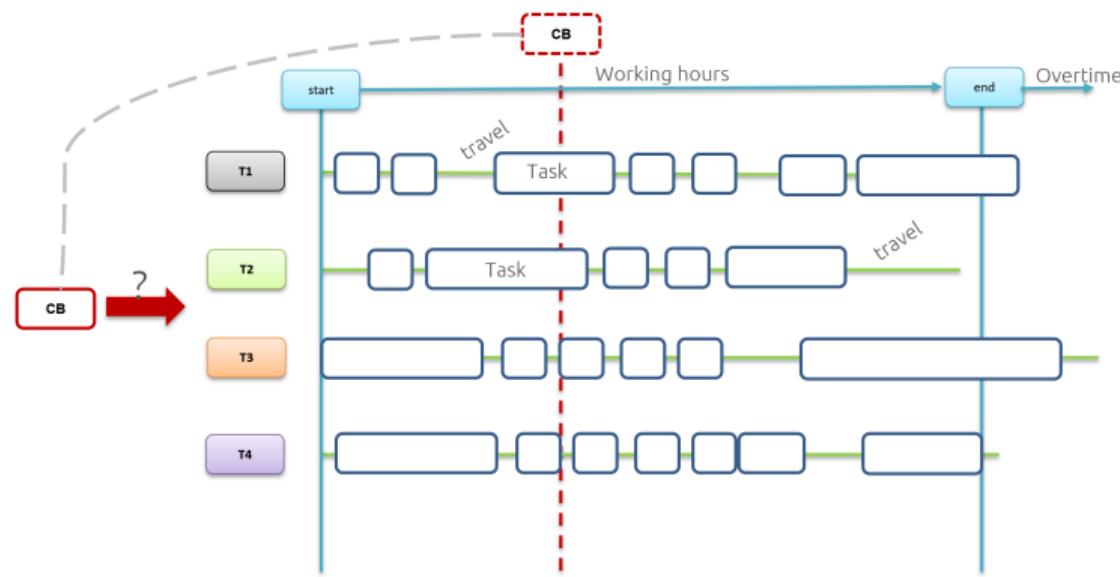
- Core MIP Model
- Iterative MIP inside Clustering
- Two stage grouping of locations to reduce expected travel
- Local Search

**Scheduling** Dynamic Programming and Set Partitioning

# Simulator Process Modelling



# Dealing with Unplanned Callbacks



- Who is dealing with the callback?
- How to adjust the schedule after callback?

# Use Cases

- Compare variants of problem to understand impact of changes
- Examples
  - Where to place depots and their area?
  - How many technicians are needed in which depots?
  - Should technicians do both planned and unplanned work?
  - When is overtime the better choice?

# Scenario Evaluation: KPI Comparison

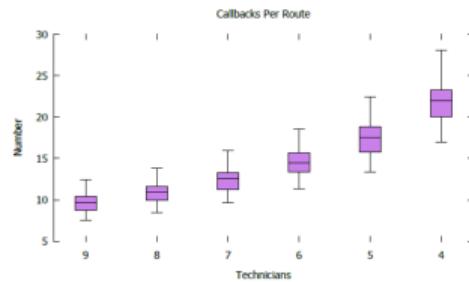


Figure 6 Callbacks per route (technician)

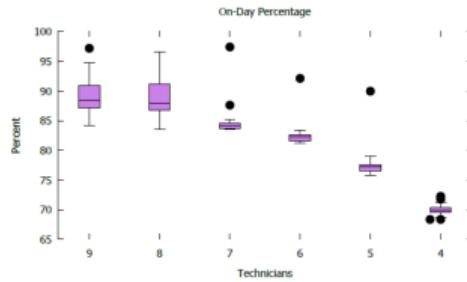


Figure 7 Percentage of tasks performed per tasks

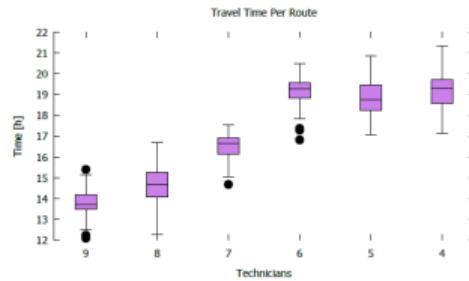


Figure 9 Travel time per technician

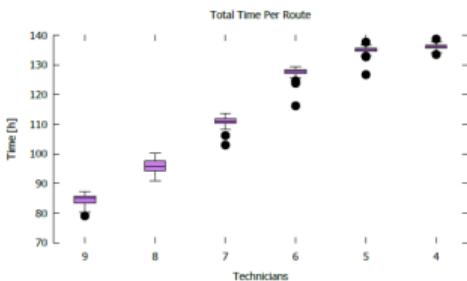
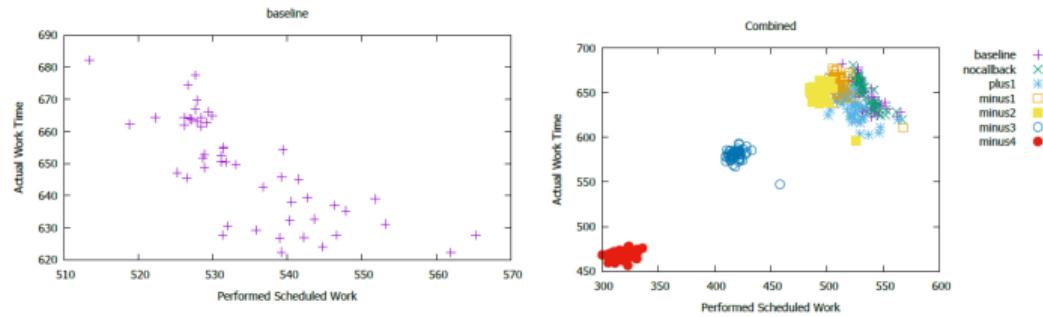


Figure 8 Total time per technician

# Scenario Evaluation: Qualitative Differences



- On left, each point shows the outcome of one month of optimization+simulation
- On right, compare outcomes for different scenarios, clear clustering of results

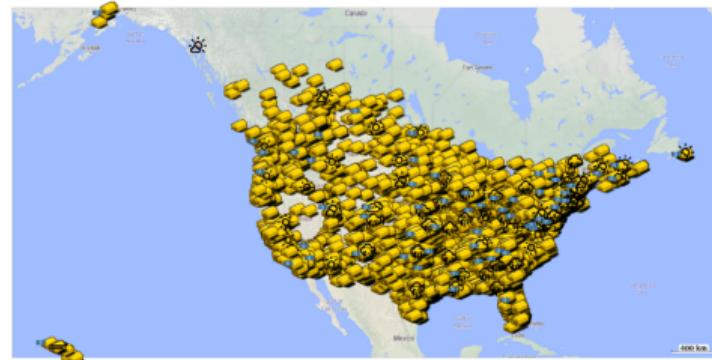
## Challenges: Data

- We need company internal data to understand problem
- Problem for publication, for continued work
- Open data as alternatives
  - New York City
    - 76,000 elevators with locations
  - Toronto, ON
    - 40,000 elevators
    - Inspection dates, outcomes
    - Accident and injury reports

# Challenges: Scalability

| Data source    | Locations |
|----------------|-----------|
| Arby's         | 3347      |
| Burger King    | 7269      |
| Dairy Queen    | 5189      |
| Dominos Pizza  | 3261      |
| Dunking donuts | 8134      |
| KFC            | 5637      |
| Little Caesars | 4019      |
| Mc Donald's    | 15474     |
| Papa John's    | 3089      |
| Pizza Hut      | 6672      |
| Starbucks      | 11788     |
| Subway         | 2213      |
| Taco bell      | 6996      |
| Wendy's        | 6140      |
| Walmart        | 22212     |

- 136663 total locations (cleaned noisy data)
- 1 Unit per location
- 63 areas (US + Canada)
- Experiments definition:
  - 1, 10, 100, 1000, 10000 technicians per area



## Challenges: Tools and Results

- We provide research and experimental software
- **Not** a solution
- End-user would like applicable results
- Managing expectations is important

# Conclusions

- We presented the Travelling Repair Person Problem
- Important as an industrial problem
- Interesting as a research challenge
- We use combination of optimization and simulation to deal with novel properties of problem
- System transferred to customer in 2019

# Outline

CP and Scheduling Literature Survey

ASSISTANT SE Use Case

Outpatient Waitlist Management

Elevator Maintenance Planning and Scheduling

Other Applications

Summary

## Other Noteworthy Applications

- NVD LoadBuilder
- Boliden Tara Mines Dewatering
- Dental School Timetabling
- Irish Naval Service Rostering
- Data Centre Load Consolidation
- Scheduling with Time Variable Energy Prices
- Characterizing EDF Power Plants with Timeseries Constraints
- Optical Network Design
- Supplier Selection Problem
- Optimizing UCC's CHP Plant Operation
- CP Conference Paper Assignment Tool

# NVD LoadBuilder

- Real-World Problem
  - Deliver cars/vans from factory/ports to dealers
  - Group cars into loads for joint delivery
  - Using specialized transporters with complex configurations
  - Balance distance travelled, utilization of fleet, priority of orders
- Status
  - In daily use at customer since 2020
  - Start-up company CMC to further develop tool



- Research Challenges
  - Vehicle routing problem with complex capacity constraints
  - Decide which cars to deliver today
  - What impact does this have tomorrow
  - Explaining solutions to end-user
- Solution Approach
  - Decomposition
  - MIP, Constraint Programming, Local Search, Data Analytics

# Boliden Tara Mines Dewatering



- Real-World Problem
  - When/how to pump water out of mine
  - Multiple pumps, reservoirs
  - Electricity cost major cost factor
  - Safe operation of mine paramount
- Status
  - Student-led project with DCU
  - Paper at AAAI 2016
  - Major flooding event in 2021
- Research Challenges
  - Scheduling with uncertain energy prices (real-time tariff)
  - Uncertain water ingress depends on operations
  - Capacity (min/max) constraints for storage
- Solution Approach
  - Electricity price prediction
  - Optimization

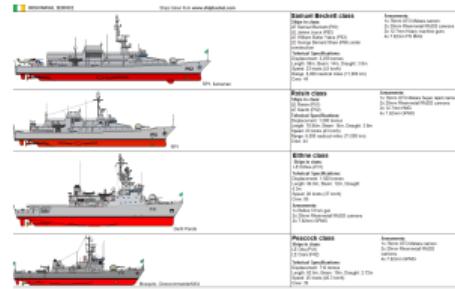
# Dental School Timetabling

- Real-World Problem
  - Change time table during period of teaching capacity increase
  - Previous schedule no longer feasible
  - Multiple courses share same lab space (dental chairs) at the same time
  - Hard capacity limits on available resources and time slots
- Status
  - Used by dental school during transition period
  - Paper in IAAI 2013, AI Mag 2014



- Research Challenges
  - Very different from standard timetabling problem
  - Hard/soft capacity constraints
  - Tool cleaning setup time constraints
- Solution Approach
  - Optimization
  - Flexible prioritization of constraints

# Irish Naval Service Yearly Rostering

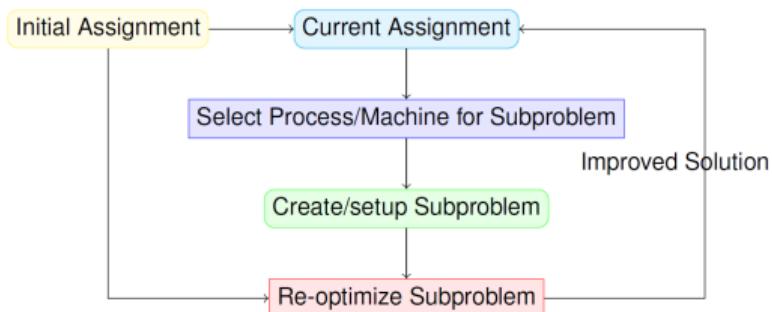


- Real-World Problem
  - Decide which ships are performing which type of duty over the year
  - Budget limitations on total time at sea
  - Fair share of work across fleet
  - Fixed maintenance periods for certain ships
  - Special events (flotilla exercises, detached duty)
- Status
  - Prototype results produced for service

- Research Challenges
  - Finding the best tool and model for problem
  - Balanced assignment under budget constraints
  - Provide consistent force levels over whole year
  - Fair assignment of work/rest days across fleet
- Solution Approach
  - Optimization

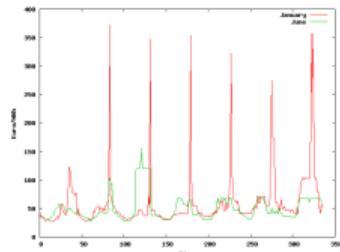
# Data Centre Load Consolidation

- Real-World Problem
  - Move virtual machines between servers in a data centre
  - Balance/concentrate workload on multiple resource types
  - Extend to multiple data centres across world
- Status
  - 2nd place in Google Roadef/Euro Challenge 2012
  - Multiple papers



- Research Challenges
  - Reassignment problem
  - Multi-bin packing constraints
  - Large neighbourhood search to deal with problem size
- Solution Approach
  - Optimization
  - New tools/propagators

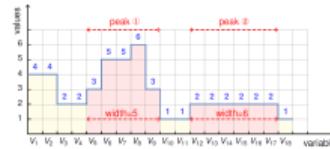
# Scheduling with Time Variable Energy Prices



- Real-World Problem
  - How do time-variable electricity prices affect scheduling of use
  - Uncertainty of prices, sudden peak prices common in Ireland
  - In most cases, we have to commit to production before price is known
  - Deal with risk/possible rewards
- Status
  - Multiple papers
  - Continued work on price prediction with industry
- Research Challenges
  - Can we use time variable electricity prices to our advantage?
  - Which properties should a price prediction model have to help with scheduling?
  - Can we tune price prediction for the use case it is intended for?
- Solution Approach
  - Machine Learning
  - Optimization

# Characterizing EDF Power Plants

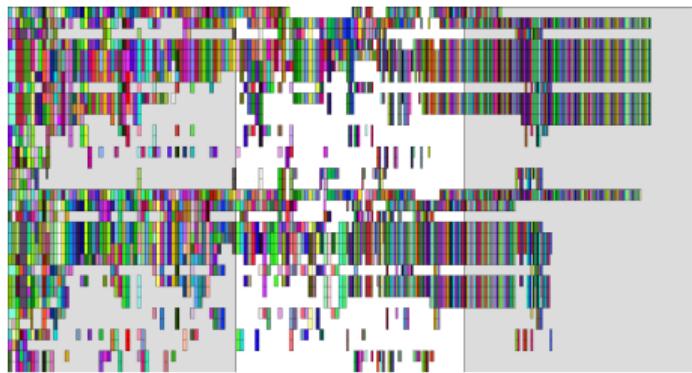
- Real-World Problem
  - Unit Commitment Model for electricity supply
  - Decide which units to run when to satisfy demand/minimize cost
  - Change of production for different units is limited over time
  - Very error-prone integration into global model
- Status
  - Joint work with IMT-Atlantique, EDF Research
  - Series of papers on time-series constraints, Volume II of Global Constraint Catalog



- Research Challenges
  - Can we characterize the production limits of power plants as time-series constraints?
  - Learn constraints from historical data (planned/actual)
  - Create model of individual plants to describe their capabilities
  - Find redundant constraints to overcome limits of propagation
- Solution Approach
  - Machine Learning
  - Automata constraints
  - Generated code for propagators

# Optical Network Design

- Real-World Problem
  - Core optical network design
  - Different from traditional IP network design
  - Define paths from source to sink
  - Use multiple frequency (light) bands over same fibre
- Status
  - paper ICTAI 2014



- Research Challenges
  - Modelling Choices
  - Amount of propagation achieved
  - Scalability of methods
- Solution Approach
  - Global Constraints

# Supplier Selection Problem

- Real-World Problem
  - Which suppliers to select to provide list of components
  - Limit number of suppliers by ordering multiple items from same supplier
  - Price/lead time/quality of service are competing objectives
- Status
  - Work with industry partner
  - Paper in Annals of Operations Research



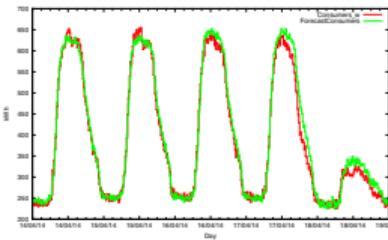
Texas Instruments SN7400N  
Logic IC Operating temperature: 0...+70°C Series: SN7400 Function: Quad 2 Input / NAND Manufacturer: Texas Instruments Package: DIL-14 Technology: T1

| Distributor | SKU            | Stock | MOQ | Pkg  | 1    | 10   | 100  | 1,000 | 10,000 |
|-------------|----------------|-------|-----|------|------|------|------|-------|--------|
| Digi-Key    | 296-54641-5-ND | 3,644 | 1   | Tube | EUR  | 1.39 | 1.24 | 0.967 | 0.631  |
| Verical     | SN7400N        | 9,975 | 525 |      | EUR  |      |      | 0.564 | 0.564  |
| Amet        | SN7400N        | 513   | 1   |      | EUR* | 1.34 | 1.15 | 0.884 | 0.884  |
| Farnell     | 1105337        | 874   | 1   |      | EUR  | 1.32 | 1.32 | 0.893 | 0.617  |
| TIstore     | SN7400N        | 5,787 | 1   | Tube | EUR* | 1.28 | 1.12 | 0.886 | 0.478  |

Show All

- Research Challenges
  - How do we learn which choices are preferred
  - Difficult to assign fixed weights to different aspects of solution quality
  - Iterative, interactive learning of preferences
- Solution Approach
  - Preference Learning
  - Optimization

# Optimizing UCC's CHP Plant Operation



- Real-World Problem
  - When to run UCC's CHP plant to create electricity/heat on-site
  - Needs demand forecast for heat and electricity
  - Uncertain Real-time grid electricity price
  - Heat and electricity demand of campus not in sync
- Status
  - Tested for several weeks with operator of plant
  - Part of EU Discipl project
- Research Challenges
  - Heat and Electricity Demand prediction for campus
  - Price prediction for real-time grid price
  - Integration of plant operational constraints
  - Wider impact of heating strategy on campus
- Solution Approach
  - Machine Learning
  - Optimization

# CP Conference Paper Assignment Tool



- Real-World Problem
  - Which reviewers to assign to papers
  - Consider bids by reviewers, avoid assigning unwanted papers
  - Deal with reviewers shared between multiple tracks
  - Balance assignment between reviewers
  - Allow pre-assignment, specific capacity constraints
- Status
  - Joint work with Data61, INRA
  - Used in 2020, 2021
  - Paper at ModRef 2020
- Research Challenges
  - Fair treatment of papers and reviewers
  - Finding mechanisms to allow Program Chair to control process
  - Not a black-box assignment
  - Integration with easychair
- Solution Approach
  - Optimization

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- Teaser for CP & Scheduling Survey
  - Live at <https://hsimonis.github.io/pthg24/>
- Provided details on some application work at Insight
- Shows the impact of practical problems on basic research
- Research can have a real impact
- It takes time to do application based research